I am Harrison John. I was fortunate to be raised in a home where I received encouragement to pursue knowledge and develop an understanding of society and the world around me. This upbringing became the foundation upon which I built my academic pursuits, driving me to explore innovative solutions to complex practical issues.

During my Ph.D. studies, I studied the system approach, enabling me to explore and comprehend complex systems. Through my research and coursework, I have deeply understood the interconnectedness and interdependencies within such systems. This approach has provided me with a comprehensive framework to analyze and evaluate various components of complex systems, considering their relationships and dynamics. By adopting a systems thinking mindset, I have been able to identify emergent properties, uncover hidden patterns, and comprehend the broader context in which these systems operate. The system approach has been instrumental in broadening my perspective and equipping me with valuable tools to navigate the complexities of complex systems during my Ph.D. journey.

School of Business, Innovation and Sustainability
Sustainable Electromobility: A System Approach to Transformation of Transportation

Harrison John Bhatti
Selection of the research title

The main title of this research is “Sustainable Electromobility.” The selection of “Sustainable Electromobility” as the title for my doctoral thesis is driven by the pressing need to address the environmental challenges posed by conventional transportation systems and explore the potential of electrification of transportation systems as a sustainable alternative. However, switching to electric vehicles is insufficient to ensure a sustainable transition in the transportation sector. Sustainability considerations encompass more than just emissions; they also need to ensure that electricity for electric vehicles comes from renewable sources. Whereas transitioning to electric vehicles and renewable sources is not a self-transitioning process, it is a mission-driven transformation that requires political support to use the economic means to encourage society to adopt new change. Thus, the term “Sustainable Electromobility” incorporates the multidimensional aspects such as technology, politics, society, and economics that need to be considered when evaluating the potential of electrification as a sustainable transportation solution.

This research is a comprehensive study on the technological, political, societal, and economic aspects, which aims to contribute to the knowledge base required for making informed decisions and formulating effective policies to promote sustainable electromobility, thereby addressing the challenges posed by conventional transportation and fostering a cleaner and more sustainable future.

The term ‘sustainable’ was first promoted as sustainable development at the Brundtland Commission of the United Nations in 1987, defined as “meeting all present requirements without compromising the ability of future generations to meet their own needs.” Whereas the term ‘sustainable’ was first used as an adjective to denote environmental goodness during the 1992 United Nations Rio Conference on Sustainable Development. The term ‘sustainable’ as an adjective is currently used to describe various concepts such as sustainable communities, sustainable development, sustainable energy policy, sustainable electromobility, etc. (Appleton, 2006).

According to the first definition of sustainable development stated in 1987 at the UN, people should meet their needs while not compromising the ability of future generations is also associated with an idea of societal advancement and an improvement in quality of life all over the world (Foley, 2019). Suppose we apply this definition in the context of the existing transportation system to seek the current need. In 2020, the Intergovernmental Panel on Climate Change (IPCC) survey found that transportation accounts for 24% of all CO\textsubscript{2} emissions globally. The amount of CO\textsubscript{2} entering the atmosphere is increasing, which causes the Earth to...
warm up more and more. In that case, we understand that the current fossil-based transportation system severely impacts the climate and environment, negatively affecting human life. Thus, the definition of sustainable development enlightened us to decarbonize the transportation sector to save the environment and improve the quality of life without harming the environment for current and future generations.

The term 'electromobility' is used for operating an electric powertrain for transporting people and goods with a view to support sustainable development (Arora et al., 2021). The practice of using fossil fuel-free vehicles considered environmentally friendly that are powered by electricity is known as electromobility. These vehicles include cars, buses, bikes, trucks, and vans (Scheffels, 2022). By lowering reliance on fossil fuels and enhancing air quality, electromobility makes it possible to solve climate change issues if the electricity supplied to electric vehicles is produced from renewable energy sources (Arora et al., 2021). The combination of the terms sustainable and electromobility is represented as a conceptual representation in figure 1.

![Figure 1: Conceptual representation of the title selection](image)

Thus, the title "Sustainable Electromobility" delivers a clear message of preference regarding societal and environmental betterment. We are creating the kind of electromobility that embraces the challenges not only in society but will benefit the environment in the long run. Although the term sustainable electromobility is not frequently used in this thesis, it still reflects the contents of the thesis that focuses on transforming the transportation system from fossil-based to electric.
Abstract

Electrification of transportation is generally analyzed from a technical aspect. Whereas the technical aspect is merely one of the main aspects of transforming the transportation system from fossil-based to electric. The other significant aspects, such as political, societal, and economic, are mostly neglected that can empower the transformation processes. This thesis aims to explore, analyze, and develop knowledge that leads to an understanding of identifying the key actors and their symbiotic relationships and dependencies in transforming the energy and transportation system from fossil-based to renewable and fossil fuel-powered vehicles to electric.

The research was explorative and categorized into two studies. The Study – I focuses on the technological development that leads toward transforming from the old fossil-based analog electricity generation and distribution system to the new digitalized renewable system. This study further explores the impact of these disruptive technologies on the market and society, and the challenges hindering the implementation and adoption of the new energy system. Study – II focuses on developing new knowledge and understanding by integrating technological, political, societal, and economic aspects into one model and named it a 'multidimensional readiness index model.' This model can serve as an analytical tool and provide a broader perspective for exploring, analyzing, evaluating, and determining the countries' positions in transforming the transformation system. The model has been applied to eight countries, two from Asia (China and India) and Australia and five from Europe (Germany, Norway, Sweden, Slovenia, and the UK). The kappa synthesizes the exploration of the papers. Additionally, the system approach is applied to explore and understand the symbiotic relationship in the new ecosystem among the key actors and stakeholders and their significant role in transforming the transportation system from fossil-based to electric.

The main conclusion is that the countries with a higher symbiotic relationship among the key actors achieved a higher level of readiness in transforming the transportation system. In contrast, other countries with a low symbiotic relationship among the key actors are slowly catching up or even far behind in transforming the transportation system towards electrification.

The analysis shows that a higher level of readiness in transforming the transportation system is achieved by the countries where their government took firm decisions to integrate their associated manufacturing industries and society into their national agenda. China is one example of these countries leading globally in manufacturing and sales of electric vehicles. Norway does not manufacture electric vehicles. However, Norway is leading globally with the highest market share of electric vehicles. The Norwegian government uses its economic means to compensate for the price differentiation with its policies and provide subsidies and
rebates to the buyers of electric vehicles. In countries that have adopted a fragmented approach toward transportation electrification and are waiting for the industries to take further initiatives, slow progress can be seen in those countries, such as Germany, Sweden, and the UK. Countries where the government showed less interest in electrification, even though they have introduced some policies, are still far behind in transforming the transportation system, such as India, Australia, and Slovenia.

The key message is that the political role is decisive in transforming the energy and transportation system. It is a revolutionary change requiring enormous investment and political support to stabilize the industry and the market to compensate as the new actors enter the manufacturing industry and threaten the old firms. The new products enter the market and threaten the old businesses. The new political policies and regulations are required to balance the price differences between electric and fossil fuel vehicles by providing subsidies or rebates to encourage society to adopt change. Thus, energy and transportation industries are intertwined and operate under the umbrella of government rules and regulations. Without firm political support, the entire transformation from a fossil-based to an electric system is difficult to achieve.

**Keywords:** Energy system, transportation system, system approach, symbiotic business model, innovation ecosystem, technology readiness, political readiness, societal readiness, economic readiness.
Acknowledgements

For me, the Ph.D. has been a thrilling journey full of doubts and joys. It has been a long trip exploring and understanding new ways of looking at things that I find interesting, valuable, and intellectually challenging. There have been moments when working on a Ph.D. has felt like a solitary pursuit. Yet, it would not have been easy to complete without a positive work environment and the assistance of many individuals.

First, I would like to thank my principal supervisor, Professor Mike Danilovic, for accepting me as a master’s thesis student, taking the initiative to get me as a Ph.D. candidate, and continuing to supervise me in my Ph.D. studies. I appreciate your patience and guidance, encouragement, and support in improving my academic skills and critical thinking. It would not have been possible without your support all the way. Traveling with you for conferences in Germany and Serbia has been a wonderful learning experience. I would thank my co-supervisor from Halmstad University, Jasmine Lihua Liu, for always being very supportive and understanding in the struggle of a Ph.D. candidate. Thanks, Jasmine, for all your guidance and support throughout my Ph.D. studies.

I am grateful to VTI, the Swedish National Road and Transport Research Institute, for accepting me as a Ph.D. candidate in collaboration with Halmstad University. Thank you, Arne Nåbo, a mentor and manager, for taking extra responsibility for being my co-supervisor when the need arose. Your calm and patient demeanor has always encouraged me to discuss my work-related challenges with you. Thank you, Andreas Käck, for your support and guidance in the early phase of my Ph.D. studies. Those days were memorable for long discussions using the whiteboard in your office, and you were always present and supported even during off-work hours. Thank you, Jonas Jansson, for your endless support from VTI during my Ph.D. journey. Thank you, Magnus Eek, for your help and motivation in the final phase of my Ph.D. journey. A special acknowledgment to all of my VTI colleagues who have been helpful and supportive, thanks to Philip Almestrand Linné, Jiali Fu, Maytheewat Aramrattana, Peter Torstensson, Svetla Käck, Linda Pettersson.

I thank Halmstad University for accepting me as a Ph.D. candidate in the innovation sciences department. I am thankful for the help and support I received from my colleagues and friends from Halmstad University: Christer Norr, Deycy Sanchez, Eugenia Perez Vico, Fábio Gama, Fazle Rahi, Fawzi Halla, Henrik Barth, Jeanette Johansson, Jonas Gabrielsson, Joakim Tell, Luis Irgang Dos Santos, Magnus Holmén, Maya Hoveskog, Svante Andersson, Thomas Magnuson, and Zara Zamani.

My dear friends Tony Jarratt (late), his wife Billy, and their daughter Nat, “your thoughtfulness is a gift I will always treasure.” You have backed and stood beside me in my
ups and downs throughout my study career from Malaysia to Sweden. I am grateful, Tony, for proofreading and improving my texts in different phases. I have been fortunate to have good friends. Thanks, Charlotta Winkler, for being a good friend, and thank you, Myasnik Galstyan, for staying by my side when I needed your help. Thank you, Ruthy Didi and Renu Didi and my sister Karil for always being present to help and support me.

Heartfelt thanks, Mom, and Dad, for your sacrifice and upbringing that has enabled me to achieve this milestone. Your unconditional love, encouragement, and guidance have always kept my feet towards my goals.

Finally, my wife, Olive. I would never have been able to complete this project without your unconditional love and support. You stood beside me like a rock when I felt weak and alone. Your company has always encouraged me to keep working hard and look forward to achieving the next milestone. Thank you for reading, giving feedback, and helping me design figures, graphs, and tables in my thesis. Thank you for believing in me and putting up with absurd working hours. You are the most wonderful person I have ever met, and I look forward to the coming phases of our lives.

Harrison John Bhatti

Halmstad, September 2023
The following brief description of each chapter provides the reader with a quick overview of the structure of the entire thesis.

Chapter 1: The introduction chapter provides a brief background of the study. It discusses the environmental problems arising from fossil-based energy and transportation sectors and the challenges hindering them from moving from oil to electricity. This chapter also includes the purpose of the study and the research questions.

Chapter 2: The research methodology chapter argues the adoption of a pragmatic and inductive approach that guided me throughout my research process, followed by the two explorative studies on energy and transportation systems, and represents the contribution to innovation sciences.

Chapter 3: The frame of reference chapter explains the three approaches, system approach, business approach, and ecosystem approach, that I adopted by the guidance of the empirical findings based on my dissertation’s papers 1 to 5.

Chapter 4: The analysis and discussion chapter explores the dynamics of energy and transportation systems and develops a multidimensional readiness index model that contributes to exploring, understanding, analyzing, evaluating, and determining the transformational processes of energy and transportation systems from a holistic perspective. Further, the system approach is applied to explore the relationship and dependencies of the actors acting in the technological, political, societal, and economic domains and impacting the transformation of the energy and transportation systems.

Chapter 5: The conclusion chapter addresses the main findings of this thesis.

Chapter 6: The implications chapter presents the significance of integrating new actors in the new ecosystem and their role in transforming the energy and transportation system.

Chapter 7: The future research chapter presents some suggestions for continuous energy and transportation systems research.

Chapter 8: The references chapter includes the references used throughout the thesis.

Appendix – I The five research papers are included in Appendix – I.
## List of appended papers

The following five papers are included in Appendix – I of this thesis.

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The following table represents a brief overview of the kappa and the five papers included in the thesis.

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<th>Exploration and contribution of the kappa and five papers</th>
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<td>Fossil fuels (coal, oil, and natural gas) have been a cornerstone of our modern industrialized world, but with time, knowledge, understanding, and technology have developed, leading us from fossil-based to clean energy sources. This shift is a massive change for businesses, industries, policies, rules and regulations, society, and economic capabilities that develops complexity and uncertainty, which needs to be explored, understood, and managed. The following papers intend to explore and contribute theoretical and practical knowledge that leads us to a new understanding of this dynamic shift which enables us to identify the primary aspects that can support transforming the transportation system from fossil-based to electric.</td>
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<td>The kappa synthesizes the exploration of the papers and guides that the advancement of technology has made it possible to revolutionize the energy and transportation sectors. However, the diffusion and implementation of technology in individual countries require political willingness and support by introducing favorable policies and using their economic means to develop infrastructure for the new technology to function and mitigate the purchase and operational cost differences between old and new technology. Therefore, it is not enough to merely understand the significance of political, societal, and economic readiness but also important to understand the symbiotic relationship, dependencies, and driving forces behind the readiness of these dimensions. Thus, in this kappa, the concept of four dimensions (technology, political, societal, and economic) is adopted from papers 4 and 5 and interpreted the term “dimension” with “domains” to apply the system approach for further analysis of the relationship and dependencies of the elements within and across domains. The exploration shows that countries with a higher symbiotic relationship among the key actors of each domain (technology, political, societal, and economic) achieved a higher level of transformation and diffusion of EVs, dominating the associated industry. In contrast, countries with a fragile symbiotic relationship among the key actors are slowly catching up or even far behind in the process of transforming the transportation system towards electrification.</td>
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<th>Paper – I</th>
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<td>The world is facing various challenges. Some of the challenges are to decarbonize the environment from greenhouse gases and the other one is to fulfill the rising electricity demand due to the increase in population and the introduction of new technologies (electric vehicles, smartphones, etc.) introduced in the market that run on electricity. This paper explores and guides that the old, centralized electricity generation and distribution system primarily depended on coal boilers and fossil fuels, which emit greenhouse gases and are harmful to the environment. The old traditional grid has a fundamentally one-way communication system. Thus, the grid cannot efficiently be integrated with advanced digitalized renewable electricity generation technologies such as solar photovoltaic (PV) and wind turbines. However, the advancement of technology has made it possible for the grid to be updated and converted into a smart distribution system that can efficiently be integrated with renewable electricity generation technologies. The smart grid enables a decentralized electricity generation and distribution system that can support to fulfill the rising electricity demand and decarbonize the environment by increasing the usage of renewable energy sources. However, the key challenges in transforming the energy system are that heavy investments are required, new policies must be introduced, and new rules and regulations must be established.</td>
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Paper – II

The smart grid has allowed new actors and stakeholders, specifically ICT (information communication technology) firms, to enter the energy markets. This change has threatened the existing energy firms and developed uncertainty, leading them to change their traditional business model. The old traditional business model canvas is applicable to a focal firm. It does not fit to support the commercialization of the new electricity distribution system embedded with multiple companies and firmly associated with government policies.

This paper’s finding shows that the firms that adopted the changes in technology and accordingly changed their business model to respond to the market were successful. In contrast, the firms that adopted the changes in technology but hesitated to change their business models died. The smart grid is a disruptive technology with the potential to revolutionize the energy industry. Thus, to survive and thrive with the new change, the energy firms need to change or develop a new business model for integrating new actors and stakeholders in the value chain to capture and deliver value for them.

Paper – III

Since environmental policies have become rigid globally, rapid advancement can be seen in the development of technology associated with the energy and transportation sector. These technological advancements have made it possible for the concept of electric roads to decarbonize society from road transportation. However, the major challenge is to achieve the rising demand for electricity for the electric road transportation system with renewable energy sources, as 70% of global energy comes from burning fossil fuels. These challenges lead to exploring cost comparison and the environmental consequences on society of using new technologies (solar PV and wind turbines) to produce electricity with renewable energy sources. The exploration shows that integrating renewable energy technologies (solar PV and wind turbines) with microgrids can enable locally produced electricity, achieving the rising electricity demand and is environmentally friendly and less expensive than fossil-based sources.

Paper – IV

Worldwide, the transportation sector is transforming from fossil fuel powered to electric vehicles. The government of different countries are adopting different approaches and strategies and developing solutions based on their countries' contexts and conditions. Most existing research focuses on the technology for transportation electrification based on battery and hydrogen technology, whereas the significant challenges are related to the charging infrastructure. The challenges associated with charging infrastructure are deeply rooted in political decisions.

Thus, to improve understanding and support the ongoing transformation of the transportation system, in this study, a new analytical tool called the "multidimensional readiness index model" has been developed and applied to three countries (China, Norway, and Sweden) for exploring and analyzing technological, political, societal, and economic readiness. The exploration shows that the development and implementation of electrification of the transportation system depends on society's readiness to pursue the development, adoption, and diffusion of electric transportation. Technology itself is a crucial foundation for electrification and must be viewed and understood when commercialization and value creation to business, people, and benefits to the entire society are also considered. Technology cannot be diffused in society and create value without a well-developed interplay of industry, academia, politics, economic institutions, and policy systems pushing and supporting economic and policy tools and regulatory tools.
This study applies the multidimensional readiness index model to eight countries of three different continents Asia (China and India), Australia, and Europe (Germany, Norway, Sweden, Slovenia, and the UK), for extensive international comparison. The purpose of the comparison is to learn from other countries and draw the attention of policymakers to the challenges and opportunities in their countries for transportation electrification. Further draw their attention to the importance of political, societal, and economic readiness, which are necessary to understand and consider if countries strive to achieve a high level of electrification.

The exploration and analysis show that China is leading globally in the electrification of transportation because of its strong technological advancements, complete control over the entire value chain, favorable policies for electric vehicles (EV), the willingness of the public sector to take the lead and the citizens support to adopt clean technology. Norway is leading in EV adoption because of its favorable government policies for transportation electrification, even though Norway itself does not manufacture EVs and charging equipment. Germany is leading in Europe’s technological sector of transportation electrification with its prestigious top-selling EV brands. However, Germany is still lagging behind in adopting EVs compared to gasoline-based vehicles. Sweden is a rapidly growing country in transportation electrification, with its three vehicle manufacturers introducing EVs in 2021 and developing an electric road system. Sweden is also working on establishing a 50 GWh battery manufacturing plant in Gothenburg. The UK government has involved transportation electrification on its national agenda and is considering setting up a Gigafactory to obtain a position as a future battery leader.

However, the adoption rate of electric vehicles is still slow compared to gasoline-based vehicles because of a lack of entire value chain and lack of charging infrastructure. India, Australia, and Slovenia are far behind in transportation electrification. One of the common reasons is that the governments of these countries have taken small steps toward transportation electrification even though they have high ambitions.
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“Never give in. Never give in. Never, never, never, never—in nothing, great or small, large or petty—never give in, except to convictions of honour and good sense. Never yield to force. Never yield to the apparently overwhelming might of the enemy.”

Mr. Winston Churchill

(Source: Never Give In! The Best of Winston Churchill's Speeches)
“Volkswagen hesitates to go all the way in the electrification process for two main reasons. The first reason is although customer demands are there, the value chain is not in a place that can fully support Volkswagen’s transformation. The second reason is the charging infrastructure is not in place and is not well developed to support the large-scale transformation to electric vehicles.”

Mr. Herbert Diess, a former CEO of Volkswagen Group

(Source: The Financial Times Event “Future of the car,” May 9th to 12th, 2022)
1. Introduction

This chapter describes the role of transportation in social and economic growth with the continuous discussion of the current energy and transportation systems as the main contributors to greenhouse gases, which lead to global warming and are thus harmful to the environment. It also provides a brief understanding of the significance of using a system approach that shows a holistic perspective of exploring and understanding the transformational processes of transforming the energy and transportation system from fossil-based to electric. This chapter also includes the research purpose and the main research questions and follows with a chapter summary.

1.1 Background of the study

Transportation is the means of connecting the world through the roads, air, and sea which performs a fundamental role in establishing social relationships among people and the economic growth of countries worldwide. People are connected through transportation, which enables new business opportunities and develops new services. The wealth for people is created through transportation when it is used to go to school, shopping, work, and tourist places for leisure activities all over the world (Fields et al., 2018). Globally, transportation is one of the most significant job-providing industries. More specifically, in 2017, land transportation supported more than 60 million direct jobs globally, or more than 2% of total employment (ILO, 2020). The crucial role of transportation systems is to satisfy everyday life’s needs and create opportunities for human beings to have a better life (Kulash, 1999). The relationship between transportation and society is profound. It is not easy even to imagine a modern world without a functional transportation system.

All kinds of transportation are probably one of the most important sources of economic development for mankind, from ancient times to the modern world as we know it today. Worldwide, in 2023, the air and land transportation sectors are expected to generate approximately US$ 1.56 trillion (Statista, 2022e). In 2023, Asia is predicted to reach US$ 0.75 trillion (Statista, 2022b), Australia US$ 21.42 billion (Statista, 2022c), and Europe US$ 364.90 billion (Statista, 2022d), respectively. The transportation sector opens the way for further development of the economy and market products and improves the standard of living. The international freight transportation system promotes the growth and diversification of trade among countries in the world. It bridges the gap between production and consumption centers where the industries have to be located away from the market due to market variation, resource availability, climate, and geographical factors (Nistor and Popa, 2014). To increase the demand for goods, transportation is used by suppliers to reach new places and
introduce their products to new customers. Another advantage of transportation is transporting goods in areas where goods are not produced locally, and consumers can enjoy the benefits of goods. Transportation systems decrease the prices of goods and increase the competition in the market as it enables a quick supply of raw materials from one place to another, allowing large-scale production and other suppliers to bring their goods to the same market (Udovičić, 2018). Thus, it is significant to have a modernized transportation system to gain competitive growth in social and economic sectors.

However, nothing good comes out without some negative consequences. In the case of the transportation system one of these are the energy being used and its adverse impacts on nature, mankind, climate, and global warming due to emissions from fossil fuels in the form of sulphur dioxide, nitrogen, and carbon dioxide negatively affect people’s health and the environment (Nurhadi et al., 2014).

The road transportation sector is one of the highest oil-consuming sectors in the Organization for Economic Co-operation and Development (OECD) countries, as shown in figure 2.

![Figure 2: Distribution of oil demand in the OECD countries by sector](Sönichsen, 2022a)

In 2020, the OECD countries consumed approximately 48.6% of all oil by motor vehicles. In contrast, the second largest consuming sector was petrochemicals which

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1 List of OECD countries: Austria, Australia, Belgium, Canada, Chile, Colombia. Costa Rica, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.
consumed approximately 16.2% of the manufacturing of resins, plastics, and other petroleum-based products.

Worldwide, among all other modes of transportation, passenger cars are one of the major contributors to greenhouse gases which are approximately 41%, as shown in figure 3.

![Figure 3: Globally produced greenhouse gas emissions by the transportation sector in 2020](image)

Source: (Tiseo, 2021)

According to figure 3, the sum of all modes of road transportation, which includes passenger cars, two/three-wheelers, light commercial vehicles, buses, minibuses, and medium and heavy trucks, contributed approximately 78% of greenhouse gas emissions in 2020. It shows that road transportation is a major greenhouse gas contributor compared to air and water transportation.

1.2 Fossil-based energy creates environmental problems

If we look into the energy sector today, we understand that the world's energy sector is still highly dependable on non-renewable energy sources, which is one of the main factors of greenhouse gases as it directly impacts global warming (Mwasilu et al., 2014). Figure 4 represents the sources of electricity production in the world during the period from 1985 to 2021.
In 2021, approximately 61.74% of the world’s electricity was generated from burning fossil fuels and 9.94% from nuclear power, whereas only 28.32% from renewable sources.

In 2020, 71.94% of Asia’s electricity was generated from fossil-based sources. Australia generated 70.28%, Europe generated 42.13%, and United States generated 60.35% of electricity from fossil-based sources in 2021 (Ritchie and Roser, 2022). Fossil-based sources are and continue to play a dominant role in producing electricity in the global energy systems. However, the usage of fossil-based sources is not without negative impacts. When fossil-based sources such as coal, oil, and gas are burned to produce electricity, they emit greenhouse gases, which are the major contributors to global climate change, air pollution, and millions of premature deaths yearly. The megacities of China and India are facing substantial pollution problems, which is the highest mortality excess caused by air pollution. “East Asia and South Asia are the regions that suffer the most deaths attributable to air pollution. In 2019, air pollution exposure caused more than two million deaths in each region, with the majority of those deaths occurring in China and India (Tiseo, 2022).” Thus, to decarbonize the environment and be less dependent on depleted fossil-based sources, the world is moving towards low-carbon energy sources such as nuclear and renewables (solar, wind, biogas, etc.) and from fossil fuel-propelled vehicles to electric.

However, moving toward clean energy sources and electrically-powered vehicles system is a profound paradigm shift (Altenburg et al., 2022). Globally, as environmental policies are becoming rigorous and enforced (Ahmed, 2020), the demand for renewable
energy is rising. This demand is leading to a massive shift in the development of new technologies such as geothermal, solar photovoltaics, and wind turbines; shifting toward the development of new technologies allowed new firms to enter the energy markets and threatened the old traditional energy firms. Some are losing their businesses, and some have gone bankrupt. However, this change did not stop there because of the incompetence of the traditional grid. The traditional grid was constructed to have a one-way communication system; thus, the grid does not have the capability to be integrated efficiently with renewable electricity generation technologies and receive immediate information if the electricity were terminated from the consumers’ end (Banerjee et al., 2011). Therefore, the “traditional grid” triggered the further transformation into the second round of innovations and allowed the development of smart grid and energy storage systems (Altenburg et al., 2022).

The development of the smart grid is a breakthrough in the energy sector as it is embedded with innovative digitalized technologies that give consumers more control over electricity usage (Clastres, 2011). The grid has a two-way communication system that efficiently integrates renewable electricity generation technologies (Forte, 2010). The smart grid enables decentralized electricity generation and distribution systems, allowing the energy firms to reach the areas to distribute electricity where it was not possible with the old traditional electricity distribution system. Thus, the smart grid has the full potential to transform the entire energy industry, market structure, physical environment, and consumer behavior. However, the major challenges of implementing the decentralized electricity generation and distribution system are finance, government support, new rules and regulations, and a new business model (Hoang, 2006). Therefore, the technological aspect will not be enough to understand the entire energy system transformation. We need to see the change from a holistic perspective that can consider political, societal, and economic aspects for understanding the complete shift of the electricity generation, distribution, and consumption sides from centralized to decentralized systems.

1.3 Electrification of transportation from a system approach

The advancement of technologies (lithium-ion battery, hydrogen gas, photovoltaic, wind turbines, smart grid systems, etc.) has opened the way for the possibility of transforming the transportation system from fossil-based to electric which can rely on the clean energy system. This transformation is not merely associated with technological development or solutions; several other aspects need to be considered, which are relatively more significant for electrification. These aspects are rooted in political policies, societal acceptance, and economic affordability; thus, they require higher system exploration.

Electrification is a disruptive transformation of technology, products, industry, and society. Disruptive technologies transform markets and businesses, changing market structure and value delivery (Christensen, 1997). However, enabling the impact of disruptive technologies requires integrating new actors in the business system that can allow and support the diffusion of new technology (Bower and Christensen, 1996). Using old fossil-based
energy sources is shifting toward renewable energy, and electric vehicles are replacing fossil-based transportation systems. The current development shows that some countries are early adopters of electric vehicles. Some focus on buying solutions, and some focus on creating their complete value chain. However, most countries support this transformation with subsidiaries and impose strict regulatory approaches (see papers 4 & 5, Appendix – 1).

World practice has proven that the societal acceptance (sales) of electric vehicles is high in those countries where governments are actively participating in transforming the transportation system (see paper 5, Appendix – 1). And where the end customers are compensated for part of the excess costs, they provide transportation tax incentives, provide high-quality charging areas, free parking, and allow driving in dedicated lanes. None of this is possible without active participation from the government.

We are at the early stage of battery-electric vehicle technology, and technological development might change economic conditions significantly in the future. Still, with time, as technology advances and manufacturers gain more expertise, they will probably shift to batteries that are affordable, lighter, smaller in size, and with higher energy capacity. Nevertheless, the most significant challenges to the widespread adoption of electric vehicles are the battery cost and the lifetime cost of the vehicle, as batteries are expensive and need to be exchanged occasionally (Andwari et al., 2017). Compared with the traditional ICE option, the actual comparison is the overall ownership costs and the payback period for the electric vehicle. Many countries worldwide are introducing and adopting various policies for diffusing the electrification of the transportation system in society. However, clear guidelines are required for reducing the electric vehicle’s initial cost and government support for the rapid transformation of the whole transportation system that enables society to adopt the changes of the new electrification system on a broader scale.

This transformation of the transportation system leads to the development of interconnected actors and their systems in the new ecosystem where development and commercialization occur. These multiple actors and stakeholders are all interrelated and interdependent. Individually dealing with any of them can cause a ripple effect on others, and the outcomes of traditional solutions are often led to further complexity. Therefore, managing this disruptive transformation needs to be explored, understood, and tackled as a single system solution in which all actors interact to successfully implement technology, new policies, and society’s acceptance of the latest trends.
1.4 Transforming from fossil energy to electricity in transportation systems

All over the world, nations are striving to transform their transportation system from the old fossil-based to the clean transportation system, reducing the negative consequences on the environment and people. The common solution until now is to switch to electric vehicles (assuming that the electricity production is not fossil-based). Another emerging solution for clean transportation is hydrogen and fuel cells. Hydrogen-based vehicles use two types of technologies, hydrogen fuel cells and hydrogen-fueled internal combustion engines (Boretti, 2011, Ehsani et al., 2018). For operating hydrogen-based vehicles, a successful hydrogen-based infrastructure is needed to deliver hydrogen from production plants to refueling stations (Grüger et al., 2018). However, the development design and technology for hydrogen-based vehicles are complex, uncertain, and more expensive than the electric vehicles that run on batteries (Shin et al., 2019). Therefore, hydrogen is not a mature technology yet for full-scale commercial operations, and the economic feasibility of hydrogen is not in place yet, but it is moving and could be an upcoming technology.

As of now, we know that the dominant solution is battery-based electric vehicles. However, operating electric vehicles require batteries to be charged. Thus, charging infrastructure needs to be connected to the grid to make it possible for electric vehicles to function. Electric vehicles require batteries to store energy, and as of now, the primary distribution of energy to vehicles is available in three ways, as represented in figure 5.

Figure 5: Charging solutions: battery swapping, conductive and inductive charging
Source: (Danilovic and Liu, 2021)

Figure 5 shows three static charging solutions for electric vehicles that are practically available worldwide: 1) Battery swapping, 2) plug-in cable-based charging, and 3) wireless charging. The dynamic charging solutions are not commercially available yet. However, this technology is still in the testing phase on a smaller scale in a few countries such as China,
Germany, Israel, Sweden, and the USA. The main reasons for the non-commercial approach yet is the lack of standardization and safety uncertainty and related lack of safety standards (Lihua Liu et al., 2021).

The battery swapping approach is to replace the discharged battery with a charged battery at a battery swapping station. Although battery swapping is an old idea, there is a rising interest in this system-oriented approach and practical solution for end users. The manual exchange is practiced in two or three-wheelers vehicles, whereas exchanging batteries from vehicles (passenger cars, buses, and trucks) requires specific equipment and skills. Therefore, battery swapping is generally done at specific battery-swapping stations. In comparison, the wireless, inductive charging system for electric vehicles is still in the testing and development phases. The three main challenges that prevent wireless charging technology from being launched into the market are: 1) the generic standard is not available yet 2) the electricity transferability speed is too low between the vehicle and the inductive electromagnetic plates 3) maintaining the effective power transfer during static and dynamic conditions of the vehicles while maintaining safety requirements (Afridi, 2018).

The vehicles’ batteries must be charged or filled for electric vehicles to operate. The plugin charging solution is the most commonly used solution for charging electric vehicles worldwide. However, the plugin charging solutions offer various charging ports and charging connectors with different charging speeds and cable standards, creating an impediment to a single standardization charging solution globally (Danilovic and Liu, 2021). A plugin charging solution is an electrical distribution system with one or more charging outlets embedded in the charging pile that supplies electricity through cables to electric vehicles. A charging solution is a complex system that is interconnected and interdependent to the incoming energy system to the charging piles and to the vehicles and battery management system to communicate intelligently.

However, all these charging solutions require electricity to charge electric vehicles. If fossil-based sources fulfill the rising electricity demand in the transportation sector, then we are not achieving what we are striving for; to decarbonize the transportation system and move towards a clean and green environment.

From another perspective, what appears to be a good solution might not be that good. Electrification of vehicles can be seen as positive, but if EVs are charged with the electricity produced by fossil-based sources then the only thing we achieve is to move the root of trouble from vehicles to the source of electricity generation. To get a positive outcome, we have to see the whole transportation system as one system, including vehicles, energy sourcing, and energy distribution for the charging infrastructure of electric vehicles. The entire system needs to be explored and seen as a coherent system of interdependent and interrelated elements influencing each other. If we increase the electrification of the transportation system, one key question arises: how to provide the system with renewable energy. Otherwise, the whole system is not bringing the expected contribution to the world ecosystem development.

Another challenge is that the old traditional centralized grid for electricity distribution is basically a one-way communication system, and it does not have the capability to receive
instant information if the electricity is terminated at customers’ end (Banerjee et al., 2011, Farhangi, 2009). The cost of energy transmission and execution of heavy power generation plants is high, energy losses during long-distance transmission, insecure, and not able to be efficiently integrated with renewable energy sources (Momoh et al., 2012). Renewable energy sources create variations in electricity generation as photovoltaic cells depend on solar light to produce electricity. Wind turbines rely on the wind’s speed to rotate the turbines to generate electricity. The old traditional grid is incapable of integrating with storage devices to store energy, managing the variations in the electricity generation, and balancing it to distribute to the end-users efficiently. The present grid with a centralized electricity generation and distribution system is not designed to charge thousands of electric vehicles simultaneously and to bear the immense rising energy demand due to the electrification of the transportation system.

1.5 Reflections

The current fossil-based energy and transportation system creates environmental problems that harm people’s health and develops a threat to global climate and global warming even though it is essential for human development, social life, and countries’ vibrant economy. Therefore, the environmental policies of the world are becoming rigorous and are enforced to be implemented. Due to those policies, rapid advancement can be seen in the development of technology associated with the energy and transportation sectors. The empirical phenomena indicate that the implementation and commercialization of technology are lagging behind as the transformation from fossil-based electricity generation sources to renewable and fossil fuel-powered vehicles to electric is a massive shift for businesses, industries, policies, rules, and regulations, society, and economic capabilities that develops complexity and uncertainty.

However, to survive and thrive with the new change requires political and economic support and societal acceptance for the diffusion of technology. Thus, this study explores and develops new knowledge and understanding that provides a holistic perspective to analyze and evaluate technological, political, societal, and economic readiness toward electrification. This study also explores the symbiotic relationship and dependencies among the actors and stakeholders in the new electrification ecosystem. The exploration intends to guide decision-makers and associated industries in making decisions and establishing new policies that favor transforming the transportation system's electrification.
1.6 My research purpose

My research purpose is to explore and understand the ongoing transformation of energy in society from fossil-based to renewable energy and the transformation of the transportation system from fossil fuel-powered vehicles to electrification and identify major obstacles and opportunities in the ongoing transformation.

1.7 Motivation of my research purpose

My research is explorative and is conducted in an area of emerging energy and transportation systems transformation. Thus, the purpose is defined by empirically based research activities, my experiences and observations, and actions taken by different actors along the value chains I observe, explore, and interpret.

This energy transformation from fossil-based to renewable is a radical change, and we have reasons to see this transformation as a disruptive transformation of industry and society. The ongoing transformation of the transportation system from combustion technology to electrification is also radical and disruptive in its nature. Studying two simultaneously introduced revolutionary processes is demanding as we have not seen this kind of disruptive transformation for long.

Energy transformation is radical, and historically we had seen similar earlier when steam energy was introduced, giving rise to the modern Industrial Revolution. The energy revolution was the platform for the industrial revolution. The second energy revolution was the introduction of fossil-based energy based on oil and combustion technology which created modern transportation systems. Now fossil-based energy is on the brink of being faced-out with renewable energy in the form of solar, wind, and wave, and this is also giving rise to new technologies and solutions, giving rise to industrial disruptions; the old industry is challenged, and a new industry is up-rising.

It also explores understanding the dynamics of actors and their actions, and solutions applied in the two complementary value chains in the transportation system, one focusing on the horizontal value chain from energy production and distribution systems to recharging electric vehicles; and the vertical processes in the logistics from transport buyers to transport distributors and recharging vehicles. The horizontal and vertical value chains meet in the area of recharging (electricity) and refueling (hydrogen) vehicle operations.

As this transformation is mission-driven, it is interesting to understand how different key actors and countries handle it in terms of energy provision and electrification.

The consequences of the research on ongoing societal, industrial, and business transformation are substantial. How do we explore transformative processes while they are underway on which we have limited knowledge prior to these changes? How are those two
processes carried out, and what are the implications on the entire system enrolled in the transformation?

My research positioning in relation to the purpose of my research is motivating me to initiate my research in a step-by-step process following the exploration of ongoing activities and empirical chain of actions and events conducted by the main actors. The purpose of this research is process oriented.

Based on the purpose of the research, the major questions were identified to explore the underlying dynamic processes that drive the transformation of the entire transportation system. These questions are stated below:

1. What is the role of innovative technologies in transforming the electricity generation and distribution system, and how do renewable electricity generation technologies impact the environment and the energy-providing firms to change their business model to enable commercializing the new energy system?

2. How to understand the development progress of electrification of transportation, and what are the conditions and prerequisites required for readiness in different countries towards the development and diffusion of total system solutions?

From the reasoning above, the research aim and purpose have directed me to adopt an exploratory and empirically driven stance and to choose an inductive approach based on qualitative inquiry and real-life data collection methods.
2. Research Methodology

This chapter describes and reflects the research approach and process that influenced this thesis’s direction, leading to an understanding of the research design, the methodological choice, and the strategy adopted during the research.

2.1 My positioning in Innovation Sciences

Innovation Sciences is a research domain introduced by Halmstad University in 2011 which the Swedish Government also approved as an area for Ph.D. education. Since then, Halmstad University has started a Ph.D. program in Innovation Sciences.

Innovation sciences is a multidisciplinary research field in which different subjects for study and complementary research domains can collaborate on exploring the empirical phenomenon of innovation (Baregheh et al., 2009). Innovation is, in my view, not a theory but a complex empirical phenomenon that can be explored from different theoretical perspectives on different analytical levels, from individual to national levels, by using many research methods. Innovation sciences combine social and behavioral aspects of management and organization with fields of social sciences and technological domains.

- The research in Innovation Sciences is mainly about exploring and understanding the dynamics of the processes, from identifying problems to developing solutions and implementing those in the real world, either in business or in society in general. This includes studies of how internal and external conditions affect innovation processes and how ideas achieve success on the market, i.e., become innovations. Innovation sciences emphasize an area where knowledge and understanding of processes and the dynamics around innovation and economic growth.

- Innovation sciences stress that different subjects work together around the common phenomenon of innovation, seen as an applied research domain where proximity to practice and empirical phenomena are central to research and knowledge development.

- In Innovation sciences, the empirical phenomena guide the formulation of research questions, research projects, and selection of methods to implement the research to develop more integrative knowledge.

- Innovation sciences involve a combination of different sciences with different approaches and methods. Innovation science is a multidisciplinary domain with
different analytical levels, Meso level (industry or market), where questions about specific industries, technology areas, and markets are addressed. Micro level (companies, processes, projects, and individuals) where innovation projects are treated, i.e., questions about organization and management, etc., of innovation projects (Danilovic, 2011).

The diffusion of solutions indicates acceptance and can lead to the widespread implementation of innovation (Freeman and Louçã, 2001). Innovation as the outcome of the innovation process is the successful diffusion and acceptance of inventions based on sustainable value creation, mostly with economic connotations.

One of the leading researchers on the subject, Joseph Schumpeter, shared this insight, who expressed that innovation is a combination of an invention’s technological and commercial realization and thereby comprises technological and social development, marketing, commercialization, and organization. Without commercialization and value creation in society, there will be no innovation. Today, the concepts of innovation and innovation sciences have been expanded to include organizational and social innovations and innovative processes (McCraw, 2009, Danilovic, 2011).

"Innovations are seen in a broader perspective as products and processes, services, and also as organizational and social innovations. Innovations can have great consequences on all levels – the individual level, the company level, and the societal level. The interplay between these levels is crucial to the researchers’ understanding and capacity to develop knowledge about the dynamic aspects of innovations’ inception.” (Danilovic, 2011)

This way of seeing innovation emphasizes the multidisciplinary approach and the interaction between different analytical levels to understand the process of creating innovation. Thus, the Sciences in Innovation Sciences should be seen as an expression of pluralism, combining theoretical and empirical approaches and methods to develop a deeper understanding of innovation processes and the final innovation as an outcome (Kahn, 2018). The process, as well as the outcome, defines the innovation. Another key aspect of creating innovation is the diffusion of solutions in the business community or society in general, as Rogers (2010) stresses.

Innovation is a dynamic process that stretches from ideas to realization, from concretization to dissemination and establishment in society (Hutter et al., 2018). Innovation comprises a new approach to what has already been established. Innovation comprises the capacity to see opportunities and develop or combine old solutions in new ways. Innovation comprises technologies, products, services, new ideas, and new social and organizational solutions. In industrial and business contexts, transforming ideas into products, services, or combinations of these and business commercialization are crucial elements of what we can call “innovation” (Kline and Rosenberg, 2010). It is not enough to simply have an invention or a new technological solution. As I have demonstrated in my research, innovation is a multifaceted empirical concept that contains processes through which new solutions emerge
with certain new values and create values for consumers and users. Those complex processes need to be understood in the context of the respective country of study.

Innovation sciences focus on empirical phenomena from the real world that need to be understood. Studies of phenomena lead to the emergence of new knowledge, new perspectives, and as natural scientists would say, the emergence of new theories. Such was the case with the solar system (the sun is in the central position, not the earth), the shape of the earth (circular, not flat), the force of gravity (Newton), antibiotics (penicillin), vitamins (vitamins c and scurvy). I see that most scientific findings have their origins in experiences, experimentation, and empirical studies of various phenomena in life. So also, in social sciences such as, e.g., Born Global in internationalization. Innovation is the study of empirical phenomena and practical action that we understand and build models from to develop new or refine established knowledge.

Electrification of the transportation system is a disruptive transformation of entire societies that occurs here and now. It is an emerging ongoing process that we cannot study historically. It is a process of actors, events, and actions taken that we need to explore and understand while the process is underway and is happening now. The transformation occurs in different ways, at different speeds, and with different solutions in different parts of the world.

I have adopted the Innovation Sciences idea into my research for an understanding of the dynamics, exploring barriers and enablers, and developing and diffusing electrification of the main subject for me, the electrification of the transportation system. I am in my research demonstrating the role of business model innovation to enable technology to be diffused in the electrification of transport systems.

My study of the adoption and diffusion of electrification of transport follows and analyzes two main dimensions, the horizontal, the vertical, and the interlocking technology in the smart grid system. The horizontal refers to the value chain from energy production to the electricity distribution in the grid system to the consumption by the electrified transport systems. The vertical one refers to the value chain from the distribution of goods from suppliers to final consumers via the different chains of transportation solutions. Those two, the horizontal and the vertical value chains, are by necessity complementary to each other. Both are important to explore in an integrated way to understand the process of creating innovation in the electrification of transportation systems.

Thus, the main topic in my research is the dynamics of the transformation from old energy to new renewable energy. This transformation is a process that I have explored in the first, second, and third papers in my dissertation. In my research, I also explored the diffusion of electrification of transport in different countries to increase my understanding of the dynamics and forces enabling and preventing the diffusion from taking place. In my work, I have developed an analytical multi-dimensional model for analyzing those differences between countries.
2.2 Reflection on Innovation Sciences

“Albert Einstein once said:

“The mere formulation of a problem is far more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks real advances in science.”

The above statement of Albert Einstein represents that formulation of a problem is much more significant than finding its solutions. Problems surrounding the world require an innovative perspective of seeing them before identifying the actual problem; more precisely, introducing a new perspective of seeing the problems contributes to innovation sciences. Otherwise, if we start finding a solution without formulating the actual problem, we will walk around the problem with many solutions, but the problem remains.

The concept of innovation is introducing something “new” either associated with products, processes, or services that adds value to the previous ones or brings some new change in the existing trends. However, without commercialization expecting a change in the existing trends is difficult to achieve. Therefore, innovation either it is associated with new product, processes or services do not have any economic value until it is put into commercially viable solution and become a “money maker” (Chesbrough, 2010, Christensen et al., 2015).

“Innovation is like a coin with two sides. One side represents technology, products, processes, or services, while the other side represents commercialization and doing business. When the commercialization process is successful, the discovery or invention becomes innovation.” (Liu, 2019)

However, not all innovations will be disruptive unless affordable and accessible to a broader population in the diffusion process. There are many examples of disruptive innovation, such as Apple iPhone, Ericsson, Nokia, Kodak, Keurig K-cup (coffee machine), etc. I have selected three vivid examples that inspire me, i.e., iPhone, Nokia, and Keurig K-cup, demonstrating a learning point to understand a disruptive innovation. These examples are mentioned below:

iPhone is a classic example of disruptive innovation that used a new technology and a new business model to disrupt an existing mobile industry. Introducing the iPhone did not eliminate smartphones, but it almost put industry giants like Blackberry and Nokia out of business. Apple’s iPhone competed successfully in the same market as established competitors due to its unique features, high quality, and innovative design. Internet browsing facilities were mainly available through personal computers or laptops until 2007. The introduction of the iPhone made it possible and enabled consumers to browse the web just as they would on a desktop or notebook computer. The “app store” for the iPhone was later
established by Apple, which debuted a new concept of doing business where the app developers use the app store to meet customer demands. Thus, the underlying factors of Apple’s success can be linked back to both improved internet accessibility and a new concept of doing business (Christensen et al., 2013).

Nokia dominated the mobile industry for over a decade. Since Apple launched iPhone in 2007, Nokia rapidly started losing its position in the mobile market. However, Nokia tried to regain its market position by developing its partnership with Microsoft, but no significant development occurred. In the meantime, Nokia also came under pressure from Google and Samsung and lost its position in the market because of its inflexibility to adopt market trends and innovate its business model. Nokia’s strategy was unclear, and its Symbian platform lacked any necessary system improvements from the start (Raouf, 2013). Nokia only saw mobile phones as a way to communicate, and the business failed to capitalize on the many other potential uses for the technology. Apple, Google, and Samsung exploited the existing technology and offered new values to mobile consumers. Nokia did not pay attention to the warning from Apple in 2007 and continued with its existing business model, but when Nokia realized what had happened, it was already too late. Nokia underrated the disruptive technologies, and attention was paid to the development of hardware, whereas its competitors came up with new user-friendly operating systems and regular updates, which outclassed Nokia from the mobile business.

I was also inspired by one of the empirical examples of disruptive innovation of Keurig K-Cup, a single-serve coffee machine. In 1990 John Sylvan introduced a single-serve plastic coffee pod. In the beginning, the idea was to use K-cup for office use. However, Keurig Green Mountain later purchased and commercialized it for home usage. In 2014, the company sold 9.8 billion individual coffee pods, disrupting the coffee market (Hamblin, 2015). When commercialization took place, it affected society and the market, and all the actors involved in the value chain, from manufacturers to consumers, benefited. Imagine if the K-Cup had not been commercialized and remained unsold, it would have been in use among a small community or somewhere in the showcase as an antique souvenir and might not have an impact on a large community.

The takeaway points from these three examples are that Nokia lost its market share because it merely focused on developing technology. In contrast, iPhone balanced between new technologies and a new business model. The lesson from the example of Keurig K-Cup is that if we want to impact the existing trends on a larger scale, commercialization is significant, supporting transforming the current market trends.

All three examples are illustrations of disruptive innovations that created dramatic impact on the existing industry.

When introducing renewable energy and electrification of transportation systems, the disruption is massive on technology, society, and people in numerous ways. Technologically, the shift towards renewables and electric vehicles drives innovation in battery technology, energy storage, and smart grid systems. This leads to the development of new products, services, and business models that are transforming the energy and transportation sectors.
From a societal perspective, the transition to renewables is altering how we think about energy and transportation, with people becoming more aware of their environmental impact and demanding more sustainable options. This is leading to changes in government policies, investment patterns, and consumer behavior. Additionally, the shift towards electrification creates new job opportunities and transforms the labor market. Overall, the move towards renewable energy and the electrification of transportation is causing significant disruption across multiple dimensions of our society and will continue to do so in the coming years.

Moreover, renewable energy and the electrification of transportation are transforming people’s lifestyles and behaviors. With the increased availability of renewable energy sources, people are becoming more energy-conscious and adopting new habits, such as using energy-efficient appliances and reducing their carbon footprint. Electrification of transportation is also altering how we get around, eliminating the demand for fossil fuel-powered automobiles and promoting the use of alternate forms of transportation like electric bikes and scooters. This leads to a shift towards a more sustainable and equitable transportation system, with reduced emissions and improved air quality in cities.

However, the transformation to renewable energy and the electrification of transportation is not without challenges. The initial costs of implementing renewable energy infrastructure can be high, and there are still concerns about the reliability and consistency of renewable energy sources. Additionally, the widespread adoption of electric vehicles requires significant investment in charging infrastructure and battery technology. Moreover, the transformation can significantly impact traditional energy and transportation industries with potential job losses and disruptions in supply chains.

Thus, the role of innovation sciences is significant from various aspects in supporting and managing the transformation of energy and transportation systems. Firstly, innovation sciences can support the development of new business models and strategies that can drive the transformation towards renewable energy and the electrification of transportation. This includes developing new financing mechanisms and policy frameworks that can incentivize deploying renewable energy technologies and promote the adoption of electric vehicles. Secondly, innovation sciences can facilitate the creation of collaborative networks and partnerships that can support the developing and deploying innovative solutions. This includes bringing together researchers, policymakers, industry experts, and civil society organizations to share knowledge, expertise, and resources and to develop joint initiatives that can drive the transformation toward fossil-free energy and transportation systems.

This is where I belong as a researcher in the innovation sciences field, understanding that the concept of innovation is not merely confined to new products, processes, or services. The concept of innovation is also associated with a new “idea” or “perspective” of seeing, exploring, analyzing, and evaluating issues and challenges from a holistic perspective. This innovative idea or perspective can lead us to new knowledge and understanding of handling current issues and challenges that can impact the more significant part of society.
2.3 Contribution to the Innovation Sciences Domain

Throughout my research process, I explored how transformation can happen, where technology, industry, and society can move from old to new, and how technology can be diffused in society on a larger scale. For this purpose, to develop an understanding, I adopted the concept of four dimensions presented by Danilovic et al. (2020), and I developed a conceptual model on the empirical content of the core dimensions by enriching the empirical data and named it a ‘multidimensional readiness index model.’ The model provides a holistic understanding of seeing, exploring, analyzing, and evaluating current and coming challenges associated with transforming technology and diffusing it in society on a larger scale.

If we see the model and break it into four dimensions (technology, political, societal, and economic), one can argue that each dimension is not new. However, the newness is how these dimensions are related and integrated into one model and the development of the political and economic scales based on the empirical phenomena and the logic behind them.

The research is about developing new knowledge that leads us to understand issues and problems from different perspectives than the perspective that we used to see them before. I am unsure if my work will significantly contribute to science or impact the scientific community, as it depends on how frequently other researchers will refer to my research in the future. However, I would argue that I have contributed to the body of knowledge associated with the innovation science domain, and this contribution can be seen on different levels, i.e., by developing a conceptual model and collecting an extensive amount of data that supports understanding of seeing the transformation of the energy and transportation systems from a holistic perspective.

Additionally, I have used the system approach that leads us to a new understanding of the interplay of key actors and their symbiotic relationships that might play a significant role in the process of transforming the energy and transportation system from an old fossil-based to a new electric system.

2.4 Innovation Sciences positioning and methodological and theoretical considerations

The positioning of my research in the domain of Innovation Sciences and its focus on the transformation of energy and the electrification of the transportation system is the motivation for my methodological stances and choices. I am studying ongoing transformation. This process is happening while I do my research. It is not possible to do a historical study, only a literature study, or a longitudinal study of events and processes from earlier times. The transformation process is here and now and requires an approach that can capture key processes and events and reflect on ongoing mission-driven transformation. Thus, I have adopted an inductive research approach letting the empirical observations guide me in
collecting information, and data, searching for patterns in the data, and doing the data-based empirical analysis.

My positioning in the Innovation Sciences and my methodological position in the explorative and inductive approach motivates me to choose the theoretical framework that is in line with empirical observations and empirically driven analysis and can shed light and understanding on the ongoing transformation. As the Innovation Sciences approach advocates, I have chosen many complementary approaches, a dynamic system approach combined with a symbiotic business model innovation approach.

My choices of methodological and theoretical positioning are purposeful and deliberately done choices. They are not merely rooted in Innovation Sciences but also in my ontological and epistemological positioning, as described in section 2.7.

In my research, I have worked with researchers in the Sweden-China Bridge project, with my supervisors, and with researchers at VTI. Thus, my empirical understanding is enriched by this intensive collaboration with experienced researchers in different research environments. This way, a deep understanding of conditions in different countries enlightened from different perspectives has supported my data collection.

My analysis shows that the main aspect explaining the differences in the diffusion of electrical solutions is political in nature, not technological. The transformation toward sustainable energy and transportation is a societal mission that aims to deploy big science to meet big human society problems (Ergas, 1987). It's co-shaped by many stakeholders (Foray et al., 2012) that require big regulatory and behavioral changes at the societal/national system level (Mazzucato, 2018). The role of and impact of politics is embedded in a multitude of aspects such as technology, individual, social, etc. This requires that researchers take a multitude of approaches and methods to explore and understand the complexity of creating innovation in the context of different countries. The processes that underlie the development and diffusion of electrification in different countries need to be understood as complex processes that cannot easily be compared without a deeper understanding of historical, social, and societal perspectives to understand the political process and the interaction between politics, industry, and markets in adopting the electrification solutions. The outcome of those complex processes is the value creation and transformation of society towards sustainable solutions and environmental improvements.

My understanding of the role, importance, and impact of the political aspects might not have been obvious to me without international collaboration. The traditional business administration and industrial management domains do not provide a deep understanding of the intensity and dynamics of the innovation processes. This is also evident in the early definitions of Innovation Sciences.

It is my sincere hope that this analysis and international comparison shed light and a deeper understanding of the necessity to continue doing research in the intersection between academia, industry, politics, and the innovation processes, particularly in the mission-driven transformation of societies as this is ongoing. This mission-driven transformation from fossil to renewable and electrification of transportation are politically driven, not industry driven.
Thus, political actors need to understand this and take a leading role in the transformation process. Contrary to the introduction of the iPhone, digital photography, and mobile phones that were industry-driven, the one I have studied is the opposite, driven by political motivations and must be understood as such.

2.5 Data Collection

To understand the phenomenon of transforming energy and transportation systems and how to develop an understanding that can support this transformation, this research adopts an explorative approach as it guides to explore and provides insights into the phenomenon dynamics (Pope et al., 2006, Yin, 2009). Exploratory research is depicted by its open-ended nature, where the focus is not on anticipating specific findings or testing a specific theory or hypothesis but rather on gaining further understanding by exploring the empirical phenomenon of the real-world (Fisher and Buglear, 2007, Creswell and Poth, 2016).

The research began with the underlying idea of exploring and understanding innovative technologies’ evolutionary impact on electricity generation and distribution systems.

Paper – 1:

In the first paper, a comprehensive list of peer-reviewed articles and reports on the smart grid and electricity generation systems was obtained by accessing various databases, including IEEE, ACM digital library, Scopus, Web of Science, Science Direct, and published government reports. As each paper in the thesis was conducted one at a time, I was able to gain valuable insights from each study and carried them forward to the next one. This allowed me to enhance my thought process for each subsequent paper, leading to a more enriched overall understanding. Each paper refers to specific data sources and databases that were used for collecting data.

Paper – 2:

The second paper explored how the introduction of disruptive technology, specifically intelligent and decentralized smart grid systems, will impact energy providers and distributors. The focus was on developing a new business model that can support commercializing the new electricity distribution systems and create, deliver, and capture value for renewable energy producers, energy distribution firms, and energy consumers. To conduct this research, the study primarily utilized three databases for the literature review. The first was ABI/Inform Global, a comprehensive database covering various research areas, including business, corporate strategies, economic conditions, management strategies, and business trends. The second database used was Emerald’s journal, which also covers a broad range of research
areas categorized into sub-fields such as accounting, finance and economics, business, management and strategy, education, engineering, health, social care, library studies, and marketing. This database provides the researcher with a holistic range of research sources. The third database used was Science Direct, operated by Elsevier, which covers engineering and business peer-reviewed articles. Additionally, reports from the International Energy Agency (IEA) published by the French government were also reviewed to gain a deeper understanding of the involvement of various governments in the energy industry.

Paper – 3:

In connection with the first and second papers, the third paper focused on exploring the impact of renewable electricity generation technologies, i.e., solar photovoltaic and wind turbines, on the environment and the integration of these technologies with microgrids for supplying electricity to the road transportation system. Further exploration was done on the cost analysis of generating electricity with solar photovoltaic and wind turbines. An extensive literature search was conducted across various prominent databases, including ABI/Inform Global, ACM digital library, IEEE, Emeralds journal, and ScienceDirect, to gain valuable insights.

Through a comprehensive review of published international energy agency (IEA) reports and peer-reviewed papers from renowned databases such as ABI/Inform Global databases, ACM digital library, IEEE, ScienceDirect, Scopus, and Web of Science, I have gained a holistic understanding of the impact of disruptive technologies on electricity generation and distribution systems. This thorough analysis has allowed me to gain valuable insights into the implications for businesses involved in electricity production, distribution, and consumption and the environmental impact of decarbonizing the energy sector.

Papers – 4 & 5:

Papers four and five were published as part of the “Sweden–China Bridge” project, a collaborative academic platform for the ongoing electrification of transportation systems funded by The Swedish Transportation Administration (Trafikverket, TRV). I actively participated in this national and international project as a front liner, where I had the opportunity to attend seminars, webinars, and meetings with Chinese and international practitioners and energy experts, and international researchers. There, I could closely observe, listen to, and collect front-line data in the field of electrification of transportation. I followed the national-level strategies adopted for electrifying the transportation system in the Chinese, Asian, and European contexts. In the Sweden–China Bridge project, I had access to interviews with Chinese individuals conducted by my project co-researchers. I had access to interviews conducted with Chinese experts in energy production, electricity distribution, electric vehicle manufacturing, and charging system providers in the Chinese industrial context. I was exploring The Chinese political aspects from secondary sources by translating text written in Chinese.
However, for papers four and five, I have also collected data from secondary sources. The reason for collecting data from the secondary sources for papers four and five is because the purpose was to gain in-depth knowledge and understanding of the development and dynamics of technology, political and economic policies, and society’s adoption of electric vehicles over the years based on empirical phenomena. In doing so, I was able to collect and observe the dynamic political policies towards electrification of each selected country and their impacts on the development of charging infrastructure in their countries over the years, and the impact of the economic policies on the sales and market share of hybrid and fully electric vehicles from 2019 to 2021. Conducting surveys or semi-structured interviews to collect this sort of diverse data from eight countries for this study would have been challenging. The study focused on the technology, political, societal, and economic “readiness,” which means what they have already done to transform the transportation system over the past years. Thus, the accuracy of the responses would depend on how well the respondents remembered the information and how much their memories might have changed over time. This could have led to inconsistent and unreliable data. Therefore, I have also collected secondary data for my fourth and fifth papers.

Being a pragmatist, the focus was to collect extensive data from various aspects, i.e., technology, political, societal, and economic, to gain an in-depth holistic understanding of an ongoing transformation of the transportation system towards electrification. For this purpose, I collected a wealth of data from reliable secondary sources, i.e., Statista, Our World in Data, Government reports and International Energy Agency (IEA) reports, which provided valuable insights and support for research and analysis.

For Statista, I took a two-year paid subscription, allowing me to access data without any specific limits. “Statista” is one of the world’s leading statistics portals that provides access to data from over 22,500 sources, covering a wide range of topics, including market research, industry reports, and consumer behavior. Their data is reliable and credible, collected from primary sources such as market research firms and government agencies. “Our World in Data” is a data-driven website that aims to provide an accurate and comprehensive picture of global trends in energy and transportation sectors and other social and economic indicators. Their data is sourced from reputable organizations like the World Bank and the United Nations. “Government reports” provide valuable information about various sectors’ policies, regulations, and trends. These reports are typically based on extensive research and analysis conducted by government agencies, making them credible sources of information. The “International Energy Agency (IEA)” reports provide detailed information and analysis on global energy trends, including energy production, consumption, and efficiency data. The IEA is a leading authority on energy policy, and these reports are widely used by policymakers, industry leaders, and researchers.

Thus, collecting data from scientific journal publications, Statista, Our World in Data, government reports, and IEA reports provided valuable insights and support for understanding various technological, political, societal, economic, and environmental trends of the ongoing electrification transformation.
I was also a team member on the national-level project assigned by the Swedish government to the Swedish National Road and Transport Research Institute (VTI), where I work as a researcher. I participated in this project as an author and wrote a chapter with Arne Nåbo as a co-author on “Techniques, user perspective, and business models for charging infrastructure.” The main title of this report was “Recommendations to facilitate data sharing and utilization of data for planning, development and operation of charging infrastructure and business models.” This project aimed to focus on the part of the mission that deals with conducting pilot projects and developing models for how data, in practice, can be made available, shared, and utilized in the best way to optimize planning, development, and operation for charging infrastructure and business models.

Thus, being part of these national and international projects provided me with broader exposure, understanding, and first-hand knowledge by conducting seminars and workshops on an ongoing transformation of the electrification of transportation systems and solutions.

### 2.6 Data Analysis

In paper – I, the analysis was divided into two main categories: 1) analysis of the technical, functional, and performance capabilities of traditional and smart grid systems, and 2) Cost comparison of old and new electricity distribution systems and integrating renewable energy sources with the traditional and smart grid system. The findings of the analysis guided me that the old analog traditional grid is inefficient for integrating renewable energy. In contrast, renewable electricity generation systems can efficiently be integrated with the smart grid system. However, a massive investment is required to upgrade the old fossil-based electricity distribution system to a new smart, digitalized system, which depends on the finance and government’s rules and regulations.

In paper – II, the analysis is categorized into two categories: 1) comparative analysis of the availability and cost of non-renewable and renewable energy sources, 2) analysis of the impact of disruptive technology (smart grid) on consumers perspective and the business models of electricity providing firms. The findings of the analysis guide that renewable energy sources are plentiful, and the cost of generating electricity with renewable energy sources is high. Still, with the advancement of technology, the cost may decrease. In contrast, the cost of generating electricity with non-renewable energy sources is comparatively low, but the non-renewable sources are depleting globally. Another finding was that the smart grid is a disruptive technology that demands a new business model to integrate new actors into the energy market.

Paper – III, the analysis focuses on the environmental impact of using renewable electricity generation technologies such as solar photovoltaic and wind turbines. The research findings guided us that the renewable electricity generation system has minimal adverse effects, which can be mitigated using various strategies compared to the fossil-based electricity generation system.
Paper IV and V, the analysis is done based on each country's data on their technology, political, societal, and economic capability, decisions, and actions towards the electrification of transport. Technology is analyzed based on electric vehicles (EVs) and 'EVs batteries' manufacturing capabilities and charging infrastructure solutions. Politics are interpreted based on government interest and demonstrated actions in transport electrification, government support to provide subsidies and rebates to EV buyers and manufacturers, and investment in charging infrastructure solutions. Societal is analyzed based on EVs' sales and market share of EVs. Economics is analyzed based on the economic conditions for the diffusion of EVs, purchasing and charging costs, the operational cost of EVs, and government subsidies to support the diffusion of EVs.

Paper – IV focuses on developing a 'multidimensional readiness index model' that enables us to explore and understand any transportation mode, including flight and shipping. But for this research in paper – V, the model is applied to eight countries, Australia, China, India, Germany, Norway, Slovenia, Sweden, and the UK, to analyze and evaluate the development progress of these countries in their electrification of the road transportation system. The political and economic readiness scales have also been developed and classified based on empirical observations. For societal readiness levels, I have been inspired by the European societal readiness levels (Büscher and Spurling, 2019) but modified them based on our need that focuses on the adoption of electric vehicles by society. Each readiness dimension is divided on a scale between 1 and 9. Each one of the 1-9 levels shows a certain level of readiness; the 9th level shows the highest readiness scoring, whereas the 1st level shows the lowest readiness scoring of the countries in the electrification of the transportation system.

The proposed four-dimensional readiness index scales are tentative and should be further developed, elaborated, and thoroughly experimented. As the diffusion of transport electrification continues, new technologies will be launched, and new experiences will be developed, thus creating reasons for reevaluating the scales of political, societal, and economic readiness to achieve high maturity levels.
2.7 Philosophical and scientific positioning

This research was explorative, started, and driven by empirical phenomena that led to theoretical contribution and practical understanding. To explain the research approach, I have adopted the modified version of Saunders’ research onion used by Lysek (2019). The revised version of the research onion is shown in figure 6.

Saunders et al. (2007) introduced the research onion, which consists of multiple layers, as shown in figure 6. These layers are divided into six major areas. According to the Saunders et al. (2007) research onion, the first outer layer begins with philosophy (positivism, constructivism, pragmatism, interpretivism, etc.) and moves inwards to the second layer, that is approaches to theory development (abduction, deduction, and induction) and further, on to third layer methodological choices (qualitative methods, quantitative methods, or mixed methods) and then to the fourth layer of strategies (action research, case study, experiments, surveys, etc.) and fifth layer defines the time horizons (cross-sectional and longitudinal), and then the final sixth layer defines techniques and procedures for data collection and data analysis.

The research onion is a metaphor that Saunders et al. (2007) introduced. Saunders et al. (2007) research onion illustrates that the core of the research onion (i.e., data collection and data analysis) can be coherent when established on understanding the other components of a research design (i.e., research philosophy, approaches, strategies, methodological choice, and time horizon). The primary difference is that Lysek (2019) modified research onion places philosophies and traditions at its core. It is because philosophies and traditions represent
various beliefs that, once they take hold in individuals, become fundamentally embedded within them and lead to different analytical perspectives. In contrast, Saunders et al. (2007) place philosophies and traditions at the outer layer of the “research onion.” However, Saunders and Tosey (2013) stated that most researchers begin their research by exploring what data is required and then focus on obtaining the data, which means they start their research from the core to the outer layer of the research onion.

The reason for adopting Lysek (2019) research onion was to illustrate the research approach which guides from the empirical foundation to the philosophical and scientific positioning rather than philosophical and scientific positioning to the empirical foundation, as Saunders et al. (2009) described in his research onion. The research was empirically driven by the facts and observations of the rapid growth of global transportation electrification rather than by a hypothesis based on the existing body of knowledge. Therefore, the onion was peeled off from the outer methodological procedures toward the philosophical stance.

In general, the term “paradigm” refers to the fundamental set of beliefs or philosophical assumptions that are significant to identify as they define the researcher’s worldview (Denzin and Lincoln, 2011). In research, these assumptions often remain hidden, but they inform the choice of beliefs and guide the methodological choices of the research (Creswell and Poth, 2016). The term paradigm was introduced by Kuhn (1970) and referred to the shared beliefs, values, and assumptions held by a group of experts about the world and its knowledge and reality. The term ‘worldview’ is often used interchangeably with ‘paradigm’ to refer to a way of thinking and explaining the dynamics of the world (Creswell and Clark, 2017).

Modern research is organized and structured by several paradigms or worldviews, such as positivism, interpretivism, pragmatism, etc. Saunders et al. (2019). However, they are all philosophical in origin and share the following characteristics: ‘Ontology’ implies the nature of reality and its attributes (Saunders et al., 2009). Therefore, ontology is the belief in objects and their bonds. It gives standards for differentiating multiple types of artifacts (real and ideal, existent and nonexistent, independent and dependent, concrete and abstract) and their bonds, such as predictions, relationships, and dependencies (Gruber, 2009). ‘Epistemology’ applies to what represents reasonable, genuine, and relevant knowledge, how we can gain and convey knowledge to others, and if there are limitations to what we might actually know (Burrell and Morgan, 2017, Wilson and MacLean, 2011).

In social science, paradigms serve as heuristics, or guides, to help researchers address specific problems (Abbott, 2004). The scientific positioning is significant as it influences the research approach and the methodological choice taken by the researcher, all of which affect the quality of the research (Royer, 2013). Therefore, these scientific traditions determine what we are as researchers and how we perceive the world. Trying to step outside the conventional process would be like stepping out of our comfort zone (Denzin and Lincoln, 2005). A wide variety of paradigms exists in the context of scientific research. Often two philosophies are seen as fundamentally opposing, i.e., subjectivism and interpretivism on one side and objectivism and positivism on the other. The remaining ones can be discovered anywhere in the middle (Thurén, 1991).
Objectivism involves natural science assumptions. It claims that researchers study the social truth as external to them and others. It suggests that objectivism, ontologically, advocates realism, which finds social beings to be like actual entities in the natural universe at their most extreme form, to that extent as they exist objectively of how we categorize and consider them or even our understanding of them. Since, according to this perspective, the interpretations and interactions of social actors do not impact the life of the social universe, an objectivist firmly claims that all social actors experience only one valid social reality. Objectivism epistemologically focuses on empirical and concrete evidence that attempts to uncover a truth concerning the social universe, which allows law-like generalizations of a fundamental social existence to be derived (Saunders et al., 2019).

Subjectivism involves creative and societal assumptions and affirms that social truth is created from peoples’ experiences and implications. Subjectivism ontologically adopts ‘nominalism,’ sometimes called ‘conventionalism.’ Nominalism believes that by using perceptions, conceptual categories, language, and consequent actions, the social order and mechanisms of the phenomenon examined are generated by us as researchers and other social actors. As per nominalists’ perspective, there is no single reality that is the same for everyone; rather than there are multiple realities, and everyone understands and identifies truth differently, and the truth is what people assign to it. Social constructionism is a less extreme form in which reality is intersubjectively created by social interaction where people create partially common interpretations and realities (Saunders et al., 2019).

Ontologically, there are two perspectives that researchers perceive the world using their cognitive understanding, either they believe that the real world exists unaffected and accessible, or it does not.

Epistemologically, there are two perspectives that researchers believe in acquiring knowledge either they believe that objective knowledge can be acquired from the world, or they cannot.

Instead, positivists believe that objective knowledge can be obtained from the real world and claim that cognitive knowledge is separated from the real world. Positivist researchers believe every research phenomenon or circumstance has a single objective reality (Hudson and Ozanne, 1988). Therefore, positivist researchers construct an appropriate hypothesis and precise research topic and adopt a suitable research methodology. In conducting research, they take a controlled and structural approach (Churchill et al., 1996). Another significant thing is that positivist researchers keep themselves apart from the research participants and do not attach emotionally to the situation and remain neutral to make a clear difference between reason and feeling. They still provide a strong difference between knowledge and personal understanding and evaluation of reality and value (Carson et al., 2001). Critical realists believe that reality is external and independent, and what researchers experience while obtaining knowledge are sensations that manifest what is real in the world. It is not an actual thing that can be directly accessed by knowing it and through our observations. Therefore, critical realists emphasize how often their senses have deceived them and how frequently researchers see the real world as a representation.
On the other hand, the main focus of the hermeneuticist approach is on the research of cultural artifacts such as images, stories, and symbols (Saunders et al., 2019). Interpretivist and social constructionists both agree that objective knowledge cannot be obtained from the real world; however, interpretivist claim that our cognitive understanding is separated from the real world, whereas social constructionists argue that our cognitive understanding cannot be separated from the real world (Royer, 2013). Pragmatic researchers are aware of the fact that there are multiple ways to interpret the world and carry out research, and there can be no one point of view that can offer the whole picture. It does not mean pragmatists always use multiple methods to obtain knowledge; instead, they use the tools and methods to obtain accurate, well-founded, reliable, and meaningful evidence that facilitates knowledge (Saunders et al., 2019). This thesis adopts pragmatism as a research paradigm, further discussed in the following section.

2.8 Philosophical positioning – Pragmatism

Pragmatism requires the researcher to be exclusively concerned with real-world practical problems (Peirce, 1982). Numerous practical problems exist in the world, such as the depletion of fossil fuels, saving organic fuels, global warming, uninterrupted power supply, the rising cost of electricity, increasing unemployment, living standards, etc. (Mwasilu et al., 2014). Whereas this thesis specifically focuses on the challenges associated with transforming energy and transportation systems.

From a pragmatic point of view, the reality is not static. It changes over time. Similarly, the world is not static but changing and evolving (Kaushik and Walsh, 2019). It is not the same as it was a decade ago. The world’s population is increasing, and new technologies are developing and revolutionizing different sectors (Weijermars et al., 2012). Similarly, emerging technologies associated with the energy and transportation sector, such as lithium-ion batteries, electric vehicles, hydrogen fuel cells, photovoltaics, wind turbines, and smart electricity distribution system, has a highly revolutionary impact on the energy and transportation sectors (Battaglini et al., 2009).

As a research paradigm, pragmatism stays out of philosophical debates about ideas like truth and reality. However, ontologically, pragmatism believes in the possibility of numerous realities that may be explored empirically (Cresswell and Plano Clark, 2011). The empirical phenomena guide that it is the reality that evolving technologies have made it possible for the energy system to transform from fossil-based to renewable and for the transportation system to transform from gasoline vehicles to electric. Scholars that take a pragmatist stance have expressed their view that there is an objective reality different from subjective perception. This reality, however, has its roots in the environment and can merely be experienced by humans (Morgan, 2013). Human involvement and their interaction with emerging technologies have become mandatory to understand and support this transformation for the benefit of society to decarbonize the environment from the hazardous
gases that are unhealthy for human health and overcome the challenges of the demand and supply side of energy.

However, implementing these technologies is the key challenge requiring finance, government support, societal acceptance, and a new business model. The empirical phenomena guide that we cannot split the function of technological systems from government policies. Neither the willingness of society to adopt new technical solutions nor the role of the business model and the economical solutions for the new technological system as the financial solutions are firmly subjected to government policies.

According to Biesta (2010), pragmatism should not merely be perceived as a philosophical stance but as a philosophical tool that can be adopted for exploring real-world problems. Pragmatism is a research paradigm that focuses on exploring knowledge and understanding real-world problems that are practical. Researchers who were more reality-based began to use pragmatism as a tool to explore (Maxcy, 2003). The pragmatist believes that no single aspect can provide an entire understanding. Thus, a pragmatist explores and contributes knowledge that supports seeing things from a broader perspective to bring change (Saunders et al., 2015). As a pragmatic, the researcher believes that merely focusing on technology will not lead us to the complete transformation of the transportation system. Thus, to understand the practical challenges hindering the transformation of the transportation system from fossil-based to electric in the context of each selected country, this thesis explores four aspects (i.e., technology, political, societal, and economic) to gain a broader understanding.

Pragmatism in social sciences refers to a philosophical approach that emphasizes practicality, action, and real-world consequences. It emphasizes the practical implications and usefulness of concepts, theories, or interventions, the implementation of technologies, and the decision-making and actions executed to tackle societal problems and enhance human conditions (Dewey, 1999). Pragmatism originated as a philosophical trend in the late 1800s and early 1900s, advocated by well-known scholars like Charles Sanders Peirce, William James, and John Dewey.

Regarding social sciences, pragmatism reveals itself through several basic principles and viewpoints:

- Practical orientation: Pragmatism strongly promotes the idea of solving practical problems and taking action that has an actual impact on individuals and society (Cunningham et al., 2005). It fosters researchers and practitioners to concentrate on issues prevalent in the real world, aiming for realistic and pragmatic solutions that can effectuate noticeable changes in society and people’s lives.

- Empirical inquiry: Pragmatists emphasize the importance of exploring empirical evidence and experiences in understanding social phenomena (Joas, 1993). They value collecting and analyzing data to guide decision-making and solve problems, focusing on the significance of observation, experimentation, and qualitative research methods. In my situation, I specifically concentrate on the interaction between technology and society.
- Anti-dogmatism: Pragmatism rejects rigid adherence to fixed theories, doctrines, or ideologies (Seigfried, 2013). It encourages openness to different perspectives, flexibility in adapting various approaches and viewpoints, enabling understanding of the phenomena being explored, and a willingness to revise or discard ideas in light of empirical evidence or practical outcomes.

- Instrumentalism: Pragmatism views theories and concepts as tools or instruments for achieving specific purposes. The value of ideas lies in their usefulness in addressing social and societal issues and problems or guiding action rather than their abstract truth or coherence (Stanford, 2014). Pragmatists focus on the practical implications and applications of existing knowledge, theories, perspectives, and approaches rather than their metaphysical or abstract aspects.

- Problem-solving and experimentation: Pragmatism emphasizes an experimental and problem-solving mindset. It encourages researchers and practitioners to engage in iterative inquiry, experimentation, and learning cycles to address social and societal problems, evaluate interventions and actions, and adapt strategies based on empirical outcomes and feedback (Prasad, 2021).

- Contextual and situational understanding: Pragmatists recognize the importance of considering the specific social, societal, cultural, and historical context in understanding and addressing social issues (Holmwood, 2014). They emphasize the need to understand a situation's unique circumstances and dynamics to develop effective interventions or policies.

Pragmatism in social sciences encourages a holistic and action-oriented approach to studying and addressing social phenomena. It values practical outcomes, empirical evidence, and adaptability and can respond to real-life challenges. By stressing the correlation between theory and application, it aspires to further societal progress and enhance the quality of life for individuals and communities.

Although pragmatists acknowledge and support that we as researchers can take the view point, perspective, or approach that we see as appropriate and in line with our research, they also recognize that certain beliefs are more likely than others to help us achieve our aims and fulfill our needs (Morgan, 2013). Thus, this study has a starting positioning with empirical observations by collecting qualitative data and using an inductive approach to explore and develop knowledge and understanding of the practical challenges of transforming energy and transportation systems that directed the researcher to adopt a pragmatic stance as a philosophical paradigm for this research.

Another motivation for adopting a pragmatic stance in this study is rooted in recognizing that the transformation of the transportation system is an ongoing and dynamic process. A rigid and single-theoretical approach may not adequately capture the complex interplay among the elements involved. Instead, by embracing pragmatism, which emphasizes flexibility and focuses on practical outcomes, we can employ a methodological framework that adapts and responds to the evolving nature of transportation transformation. This approach ensures a more inclusive, holistic, and deeper understanding of the process and its impacts,
thereby enhancing the relevance and practicality of research outcomes in real-world situations.

2.9 Putting pragmatism in the research practice of social science

In social science research, the exploratory approach refers to a method of investigation that aims to explore and understand a phenomenon or topic of interest in a flexible and open-ended manner. It is often used when there is limited existing knowledge or when the research objective is to generate new insights, theories, or hypotheses (Swedberg, 2020).

The exploratory approach typically involves the following characteristics:

- Open-ended research or inquiry questions: Instead of starting with specific hypotheses or predictions, researchers begin with broad, open-ended inquiry or research questions. These questions allow for a comprehensive exploration of the phenomenon under study and provide flexibility in the research process depending on the outcomes (Rorty, 1982). The research process is dynamic.

- Qualitative methods: The exploratory approach often uses qualitative research methods such as interviews, focus groups, participant observation, or case studies. These methods allow researchers to gather rich and in-depth data, capturing the complexity and nuances of the investigated phenomenon (Hollstein, 2011).

- Iterative and flexible research design: Researchers may modify their research design and methods during the study as they gather new insights and refine their understanding of the phenomenon. This iterative process allows data collection and analysis adjustments to explore better-emerging themes and patterns (Kloppenberg, 1996).

- Inductive reasoning: Instead of starting with preconceived perspectives, theories, or hypotheses, the exploratory approach emphasizes inductive reasoning. Researchers analyze the collected data to identify patterns, themes, or relationships, which are then used to generate new hypotheses or theories (Hayes et al., 2010).

- Exploratory data analysis: Researchers use different techniques to explore and analyze the data, such as thematic analysis, content analysis, or grounded theory. These methods focus on identifying commonalities, outliers, or emerging themes within the data to obtain a more profound insight into the subject matter of the study (Swedberg, 2020).

- Generating new insights and developing new approaches and theories: The exploratory approach in the research focuses on generating new insights, theories, or hypotheses which can provide guidance for future research or add to the existing
knowledge base. The outcomes of an exploratory study often serve as a foundation for more focused and hypothesis-driven research in the future (Brink, 1998).

- The exploratory approach refers to a method of investigation in social science research that aims to explore and understand a phenomenon or topic of interest in a flexible and open-ended manner. It involves open-ended research questions, qualitative research methods, iterative research design, inductive reasoning, exploratory data analysis, and the generation of new insights or theories (Miles and Huberman, 1994).

- The exploratory approach in social science research allows researchers to explore a research topic without preconceived hypotheses or specific predictions. It is particularly useful when there is limited existing knowledge or when investigating complex or emerging topics. The focus is gathering rich, qualitative data, analyzing it to identify patterns or themes, and generating new insights or theories to guide further research or contribute to existing knowledge (Brink, 1998).

Thus, the exploratory approach is beneficial when there is limited prior knowledge or understanding of a phenomenon or when researchers investigate complex or emerging topics. It allows researchers to gain a comprehensive and nuanced understanding of the subject matter and paves the way for further research and theory development.

The exploratory approach is often based on researchers’ capabilities to interpret and conceptualize the observed phenomena.

2.10 What is the interpretative research approach?

Interpretative research, also known as interpretivism or qualitative research, is a methodological perspective used in social sciences that focuses on understanding and interpreting the meanings, experiences, and subjective perspectives of individuals and groups within a specific social context (Berger and Luckmann, 1967). It primarily explores the complexities and nuances of human behavior and social phenomena (Thorne, 2014).

Key characteristics of the interpretative research approach include:

- Subjective understanding: The interpretative approach recognizes that individuals and groups assign meanings and interpretations to their experiences and the social world. Researchers aim to understand and interpret these subjective meanings rather than seeking universal laws or generalizations (Schultz and Hatch, 1996).

- Contextual understanding: The approach emphasizes the significance of social, cultural, and historical contexts in shaping individuals’ experiences and behaviors. Researchers strive to understand the contexts in which social phenomena occur, recognizing that they influence people’s perceptions and actions (Zoller and Kline, 2008).
Qualitative data collection methods: Interpretative research often employs qualitative data collection methods, such as interviews, participant observation, focus groups, or document analysis. These methods allow researchers to gather rich, detailed, and nuanced data that capture the perspectives and experiences of individuals in their natural settings (Frey, 1994).

Inductive reasoning: The interpretative approach typically follows an inductive reasoning process. Researchers derive themes, patterns, or theories from the data rather than imposing pre-existing theories or hypotheses. They analyze the data systematically, often using coding or thematic analysis techniques, to identify recurring ideas, categories, or relationships (Deetz, 1982).

Reflexivity and researcher involvement: Interpretative researchers acknowledge that their biases, assumptions, and interpretations may influence the research process and findings. They engage in reflexivity, critically examining their role and positionality concerning the research topic and acknowledge the potential impact of their perspectives on data interpretation (Cooren, 2015).

Rich and thick descriptions: Interpretative research emphasizes the importance of providing rich and detailed descriptions of the research context, participants, and findings. Researchers aim to present thick descriptions that capture the studied phenomena’s nuances, complexity, and contextual factors (Geertz, 1973).

Thus, the interpretative research approach is particularly suited for exploring subjective experiences, social interactions, cultural practices, and complex social phenomena that cannot be easily quantified or measured. It is often used in disciplines such as anthropology, sociology, psychology, and qualitative studies in education, as it provides insights into the lived experiences and social meanings of individuals and groups, contributing to a deeper understanding of social phenomena from their perspectives.

Also, the interpretative research approach is relevant in studying the transformation of the transportation system. This approach values the complexity of human experiences and perceptions, enabling a rich understanding of how various actors make sense of and navigate the changing transportation landscape. By focusing on context, interpretive research uncovers the underlying meanings, norms, and values that influence behaviors and decisions within this transformation. These insights are invaluable in an era where transportation is becoming increasingly integrated, and user centered. They allow us to design and implement changes in transportation systems that are both technologically advanced and efficient and resonate deeply with the people they serve, thereby ensuring more sustainable and successful transformations.
2.11 Defining research approach – explorative approach

An essential consideration of research design is often based on its focus. If a researcher’s starting position begins with the existing body of knowledge from which the research purpose, questions, and data collection are derived, known as the deductive approach, or if a researcher’s starting point begins with an explorative and empirical perspective of the real world by collecting data to explore a phenomenon where a researcher often develops a conceptual framework called the explorative and inductive approach (Saunders et al., 2007).

The purpose of the inductive approach is not to test the existing body of knowledge or ‘fill the gaps’ but to explore and understand the dynamics of the social world (Alvesson, 2011). The existing theories and knowledge we have today are based on an understanding of yesterday’s world. Whereas the world is changing over time, new digitalized technologies are emerging and revolutionizing the market, industry and society.

2.12 The explorative approach in social science

In social science research, an explorative and inductive approach is an approach of reasoning that involves developing general conclusions, perspectives or even theories based on specific observations or evidence (Reiter, 2017). It is the opposite of the deductive approach, which starts with general theories or hypotheses and seeks to test them through empirical observations.

Several scholars (Sabherwal and King, 1991, Hayes et al., 2010, Klauer and Phye, 2008, Zalaghi and Khazaei, 2016, Hayes and Heit, 2018) define the inductive approach, which typically involves the following steps:

- Observation: Researchers begin by gathering specific observations or data from the field. This can involve qualitative methods such as observations, conversations, interviews, textual analysis or quantitative methods such as surveys or experiments.
- Pattern recognition: Researchers analyze the collected data to identify patterns, similarities, or recurring themes within the observations. This can involve categorizing data, looking for commonalities, or identifying emerging trends or relationships.
- Formulating conclusions, conceptualization, and theorizing based on a conceptualization: Researchers develop conclusions, perspectives or even theories that explain the observed phenomena based on the patterns or themes identified in the data. These conclusions or theories are tentative and subject to further development and refinement.
- Developing and refinement: Researchers design further studies or gather additional data to build and expand the understanding and conceptual models or theorizing from
the initial observations. This can involve more focused data collection, quantitative analysis, or comparison with existing theories or findings.

- Evaluation and further exploration: Through the evaluation and refinement process, researchers evaluate the preliminary questions, and purposes, in light of the new observations and conceptualization. If the data and the interpretations indicate a certain conceptualization the conclusions, concepts, or even new “theories” can be presented, and they can be further developed and conceptualized based on new perspectives in the analysis and conceptualization.

The explorative and inductive approach in social science research allows for identifying new empirical phenomena not being known before, shaping new knowledge and perspectives by building from specific observations to more abstract understanding and conclusions. It is particularly useful when exploring new or understudied areas, generating questions, or developing new perspectives based on empirical evidence.

It's important to note that the explorative inductive approach is not a definitive process and often involves an iterative and cyclical nature. Researchers may move back and forth between data collection, analysis, question formulation, and deepening the understanding, refining their understanding of the phenomenon under study as they gather more observations and insights.

2.13 Exploring the dynamics of the transformation of energy and transportation systems

The starting point of this research was to explore and understand the dynamics of technological development in energy and transportation systems. Emerging technologies such as solar photovoltaic, wind turbines, smart sensors, batteries, and electric vehicles are transforming energy and transportation systems. However, this transformation is not merely limited to technological systems. For instance, renewable electricity generation technologies and smart distribution systems are transforming the electricity generation and distribution system from a centralized to a decentralized system that empowers consumers to have more control over electricity usage. Still, to manage this transformation, governments are supposed to introduce new policies, and the electricity suppliers need to change or develop new business models.

Considering the transportation sector leads to understanding that rigorous global environmental policies triggered the emergence of new technologies associated with the automotive industry (Altenburg et al., 2022). This new technology, i.e., electric vehicles, has introduced the concept of replacing fossil fuel-propelled vehicles with electric vehicles to decarbonize the road transportation system. However, transforming the transportation system from fossil-based to electric does not merely require replacing vehicles of one form with another. It also requires societal acceptance of new technology and government support
to establish new charging infrastructure for electric vehicles to function. The involvement of various aspects such as political, societal, and economic make this transformation complex and dynamic which needs to be explored and understood.

Thus, the inductive approach was adopted for this research, where the researcher began research by collecting data to explore and understand the empirical phenomena in the context of its existence (Saunders et al., 2015) of an ongoing change in the energy and transportation sectors. The observation guided the researcher to propose a new conceptual model (Bryman and Bell, 2007) for seeing and understanding the transformation of energy and transportation systems from a holistic perspective.

2.14 Choosing a qualitative approach

Choosing a research approach is a fundamental and significant part of the research design. There are three main research approaches: quantitative, qualitative, and mixed methods (Creswell, 2003). Quantitative research is commonly connected with positivism, precisely when data collection techniques are highly structured and collect data from large number of respondents, and all questions are predetermined (Saunders and Tosey, 2013). However, quantitative research is not merely confined to positivism, and it can also be used with pragmatism and realism. The deductive approach is generally associated with both quantitative and qualitative research, approaches and methods, focusing on using data to test hypotheses, develop understanding and even define new theories (Saunders et al., 2009).

Qualitative research is generally correlated with interpretivism (Denzin and Lincoln, 2005). In qualitative research, the researcher interprets the subjective and socially constructed phenomenon being studied. Pragmatists and realists can also use qualitative research (Saunders et al., 2009). Generally, qualitative research begins with the inductive approach, where the researcher uses the data to develop a comprehensive conceptual framework than what is already available in the existing body of knowledge (Yin, 2009). The main difference between qualitative and quantitative approaches and methods is that the qualitative method avoids prior commitment to any theoretical model, even though the qualitative data might be based on numbers, whereas the quantitative approach is based on statistical analysis and depends on correlations and explanations (Silverman, 2015). The other difference is that the qualitative research approach explores phenomena in context and explores understanding and interprets processes or meanings (Silverman, 2015), and the data is not based on large-scale samples (Yin, 1988).

This research followed the qualitative research approach as the research was explorative, and each of the individual papers explores and contributes to the body of knowledge that supports understanding the transformation of the energy and transportation system. The first paper of this study explores and understands the development of new technology associated with energy systems and its implementation that transforms the electricity generation and distribution system from a centralized to a decentralized system.
based on integrating renewable electricity generation technologies such as solar and wind. The second paper explores the impact of disruptive technology (smart grid) on the existing business models of energy-providing firms as the new technology empowers consumers to have more control over electricity usage. It also explores the need for a new business model to support commercializing smart grid systems for the mutual benefit of creating, delivering, and capturing value for consumers of electricity and renewable electricity generation and distribution firms. The third paper explores the cost of generating electricity with renewable electricity generation technologies such as solar photovoltaic and wind turbines and the impact of these technologies on the environment.

The fourth and fifth papers of this study explore and develop knowledge and understanding holistically of transforming the transportation system from fossil-based to electric. The study spans different areas of knowledge, i.e., technology, politics, society, and economics, in which the exploration is based on the conditions and context of the eight selected countries. The study explores the empirical phenomena of the readiness of political policies and how these policies impact the readiness of technology (electric vehicles) and technological solutions (charging infrastructure) for the electric transportation system. The study also explores the correlation of the political and economic policies’ impact on the willingness of society to adopt new technology (electric vehicles) and how technological, political, societal, and economic aspects are interrelated and interdependent and have an impact on the transformation of the transportation system.

Thus, the overall research is exploratory, where the researcher explores the integration and relation of technological, political, societal, and economic aspects and their impact within the specific context and conditions of transforming the transportation systems. The electrification of the transportation system is an emerging area where countries are developing new technologies and technological solutions, establishing new policies offering new subsidies and rebates to encourage society to adopt new technology, making the system more complex and dynamic. Therefore, to develop new knowledge and understanding of transforming the transportation system, this study chose the qualitative approach as it is appropriate for an explorative study where complex issues and problems need to be explored, and insufficient knowledge exists to address the issues or problems (Creswell and Poth, 2016).
2.15 Research Process

This section presents the research process that explains why I have made such decisions and adopted those directions during my research.

I was guided to write this thesis by the five published papers that are the core of this research. Table 1 represents the list of five papers and the contribution that I have made during the study with my co-authors.

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<th>Papers</th>
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<tr>
<td>Kappa</td>
<td>The entire Kappa is my own elaboration. The content of the Kappa is based on my five papers and interpretations originating from the papers and also on an aggregative level integrating all of the five papers.</td>
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<td></td>
<td><em>My supervisors have had opportunities to give comments as well as opponents on the final seminar and senior professors during the evaluation process.</em></td>
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<tr>
<td>Paper – I</td>
<td>Making the world more sustainable: Enabling localized energy generation and distribution on decentralized smart grid systems.</td>
</tr>
<tr>
<td>My contribution</td>
<td>This paper explores and guides that the old, centralized electricity generation and distribution system primarily depended on coal boilers and fossil fuels, which emit greenhouse gases and harm the environment. The old traditional grid has a fundamentally one-way communication system. Thus, the grid cannot efficiently be integrated with advanced digitalized renewable electricity generation technologies such as solar photovoltaic (PV) and wind turbines. However, the advancement of technology has made it possible for the grid to be updated and converted into an intelligent distribution system “smart grid” that can efficiently be integrated with renewable electricity generation technologies. The smart grid enables a decentralized electricity generation and distribution system that can achieve the rising electricity demand and decarbonize the environment by increasing the usage of renewable energy sources. However, the key challenges in transforming the energy system are that heavy investments are required, new policies must be introduced, and new rules and regulations must be established.</td>
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<td><em>I was primarily responsible for conceptualization, methodology selection, data collection, analysis, and writing the entire paper.</em></td>
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<tr>
<td>Paper – II</td>
<td>Business model innovation approach for commercializing smart grid systems.</td>
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| My contribution | The smart grid has allowed new actors and stakeholders, specifically ICT (information communication technology) firms, to enter the energy markets. This change has
threatened the existing energy firms and developed uncertainty, leading them to change their traditional business model. This paper's finding shows that the firms that adopted the changes in technology and accordingly changed their business model to respond to the market were successful. In contrast, the firms that adopted the changes in technology but hesitated to change their business models died. The smart grid is a disruptive technology with the potential to revolutionize the energy industry. Thus, to survive and thrive with the new change, the energy firms need to change or develop a new business model for integrating new actors and stakeholders in the value chain to capture and deliver value for them.

I was primarily responsible for conceptualization, methodology selection, data collection, analysis, and writing the entire paper.

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<td>My contribution</td>
<td>This paper is a bridge between Papers 1 and 2 and Papers 4 and 5, where I used the concept of a microgrid system as the electricity distribution system to the electric road transportation system. In this paper, extensive analysis has been done of renewable electricity generation technologies, i.e., solar and wind on the environment, and further cost analysis of solar and wind power. Since environmental policies have become rigid globally, rapid advancement can be seen in the development of technology associated with the energy and transportation sector. These technological advancements have made it possible for the concept of electric roads to decarbonize society from road transportation. However, the major challenge is to achieve the rising demand for electricity for the electric road transportation system with renewable energy sources, as 70% of global energy comes from burning fossil fuels. These challenges lead to exploring cost comparison and the environmental consequences on society of using new technologies (solar PV and wind turbines) to produce electricity with renewable energy sources. The exploration shows that integrating renewable energy technologies (solar PV and wind turbines) with microgrids can enable locally produced electricity, achieving the rising electricity demand and is environmentally friendly and less expensive than fossil-based sources.</td>
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I was primarily responsible for conceptualization, methodology selection, data collection, analysis, and writing the entire paper.

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<tr>
<td>My contribution</td>
<td>In this paper, I have defined all four dimensions in 9 steps based on an extensive literature review and conceptually designed the “Multidimensional readiness model” firmly based on empirical data. Three countries’ real data was collected to develop the model and evaluate if the proposed model is relevant and meaningful.</td>
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Different countries’ governments are adopting different approaches and strategies and developing solutions based on their countries’ contexts and conditions. Most existing research focuses on the technology for transportation electrification based on battery and hydrogen technology, whereas the significant challenges are related to the charging infrastructure. The challenges associated with charging infrastructure are deeply rooted in political decisions. Thus, to improve understanding and support the ongoing transformation of the transportation system, in this study, a new analytical tool called the “multidimensional readiness index model” has been developed and applied to three countries (China, Norway, and Sweden) for exploring and analysing technological, political, societal, and economic readiness. The exploration shows that the development and implementation of electrification of the transportation system depend on society’s readiness to pursue the development, adoption, and diffusion of electric transportation. Technology itself is a crucial foundation for electrification. It must be viewed and understood when commercialization and value creation to business, people, and benefits to society are also considered. Technology cannot be diffused in society and create value without a well-developed interplay of industry, academia, politics, economic institutions, and policy systems pushing and supporting economic and policy tools and regulatory tools.

I was primarily responsible for conceptualization, methodology selection, data collection, analysis, and writing the entire paper.

**Paper – V**

A system approach to electrification of transportation – An international comparison.

**My contribution**

In paper 5, the empirical data collection was significantly extended to eight countries based on insights that different countries are taking different approaches. I have done extensive empirical research on the data of electrification of transport in all chosen countries, using the comprehensive data of the ongoing electrification process, and demonstrated that the most critical aspect of readiness for countries to go the electrification way is rooted in the political decision-making and willingness to make decisions regarding the choice of technologies and economical solutions such as subsidiary levels, etc.

Paper 5 extensively presents the data for eight countries underlining the heavy work for thoroughly verifying the multidimensional readiness model. This study applies the multidimensional readiness index model to eight countries of three different continents Asia (China and India), Australia, and Europe (Germany, Norway, Sweden, Slovenia, and the UK), for extensive international comparison. The purpose of the comparison is to learn from other countries and draw the attention of policymakers to the challenges and opportunities in their countries for transportation electrification. Further draw their attention to the importance of political, societal, and economic readiness, which are necessary to understand and consider if countries strive to achieve a high level of electrification. The exploration and analysis show that China is leading globally in the electrification of transportation because of its strong technological advancements, complete control
over the entire value chain, favourable policies for electric vehicles (EV), the willingness of the public sector to take the lead and the citizens support to adopt clean technology. Norway is leading in EV adoption because of its favourable government policies for transportation electrification, even though Norway itself does not manufacture EVs and charging equipment. Germany is leading in Europe's technological sector of transportation electrification with its prestigious top-selling EV brands. However, Germany is still lagging behind in adopting EVs compared to gasoline-based vehicles. Sweden is a rapidly growing country in transportation electrification, with its three vehicle manufacturers introducing EVs in 2021 and developing an electric road system.

My work underlying paper 5 is extensive data collection from various databases and international sources of information that is highly up-to-date data in the progress of electrification of transportation systems. I was primarily responsible for conceptualization, methodology selection, data collection, analysis, and writing the entire paper. The supervisors supported me with advice.

Table 1: List of five papers that influenced on writing the kappa
Source: (Author)

The first two papers are published in international peer-reviewed journals. The third paper was published at the 3rd electric road systems conference held in Frankfurt, Germany, in 2019. The fourth paper is submitted as a full-length paper to a well-reputed scientific journal on level 1 on the Norwegian scale. The fifth paper will be scrutinized later during the autumn of 2023 and turned into two different scientific publications. One will be the model as a conceptual tool, and the other will reflect on the differences between countries and how and why different countries take different routes. Therefore, empirical and data richness is crucial to develop insight into the rapidly emerging area.

The selection of papers was purposefully aimed at deeply exploring the diverse aspects of emerging technology and societal transformation concerning energy and transportation systems. Each paper presents a distinct viewpoint, yet they are all intertwined to provide a comprehensive understanding of how these systems are both shaping and being shaped by modern society. The exploration through these papers not merely contributes to ongoing academic and industry discussions but also supports formulating a strategic roadmap for future policymaking, technological advancements, and societal engagement in the context of transforming energy and transportation systems. Thus, these papers serve as an essential resource for anyone interested in the intersections of technology and society.

The research was categorized into two categories: Study – I and Study – II. Study – I consist of papers 1, 2 and 3. These papers focus on transforming the electricity generation and distribution system from centralized to decentralized and business model innovation for commercializing the new electricity distribution system. This study also discusses the impact of renewable electricity generation technologies such as solar photovoltaic and wind turbines on the environment and the cost analysis of generating electricity from renewable sources.
Study – II comprises papers 4 and 5. These papers focused on developing an analytical tool that can support the integration of technology, political, societal, and economic dimensions in one model. The model is intended to provide a broader perspective for seeing, analyzing, and evaluating the countries’ readiness positioning in transforming the transportation system.

The following sections provide a detailed description of how Study – I, exploring the energy system, and Study – II exploring the transportation system, are conducted, and the decisions were made during the research process.

2.15.1 Study – I, Exploring Energy Systems

I am an engineer with a technological background. I began to understand the transformation of energy and transportation systems from a technical point of view. To achieve the overall purpose of this research, in my first paper, from a technical point of view, I started exploring electricity generation, distribution, and consumption systems that can fulfill the demand rising due to the transformation of the transportation system from fossil-based to electric with the integration of renewable energy sources.

My insight was that the old electricity distribution system does not have the capacity to meet the increasing electricity demand with non-renewable sources, as massive modifications and improvements are required to integrate renewable energy sources into the energy system and the grid (Feist et al., 2008). Therefore, a new smart digitalized electricity distribution system is required to support the integration of renewable energy sources and to balance the demand side. The technology that belongs to the electricity generation system is rapidly developing and improving as utility companies control it.

In contrast, the transformation of the distribution system (electricity grid) is facing challenges as it requires finance, government support, new rules and regulations, and the assurance to gain value for each stakeholder (Angelos et al., 2011, Hoang, 2006). I developed my understanding through the findings of my first paper that merely dealing with technological issues may not be enough to encourage and handle the transformation of energy systems that can handle the rising demand for energy from the transportation sector.

The understanding that I got while exploring and writing my second paper was that disruptive technology demands a new business model that can integrate new customer segments and enables the impact of the disruptive technology (Christensen, 1997, Bower and Christensen, 1996). Kodak and Nokia are two vivid examples of not timely realizing and acting accordingly to change their business model. Thus, these companies lost the opportunity that disruptive technology created for the associated businesses. The new electricity distribution system (smart grid) is a disruptive technology as it can change the entire process and structure.
of the market (Shomali and Pinkse, 2016, Weiller and Pollitt, 2016). The new electricity
digitalized distribution system (smart grid) integrates ICT firms and firms that can generate
electricity with renewable energy sources. It opens up a new market segment to supply fossil-
free electricity to, for example, the electric vehicle charging infrastructure. Therefore, it
requires a new business model to integrate new actors and customer segments to support the
transformation of the old traditional analog to the new modern digitalized renewable
electricity distribution system.

However, one dominant business model framework in the literature and in practice is
Osterwalder (2004) business model canvas, which is applicable for a focal firm to design and
visualize several business model components. The traditional business approach (Osterwalder
model) and similar will be discussed in section 3.2 in the Frame of References. Therefore, a
new business model is required to support the integration of new actors, such as policymakers
and new ICT firms, as these actors can play a significant role in transforming the new electricity
distribution system.

The cost has become a significant factor when deciding on the energy source and
energy-producing technology as fossil fuels are depleting, and the energy demand is rising due
to the transformation of the fossil-based transportation system to electric. From 1998 to 2011,
the cost of photovoltaic (PV) systems declined by approximately 5% to 7% each year (Feldman
et al., 2012). We may predict the cost of producing electricity with renewable energy sources,
whereas the prices of fossil fuels are more unpredictable. Approximately 15% of fuel prices
increased in the international market due to the war between Russia and Ukraine
(Kolaczkowski, 2022). Although the cost of producing electricity from renewable energy
sources is decreasing, it is too early to say that compared to the price of fossil fuels, the price
of generating electricity from renewable sources will be lower in the future market (Timmons
et al., 2014). The cost is subjected to governmental import/export tax and the subsidies
policies, which vary from country to country.

In my Study – I, I explored that merely relying on technological development and
technological solutions will not take us toward transforming the energy and transportation
systems. Therefore, we need to explore, understand, and develop new knowledge that can
contribute to seeing and handling the transformation from a holistic perspective. I also came
to understand that there is a great variation between countries in their approaches to
electrification and greenification of energy, i.e., introduction of renewable energy. Technology
is basically available to all that want to implement it. The technology itself is not the barrier to
electrification as one might think. For this reason, I chose to expand my scientific positioning
and take on a social science perspective as a complementary approach to technology.
2.15.2 Study – II, Exploring Transportation System

Innovation has not only a rate but also a direction (Mazzucato, 2018). Low carbon emission and environmental sustainability are more and more becoming the new selection criteria or ex-ante selection (Dosi, 1988) in the social-technical landscape. Human society is trying to develop renewable energy-based mobility solutions to replace fossil energy-based vehicles purposefully. It is a technological transition. As Geels (2002) defines, technological transitions are major, long-term technological changes in the way society functions are fulfilled. Technology can only fulfill its societal functions when embedded in the social context. Technological transitions do not only involve changes in technology but also changes in user practices, regulation, industrial networks, infrastructure, and symbolic meaning or culture. During technological transitions, sociotechnical configurations centered on the old technology will destroy, and a new configuration centered on the new technology will shape and unfold. Therefore, the transition’s success depends not only on the technology itself, but also on the economic, societal, and political context it is embedded in.

The process of electrifying the transportation system is currently taking place all over the world. Countries are developing and implementing different approaches and strategies to decarbonize their societies from fossil-based transportation systems. The developed solutions vary based on each country’s specific context and conditions. Each country faces different challenges, problems, and conditions, making it necessary for them to approach the transformation to electric transportation in a distinct manner. The impact of this transformation is extensive to countries, businesses, policymakers, society, and individuals across the globe. Each country's specific context and conditions will determine the speed at which this transformation occurs.

The empirical phenomenon guides that the technological development obstacles, which were significant at the early stages of this transformation two decades ago, are no longer a major concern. Nowadays, the technology needed for electrically driven transportation and devices is easily accessible, even though it is continually evolving and improving. However, implementing technology and its adoption and diffusion on a larger scale is still challenging.

Pragmatists believe that merely focusing on a single aspect, technology, will not provide us with an entire understanding of transforming the transportation system. Radical innovation requires changes in both the supply and demand sides. However, there are no established markets and no fixed preferences. As the sustainability transition field emphasizes, radical technologies, markets, and user preferences co-evolve. Coordinating the diverse and nascent resources involved in a radical innovation often requires robust state intervention (Smith et al., 2005). Political actors are major sources of selection pressure and legitimacy. The selection pressure of abolishing old technological solutions and legitimating the new technological solution creates the market, changes public opinion, and influences the cost of the new technology.
To understand and support the dynamics of ongoing technological transformation in the transportation field, we need to consider political, societal, and economic aspects that influence the process.

For this, I developed a conceptual model that can serve as an analytical tool based on an idea presented by Danilovic et al. (2020). Thus, my research underlying the fourth paper is divided into two main parts.

In the first part, I developed an analytical tool based on empirical phenomena where I practiced the explorative and inductive approach combined with literature review on similar readiness models presented by other researchers. The tool integrates technology, political, societal, and economic dimensions into one model and named it a "multidimensional readiness index model." The model supports analyzing, evaluating, and determining the countries' positioning in transforming technologies, policies, societal adoption of electric vehicles, and economic conditions, which guides the countries to learn from each other. Thus, each country does not have to start developing the same technology from scratch or make the same mistakes by introducing socio-economic policies or solutions that hinder the transformation of the transportation system.

In the second part of the fourth paper, the model is applied to three countries, China, Norway, and Sweden, to analyze, evaluate and determine these countries' position in the process of the transformation of the transportation system based on their conditions and contexts. The reason for selecting China is its current position as the leading country in developing equipment and systems for the electrification of transportation. On the other hand, Norway was chosen because it is one of the world's most highly adopted electric transportation system countries and contrary to China, Norway is a small country. At the same time, Sweden is selected for its aspirations to become a leading country in the electrification of transportation, and Sweden is the country of my Ph.D. education, and I used it as a reference in my research. The chosen countries share a common desire to pursue the electrification of transportation actively, and we clearly understand their intended developmental direction, even if they take divergent approaches.

However, environmental and climate-related problems and challenges are being experienced by all countries globally. Most countries are adopting rigorous policies to reduce or eliminate the harmful effects of emissions from transportation, energy production, and the usage of fossil fuel products in vehicles. Technological developments have introduced various solutions, including biogas, battery-operated vehicles, and vehicles that rely on hydrogen energy. Whereas currently, the dominant solution is battery-based vehicle systems. The hydrogen-based solution is developing, although it has not yet seen widespread commercial and practical use.

To understand what, why, and how different countries have chosen different paths for transforming the transportation system, paper five adopts an experimental approach where the newly developed “multidimensional readiness index model” was experimented with by applying it to eight different countries. These countries are selected from three continents: Asia (China, India), Australia, and Europe (Germany, Norway, Sweden, Slovenia, and the UK).
to study eventual differences in readiness level in the process of transformation of the transportations systems in technology, political, societal, and economic dimensions in each country context. The reason for selecting these countries precisely from these continents is because they have shown diversification in adopting the electrification of the transportation system solutions. The analysis is conducted based on extensive empirical data from all four dimensions technological, political, societal, and economic.

The purpose was to collect data from large, small, eastern, and western countries showing different stages in their development to deepen the understanding of the role and interplay of four dimensions in the dynamics of the transformation to the electrification of the transportation system. Thus, paper fourth and fifth are intertwined and complement each other.

Thus, these two studies, Study – I and Study – II, lead toward developing a holistic exploration that provides a broader understanding of the dynamics and the new trends leading the energy and transportation system toward transformation, more extensively and deeper than is possible only by focusing on technology.
3. Frame of References

The main focus of this chapter is to explore the literature and the main body of knowledge that provides a deeper understanding of the collaboration and integration of new actors and their symbiotic relations among them that can support to transformation of complex and dynamic energy and transportation systems.

In choosing the content of this chapter, I was guided by the empirical findings based on dissertation papers 1 to 5 to select the appropriate frame of reference. Thus, I have chosen three complementary theoretical approaches: 1) the System approach, 2) the Business approach, and 3) the Ecosystem approach, as shown in figure 7.

![Diagram](image)

Figure 7: Represents the exploration of literature based on the empirical phenomena
Source: (Author)

The system approach, the main theoretical platform for this thesis, was not in the early plan when this research was started. However, it came later during the research process after having empirical findings of the first three papers. I have adopted an inductive approach to understanding the dynamics in the energy and transportation sector. The world is changing over time; it is not the same as it was ten years ago, and so is the energy and transportation
sector. Evolutionary technologies (lithium-ion batteries, electric vehicles, hydrogen fuel cells, photovoltaics, wind turbines, smart electricity distribution system, etc.) are constantly changing the energy and transportation systems and impacting the way of doing business. This advancement leads to the development of interconnected actors and their systems in the new ecosystem where development and commercialization are taking place. The rapid growth of electric vehicles in China, Europe, and the US can be seen in the last few years. Governments are introducing new policies, and societies are adopting new technology; therefore, to understand the transformation of the transportation system, the empirical observation of papers 4 and 5 gradually guided me to select the system approach as the theoretical perspective for this research.

3.1 System approach

The term “system” is derived from the Greek word “systema,” which represents a collaborative relationship between any group of various elements working together to achieve particular goals (Churchman, 1968). The concept of “system” is used in several research disciplines, such as business, economic, engineering, and management literature. Although the system concept is widely used, its meaning is not always clearly defined. There is seldom consensus on the precise definition of a concept, even when and where it is described. The misunderstanding appears to originate from the fact that many individuals frequently interpret the concept of “system” differently. For an engineer, it might refer to a physical object. An economist might interpret the concept of “system” as an inventory or universal economy. A computer scientist may use the concept to refer to the computer’s hardware and software. Thus, the concept “system” has become general and is used in various contexts.

The system approach was a breakthrough of Churchman’s acknowledgment, regardless of the approach used, that the complex social systems in which we live make it complicated for our mental capabilities and technological abilities to identify the core issues and determine how they should be resolved (Churchman, 1968). Acknowledging our cognitive limitations, Churchman proposed to conduct a continuous debate and a logical review of the social system that involves various attitudes of minds from different societies (Churchman, 1968). The system approach provides an effective way of thinking which enables us to inquire about the system in its dynamic process from the time it is conceived until it is put into action and also allows us to make informed decisions that are based on logical arguments regarding the social systems (Churchman, 1968).

Richmond (1994) well-known in the field of system approach, writes that we need to learn new ways to handle complex and interdependent systems. It will not be sufficient in the future to simply get better and smarter about our specific “piece of the rock.” The system approach is required to understand the complexity and interdependency of the systems. Many experts in the field of system approach have the same viewpoint as Richmond’s that the system approach has the great importance of understanding the complexity of the coming
century, and without the system approach, the expected outcome of the systems will be less viable (Meadows, 2008, Plate, 2010, Senge, 1990, Sterman, 2002).

The system approach uses models to examine a system holistically (Churchman, 1968). A model is a way that the human cognitive process may be increased or as a means of measuring reality in estimating it (Churchman, 1968). Models can also be viewed as tools that can be used to understand reality. Models are useful, but it is significant to avoid oversimplification, as a mathematical model can never fully reflect the complexity of a system. The fact that most technological systems are a part of a larger system means that, while a technological model may be effective in achieving the goals of a particular system, it may be entirely unsuccessful in attaining the goals of the larger system embedded with social or political system (Churchman, 1968).

3.1.1 Classifying Systems

The concept of classifying a system by its purpose is common and many of these systems can be found around us (Arnold and Wade, 2015). Systems can be of different types, but these systems are all named by their purpose such as, transportation system, energy system, business system, technology, or hardware-based systems, social system, or a hybrid of the two. The most complex and challenging systems are hybrid systems. Figure 8 represents the hybrid system which integrates hard and soft systems in the context of the system approach.
The hybrid systems are the systems in which hard and soft systems are interconnected (Checkland, 2000). The hard systems deals with designing engineering and technological solutions (Churchman, 1968), while the soft systems deals with business, economy, political and societal solutions (Checkland, 1999).

The main challenge is to bridge the relationship between hard and soft systems. The hard systems are associated with engineering and technological systems, whereas the soft systems are associated with business, economics, government, politics, institutions, and societal systems. The soft system supports the actors' and stakeholders' opinions and the problem definition, while the hard system provides solutions and metrics for success. The specific correlation between hard and soft systems is not always necessary for every system. However, it is significant to put both systems in a larger context of a system approach to see and understand a system from a holistic perspective (Edson, 2008). The soft system better supports understanding the interaction between the technological solutions and the external context based on business, social, and governmental policies. It is important to consider the businesses, social, and governmental policies when developing technological solutions for problems. Otherwise, due to constraints of governmental policies, institutions, regulations, industries, or social demands will not accept the exceptional technical solution that solves the problem (Checkland, 1999).

“How can we design improvement in large systems without understanding the whole system, and if the answer is that we cannot, how is it possible to understand the whole system?” (Churchman, 1968)

The above statement of Churchman (1968) indicates that without understanding the whole system, it is difficult to improve or transform large and complex systems. To effectively deal with these problems, the system approach provides a way to understand complex problems and see the issues from a holistic perspective that considers the interactions between the system and the surrounding (Aronson, 1996, Richmond, 1994). Similarly, evolutionary technologies are pushing energy and transportation systems to be transformed from fossil-based to renewable and fossil fuel-powered vehicles to electric. These evolutionary technologies are increasing the interrelated and interdependent elements, causing variations among them; thus, the system is complex and challenging to transform. To understand the whole system and see things from holistic perspective, the system approach provides a way to explore and understand the challenges and the approach to deal with them by adjusting their outcomes based on the desired expectations (Edson, 2008).
3.1.2 Exploring considerations for understanding system approach

Churchman (1968) provides five considerations to think about when trying to understand what a system approach means: 1) the overall objective of the system and performance measures, 2) the system’s constraints and its environment, 3) the system’s resources (including finance, people, government support, and equipment) 4) the system’s elements and their goals, measures, and activities 5) the system’s management. Figure 9 shows Churchman’s five considerations for understanding and exploring the system approach.

Figure 9: Five considerations of system approach
Source: My rework based on five consideration introduced by Churchman (1968)

The first consideration is that there could be a difference between the expected objective and the system’s actual performance because the different elements at different stages might affect the system’s performance (Churchman, 1968). It means to achieve the
expected objective and eliminate the difference between the actual performance of the system, we need to understand the system from the dynamic perspective, and the system needs to be formed in which each element of the system coordinates and provides prompt feedback to each other.

The second consideration is the environment that is normally considered outside of the system. Determining the environment or constraints of the system is certainly not simple. The environment comprises objects and people that are noticed to be "fixed" or "given" from the system management's perspective regarding its limitations and possibilities. The universe is not considered as the environment of the system. A system's boundary is not clearly defined between the system and its environment. Churchman (1968) stated that the "environment of the system and the system itself are both elements of an even larger system." The system's poor performance is commonly due to assumptions about elements considered outside the system and not subjected to any management.

The third consideration is the system's resources required to perform its function. Churchman (1968) highlighted that it is challenging to consider the gap between the actual required and assigned resources in a system where human values are mostly neglected, and opportunities are lost. The deliberate efforts required during the system's design to anticipate issues, such as finance, politics, society, etc. These issues might act as 'enemies' or counterforces that can hinder the overall system's performance. Thus, collaborative strategies are required to shrink the gap and enhance the system's performance.

The fourth consideration is the system's elements and their goals. The system's division into elements is controversial as Churchman (1968) stated that even though the logical division of the system into various task-oriented elements may be rigid and impose constraints. Thus, instead of constructing isolated divisions to deal with this problem, the challenge becomes how to develop effective coordination between various elements as the system's overall performance is based on the coordination of the system elements (Churchman, 1968). In other words, while conceptualizing a system, we should start with and prioritize thinking about the system's main goal and how each element is connected to all its potential sub-systems rather than focusing on the system's structure. The elements are effectively developed when the connections between their functions are precisely understood.

The fifth consideration is system management, which deals with allocating resources, environment, developing elements and setting the system's overall goal. It is a continuous design process requiring management consideration for constant evaluation and feedback in terms of improving the system's progress. Churchman (1968) highlighted that the system's performance lies in the management's deliberate measures in collaborating and integrating new elements that can affect the system's overall performance.

The above-discussed Churchman's (1968) five considerations of understanding the system approach provide a broader spectrum from the initial planning phase to the implementation and management of a system efficiently to attain the system's expected performance. However, the following section explores the various definitions introduced by
different scholars on the system approach. These definitions are analyzed against Churchman's (1968) five considerations of understanding the system approach to examine if these definitions accomplish all five considerations (Purpose or objective, environment, resources, elements, and management) in developing and managing hybrid systems discussed in section 3.1.1.

### 3.1.3 Different definitions of system approach

In the system literature, the term “systems thinking” is commonly used to describe the definitions of systems thinking, whereas this thesis has adopted the term “system approach” influenced by Churchman (1968) five considerations of understanding system approach. According to Meadows (2008), the system approach comprises three main components. The first is the ‘purpose’ or a ‘function’ of a system. The second is ‘elements’ or the ‘characteristics’ of a system, and the third is the ‘interconnections,’ which means the way through which the elements of a system relate to each other, as shown in figure 10.

![Diagram of system approach components](image)

**Figure 10: Main components of system approach**

*Source: My rework based on Meadows (2008) viewpoint on system approach*

1. The goal, purpose, or function of a system should be well defined so that it can clearly be understood.
2. Elements demonstrate the characteristics or attributes of a system.
3. Interconnections show the relations among the different attributes or characteristics of elements.
According to Meadows (2008), the complete definition of the system approach contains all three components (purpose, elements, and interconnections). The purpose is the most significant component of the system approach as it represents the system’s behavior, goal, or objective. It is critically important to convey the purpose of the system to express the system approach definition, especially to those unfamiliar with the term. Thus, the comprehensive definition of the system approach does not complete without demonstrating the final goal of the system. However, Meadows (2008) definition of the system approach that comprises three components is merely the fundamentals of designing any technological system and does not provide a comprehensive understanding of hybrid systems in which people, businesses, finance, and government policies are deeply rooted. Therefore, understanding and managing hybrid systems requires additional components that can allocate resources and continuously manage and examine the system’s performance. Thus, Meadows (2008) definition of the system approach is incomplete and does not provide a comprehensive understanding of managing and operating hybrid systems.

Other scholars have also defined the system approach from their point of view, encapsulated in table 2.

<table>
<thead>
<tr>
<th>Author(s), Year</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richmond (1994)</td>
<td>“The art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure.”</td>
</tr>
<tr>
<td>Senge (1990)</td>
<td>“A discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static ‘snapshots.’”</td>
</tr>
<tr>
<td>Sweeney and Sterman (2000)</td>
<td>“The art of systems thinking involves the ability to represent and assess dynamic complexity (e.g., behavior that arises from the interaction of a system’s agents over time), both textually and graphically.”</td>
</tr>
<tr>
<td>Stave and Hopper (2007)</td>
<td>“Stave and Hopper define seven characteristics of the system approach. These characteristics are 1) recognizing interconnections, 2) identifying feedback, 3) understanding dynamic behavior, 4) differentiating types of flows and variables, 5) using conceptual models, 6) creating simulation models 7) testing policies.”</td>
</tr>
<tr>
<td>Kopainsky et al. (2011)</td>
<td>“Systems thinking should include appreciation for long term planning, feedback loops, non-linear relationships between variables, and collaborative planning across areas of an organization.”</td>
</tr>
</tbody>
</table>
Squires et al. (2011)  
"Squires et al. describe the description in a way that the system approach incorporates multiple perspectives; reliably predicts the impact of change to the system; works within a space where the boundary or scope of problem or system may be fuzzy; understand complex system behavior; identity interrelationships, and dependencies; and understand diverse operational contexts of the system."

Arnold and Wade (2015)  
"The system approach is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects. These skills work together as a system."

Table 2: Selection of definitions of the system approach

The above table presents various definitions of the system approach. Richmond (1994) emphasizes that people adopt a system approach to seeing both the forest and the trees. The underlying idea of “seeing both the forest and the trees” reflects that the system approach provides a holistic perspective of seeing things that can lead to a deeper understanding of the fundamental objective of the system. Senge (1990) defines the characteristics of the system approach as a discipline that provides seeing as a whole rather than isolated parts; it is a framework that allows seeing the relationship and the dynamics rather than static snapshots. Sweeney and Sterman (2000) also define the characteristics of the system approach that has the capability to represent and evaluate the dynamic complexity of a system which arises due to the interactions among various elements of a system over time.

For the definition of the system approach to be widely accepted, Stave and Hopper (2007) have performed a thorough review of the literature on the system approach and integrated Richmond (1994), Senge (1990), and Sweeney and Sterman (2000) work to build their definition to describe the system approach. They defined seven characteristics of the system approach which are mentioned in table 2. However, these characteristics merely describe what the system approach “does” but does not describe what actually the system approach “is.” Kopainsky et al. (2011) also includes the various characteristic of the system approach in their definition, such as long-term planning, feedback loops, non-linear relationships, and collaborative planning. Whereas the definition defined by Squires et al. (2011) of the system approach is more descriptive, as it explains what the system approach requires to do (Arnold and Wade, 2015), it still describes the characteristics of the system approach.

All of these definitions of the system approach uncover the differences. The definitions of systems approach presented by various scholars have concentrated on interconnections, the idea of seeing the system from a holistic perspective rather than the system as an isolated component, and the concept of understanding the system’s structure and the dynamic
behavior of the system. Although it is important to consider and synthesize critical elements of these concepts to define the system approach, however, they have neglected to clarify the "essence" of what the system approach "is" and what it "does" (Arnold and Wade, 2015). According to Richmond (1994) views to consider both the forest and the trees, it emerges that several of these definitions might have concentrated on either the "forest" or the "trees." Some scholars define the definitions of system approach ambiguously, while others have simplified it. Thus, both approaches fail to capture the "essence" of the system approach.

However, these definitions of several scholars merely describe the characteristics of the system approach and neglect the core meaning of defining the "system" aspects of the system approach.

In comparison with the above definitions, Churchman's (1968) five considerations are still valid for understanding the system approach (discussed above in section 3.1.2) even after more than six decades as it provides a comprehensive understanding of the aspects of a system that guides in developing and managing hybrid systems. Thus, this thesis adopts Churchman's (1968) five considerations for exploring and understanding the electrification of the transportation system.
3.1.4 Reflection of system approach to electrification of the transportation system

According to the five considerations for understanding the system approach defined by Churchman (1968) discussed in section 3.1.2, the first consideration illustrates setting a system's objective or expected performance. In connection with the first consideration in decarbonizing society, political leaders and government agencies have the right to set objectives and action plans to be less dependent on fossil-based sources.

Following the objectives, we understand that the major carbon contributor is the current transportation sector, which contributed approximately 7.3 billion metric tons of CO$_2$ emissions globally in 2020 (Tiseo, 2023). To achieve the objective of decarbonizing society, we need to transform both the energy and the transportation systems, as both are primarily dependent on the usage of fossil fuels.

The electrification of the transportation system is not merely an isolated technological system. It is embedded with political, societal, and economic domains and thus forms a whole system called "electrification of the transportation system." Each of these domains holds multiple elements. Achieving the expected objective of the overall system requires coordinating and collaborating with these potential elements and their domains. The concept of 'domain' is inherited from the 'dimensions' explained in this thesis's research methodology, analysis, and discussion sections.

The environment is the second consideration when designing any system. However, the definition of environment is defined differently by different people. Some people consider that stakeholders of a system are part of the system. In contrast, others think they are the influencers and consider them outside the system and, thus, part of the environment.

"A system, therefore, is a whole that cannot be divided into independent parts. From this, two of its most important properties derive: every part of a system has properties that it loses when separated from the system, and every system has some properties—its essential ones—that none of its parts do." (Ackoff, 1971)

In the above statement, Ackoff (1971) describes the system’s environment as a combination of various elements and their relevant properties. Although these elements are not part of the system, changes in any of them and their properties can affect the system’s state. Therefore, the elements considered outside the system as an environment can change the state of the system. However, external elements that have an impact on the system's irrelevant properties are not part of the system's environment. Ackoff (1971) also stated that the environment determines the conditions or boundaries within which the system achieves its objectives, even if it is not an element of the system. Churchman (1968) defined the 'environment' as outside the system's boundary and is not considered a part of a system. However, it might impact the systems' overall performance, mainly considered an 'enemy.'
One of the 'enemies' could be a political system whose existence cannot be underestimated based on people who advocate for their viewpoint. The political role is often neglected, and only a single issue is focused on at a time while ignoring the larger picture. However, the political role cannot be underestimated as it is an integral element of the whole system (Churchman, 1979). Therefore, to understand the system's goals and constraints of the system it is necessary to understand the whole operational picture (Senge, 1990).

The definition of 'environment' is directly associated with the system's problem. The environment of a system is subjective and depends on how the system is defined. In some cases, some elements are considered part of a system, whereas in others, they are considered part of the environment. Thus, no universal agreement exists on choosing elements as part of the system or as an environment. However, Churchman (1968) indicated that the element considered outside the system might cause the system's poor performance. In the context of electrification of the transportation system, the 'political' domain is considered part of the system as it is one of the main stakeholders in value creation in terms of setting the targets, shaping the environment, developing, allocating resources, establishing new rules and regulations, managing, and operating the entire transportation system. Favorable political policies toward the electrification of the transportation system guide the public willingness and effort to adopt transformation.

The concept of 'enemies' or 'counterforces' is not only associated with the 'environment' of a system. It is also associated with allocating resources to a system to perform its function. Churchman (1968) highlighted that sometimes there is a difference in assigning resources to a system than actually required resources. These most neglected resources are finance, political, and societal support. Therefore, opportunities are lost, and the system's performance is not what we expected. In the context of the electrification of the transportation system, we see these resources as significant domains or part of the system that holds various elements which develop the entire transportation system. Each domain acts as a stakeholder and contributes to creating value for the whole system in achieving the expected goals. The role of politics is to establish policies and use its economic means to encourage society to adopt new technology (electric vehicles). Thus, all these resources, finance, politics, and society are required for the transportation system to perform its functions.

However, the significant step in designing and developing a system is establishing coordination and collaboration among the domains and their elements, which leads the system to improve its operation and achieve its expected goal.

"The ability to see the world as a complex system, in which we understand that 'you cannot just do one thing,' and that everything is connected to everything else." (Sterman, 2000)

The world is a complex system consisting of multiple subsystems such as people, technology, nature, resources, transportation, etc. All of these domains or subsystems are connected and form a complex system. For instance, the electrification of a transportation
system is a combination of multiple elements such as electric vehicles, charging infrastructure, society, government rules and regulations, and the economy. All of these elements are connected and impact the system’s overall performance. None of these elements can be treated as an isolated element as each is connected and affects the other.

“Seeing beyond what appear to be isolated and independent incidents to deeper relationships. You recognize connections between elements, to better understand and influence them.”
(McDermott, 1997)

It is significant to see the system from a holistic perspective to manage complex and dynamic systems rather than the system as an isolated element. The holistic perspective provides a way to understand the symbiotic relationships and underlying connections among the domains and their elements. Understanding the symbiotic relations and dynamic behavior of the system lead the management to allocate resources effectively, assign system boundary, collaborate, and integrate new elements that can enhance the system’s performance and support achieving the overall goal. The system approach supports understanding the complexity and interdependency of the domains or subsystems and their elements of systems (Richmond, 1994).

It is not unreasonable to argue that the system approach is still relevant and is probably a viable approach for developing, planning, and managing the electrification of the transportation system. The electrification of the transportation system is a complex, dynamic and large hybrid system that combines technological, political, societal, and economic domains and their elements. We need to learn new ways to handle complex and interdependent systems. Therefore, the system approach is significant as without understanding the whole system, a slight change might harm the different parts of the system, which can cause severe damage. The system approach provides a holistic understanding of a system, its elements, its relationship, and dependencies within and across domains. Thus, improving or transforming complex and dynamic systems requires a system approach to understand the entire system.
3.2 Business Approach

Innovation comprises two main elements. One represents the innovation in technology, products, and services or combinations of these, while the other refers to the fact that "the innovation" needs to be commercialized to survive and be accepted by society. "Innovation" either in technology, product, or services, also needs to achieve a certain level of diffusion in society and commercial success. Often the focus is on technology and products while the commercial side is underestimated.

As Chesbrough (2010) stressed, technology does not have any economic value until it is put into commercially viable solutions and becomes a “money maker.” Both are needed to make innovation happen. Electrification of transportation brings in new technology, new technological elements, and new system solutions, but without proper commercialization via a suitable business model, success might not be in place.

"Technology by itself has no single objective value. The economic value of a technology remains latent until it is commercialized via a business model. Companies commercialize new ideas and technologies through their business models. In fact, it is probably true that a mediocre technology pursued within a great business model may be more valuable than a great technology exploited via a mediocre business model. A successful business model creates heuristic logic that connects technical potential with realizing economic value." (Chesbrough, 2010)

Nowadays, we see the commercialization process as an outcome and end result of the use of business models. The electrification of transportation is disruptive in its nature, and we need to explore and understand deeper the commercial and business aspects of this transformation to electrification.

The business model as a practice has always been there in practice since mankind started to trade and do business. However, in the academic field business models are relatively young and still under development based on different perspectives. In 1954, the business model concept first emerged in “The Practice of Management” book by Peter F. Drucker and in an academic article in 1957 (Bellman et al., 1957). In the early 1970s, the business model concept was used as a business activity modeling tool in the context of information technology (Lehmann-Ortega and Schoettl, 2005). During the mid-1990s, the scholars of strategy and entrepreneurship were interested in business models as they sought to comprehend and categorize the new business logic of emerging e-business ventures, also known as e-business models (Amit and Zott, 2001).

The term “business model” primarily represents the conceptual sense of how the firm establishes and adopts economic value (Penker, 2000, Magretta, 2002, Osterwalder, 2004). The business model demonstrates the firm’s strategy and further depicts the involvement and the function of all the actors and the sequence of the production factors (Casadesus-Masanell and Ricart, 2010). The significance of business models went through various changes according to their approaches, such as technology to an organization and strategy (Wirtz,
The understanding of a business model is classified into two mainstream approaches (Baden-Fuller and Morgan, 2010, Abdelkafi et al., 2013, Zott et al., 2011).

The first approach to understanding the business model is available in the ‘technology and innovation management’ literature. In that literature, the business model concept is used as a mediator between the customers’ needs and a firm’s technology, which refers to how companies create, deliver and capture value (Magretta, 2002, Osterwalder et al., 2005). In the scenario of value based a business model is used as a tool which represents how value is created and delivered, for both the firm and the customers (Baden-Fuller and Morgan, 2010, Abdelkafi et al., 2013). In the value-based scenario, the three main elements of a business model are represented in table 3.

<table>
<thead>
<tr>
<th>Value proposition</th>
<th>It represents the fundamental approach of the firm to competitive advantage. What the firm offers to its customers and why the customers should be willing to pay for it.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value creation and delivery</td>
<td>It represents the firm’s source and its competitive advantage. The firm determines the manner of creating and delivering value to its customers.</td>
</tr>
<tr>
<td>Value capture</td>
<td>The firm determines the ways of generating revenues and making a profit by the firm.</td>
</tr>
</tbody>
</table>

Table 3: Main elements of a business model
Source: (Richardson, 2005)

As a result of this approach, Osterwalder (2004) developed a business model canvas. It has nine building blocks: channels, cost structure, customer relationships, customer segments, revenue streams, key activities, key partners, key resources, and value propositions, as depicted in table 4.

<table>
<thead>
<tr>
<th>Value proposition</th>
<th>What the firm offers to its customers and why the customers should be willing to pay for it.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer segment</td>
<td>The firm seeks its targeted customers for whom the value could be an offer.</td>
</tr>
<tr>
<td>Distribution channel</td>
<td>The ways that a firm uses to reach its targeted customers.</td>
</tr>
<tr>
<td>Customer relationship</td>
<td>The firm establishes and maintains a relationship with its loyal customers.</td>
</tr>
<tr>
<td>Key activities</td>
<td>The main activities that enable the firm to offer and deliver value.</td>
</tr>
</tbody>
</table>
The business model canvas is treated as a conceptual management tool by firms to describe what the company offers to sell, who will be the targeted customers, how the firm will create value and how much economic return should be expected.

The second approach to understanding the business model is available in the ‘strategy’ literature. In that literature, the business model concept is used to go beyond the customer and firm relationship. It stresses considering the business model to deliver value to each stakeholder in a value network (Zott et al., 2011), representing a business model as a holistic illustration of firms’ creating, delivering, and capturing value. In the scenario of activity based the business model is used as a tool which represents the activities and resources are exploited to do the business to attain growth (Baden-Fuller and Morgan, 2010, Abdelkafi et al., 2013). Entrepreneurs and managers can practice this approach through the activity of a system design framework. For instance, entrepreneurs and managers can visualize and conceptualize the list of conducted activities, their link and sequence, and where and who should perform what (Zott and Amit, 2010). Since value creation often occurs outside traditional company or organizational boundaries, the activity system is placed at the focal-firm level where the business model supports the firms in designing their business activities for a complete cross-company description and assessment (Zott et al., 2011). A business model is positioned between the operational and strategic layer in the architecture of a firm (Liu, 2019) as represented in figure 11.

Business models have drawn the attention of academics interested in ‘strategic management’ since business models offer a competitive edge in a particular sector and directly impact company performance (Zott and Amit, 2008). However, a business model differs from the strategy (Casadesus-Masanell and Ricart, 2010). The ‘business strategy’ guides what business model to use and where to compete, whereas a ‘business model’ is a precise execution of a company’s strategic choices and thus, complements a ‘strategy’ (Zott and Amit, 2008). Most studies on business models generally consider a static picture of the business model, depicting it as an instantaneous snapshot captured at a specific period.

Business model innovation is represented in the available literature as an addition to the business model concept, which represents emerging ideas in innovation research and

| Key resources | The primary resources (assets and technologies) are required to produce and deliver value. |
| Key partners  | The leading partners and suppliers support in offering and delivering value to loyal customers. |
| Cost structure | The firm estimates the cost required to execute the overall business. |
| Revenue model | The firm estimates the investment cost and return cost in terms of profit. |

Table 4: The business model canvas
Source: (Osterwalder et al., 2011)
considers the dynamic nature of innovation (Foss and Saebi, 2017). The concept of ‘business model innovation’ is associated with exploring an entirely new business model in an established industry rather than replicating an existing business model (Markides, 2006). Developing new innovative products, processes, and services consumes time and extra cost, and the outcome is uncertain (Chesbrough, 2010). Therefore, the research scholars in the field of innovation pointed out that firms need to consider using business model innovation as the traditional business model might not fit for integrating new stakeholders involved in innovating new products, processes, or services.

Although ‘business model innovation’ and ‘technology innovation’ are two distinct concepts, they are closely related (Baden-Fuller and Mangematin, 2013). The concept of business model innovation appears in two scenarios. The first scenario represents without technology development, as in the case of the just-in-time production system (Hossain, 2017), and the other is developing new technology. The business model innovation is encouraged to be developed by innovative technologies. For instance, mass production business models were made possible by steam engines; e-business models were made possible by the Internet.
Whereas, to unlock and convey the value of innovative technologies, business model innovation is needed (Zott et al., 2011). Therefore, the innovative technology has no economic value unless commercialized through the business model innovation. Chesbrough (2010) explained this by using the example of two distinct business models used for commercializing the same technology, ‘the Xerox copier.’ The old traditional business model, ‘razor and blade,’ failed to commercialize the Xerox copier. In contrast, the business model innovation through which the idea was to sell the Xerox copier on leasing supported the company very successfully.

The advancement of technologies is revolutionizing the energy and transportation industries (Hoang, 2006, IEA., 2017). However, technological evolution and shifting from one technology to another are often associated with business model inertia. The firms find it challenging to adopt the new technology because of business model inertia (Vorbach et al., 2017). Figure 12 is a conceptual representation of the energy and transportation technological systems pointing towards the business model, which requires integrating new actors and new rules and regulations for the diffusion and adoption of new technological systems.

![Conceptual representation of energy and transportation transformation](image)

**Figure 12: Conceptual representation of energy and transportation transformation**  
Source: (Author)

In the context of the electrification of the transportation system, the transportation industry is transforming from fossil-based to electric transportation system, and the new transportation system requires a new charging infrastructure. One of the main challenges for the energy firms is to transform from the old analog electricity distribution system to the new innovative digital decentralized system that can efficiently integrate renewable sources and distribute clean electricity to the new digitalized charging infrastructure for electric vehicles and balance the rising electricity demand due to the transformation of the transportation
system (Mwasilu et al., 2014, Zakhidov, 2008, Prabhu et al., 2016) also (see article 1 and 2, appendix 1). But the electricity distribution system is deeply rooted in governmental policies, institutional rules, and regulations. A considerable investment is required to transform the old electricity distribution system into the new digitalized system. The electricity distribution firms do not have sufficient financial resources to fund transforming the entire electricity system (Valsamma, 2012, Mohamed et al., 2015) also (see article 1 and 2, appendix 1). Therefore, governments are expected to take the initiative to collaborate with various actors and stakeholders to support the transformation of the energy system.

However, the key challenge is the traditional business model, which is static and considers government and political actors as part of the environment but not part of the business model. Churchman (1979) argued that the political aspect is mostly neglected from designing a system; as a result, the entire system does not perform as expected. Christensen (2006) stated that technology is not an issue but the business model that hinders firms from transforming or adopting old to new technology. The old traditional business model has limitations and is incapable of creating value for each actor and stakeholder in the network, which develops uncertainty among them and prevents them from taking further steps. Therefore, the traditional business model does not support the dynamics of the electrification of the transportation system that comes from the new actors and stakeholders (politics, governments, institutions, etc.) involved in transforming the transportation system.

3.2.1 Towards symbiotic business model

The term “symbiosis” was first introduced in 1878 by a German mycologist named Heinrich Anton de Bary (Paracer and Ahmadjian, 2000).

“Symbiosis refers to the phenomenon whereby two or more organisms with distinct genealogical, evolutionary histories live in close association with one another.” (De Bary, 1878)

In biology, “symbiosis” means when more than one organism from various species lives closely in such a way that one or both species gain benefits (Fagerstrom, 1996, Graedel and Allenby, 2010). Furthermore, Graedel and Allenby (2010) stated that the word “symbiosis” normally represents relationships in nature, such as more than one species exchanging energy, materials, or information for mutual benefits. Therefore, Fagerstrom (1996) further explained and pointed out that symbiosis could be commensal, mutualistic, or parasitic, which means that one gets the benefit while the other is entirely unaffected or both get the benefits or one benefits the detriment of the other. Finally, Sapp (1994) acknowledged that the theory of symbiosis had been used in several fields, including economics, anthropology, sociology, ecology and even politics.
3.2.2 What are symbiotic relations?

Symbiotic relationships, or symbiosis, refer to close and long-term interactions between two or more species. These interactions can be mutually beneficial, harmful, or neutral, depending on the nature of the relationship (Graedel and Allenby, 2010).

There are three primary types of symbiotic relationships:

- **Mutualism**: Mutualistic symbiosis occurs when both participating species benefit from the interaction. Each organism provides something the other needs, resulting in a mutually profitable relationship (Gough, 2002, Herre et al., 1999). An example is the relationship between flowering plants and their pollinators, such as bees. The plants provide nectar as a food source, while the pollinators transfer pollen, aiding reproduction for both parties (Roossinck, 2015).

- **Commensalism**: Communalistic symbiosis occurs when one species benefits while the other is unaffected. In this relationship, one organism benefits from the association, while the other neither benefits nor suffers harm (Hulme-Beaman et al., 2016). For instance, certain bird species may build their nests in trees, obtaining a protected habitat, while the tree is not significantly affected.

- **Parasitism**: Parasitic symbiosis occurs when one organism (the parasite) benefits at the expense of another organism (the host), which is harmed. The parasite relies on the host for resources, such as nutrients or shelter, often causing damage or disease (Musheno and Lawson, 1999). Examples include fleas on mammals or ticks on birds.

It is important to note that symbiotic relationships can be complex and dynamic, and the categorization of a specific interaction may vary based on different factors, such as the environmental context or the perspective of the organisms involved (Uribe et al., 2018). Additionally, symbiotic relationships are not limited to these three categories, as variations and intermediate forms can exist.

Symbiotic relationships are widespread and play a significant role in environmental systems. They contribute to the interconnectedness and balance of ecosystems by facilitating the exchange of resources, energy, and environmental services between different species (Terra and Passador, 2016). Thus, we need to recognize symbiotic relations in the social sciences and business studies as well as their influence and impact on relations between people, actors of society, industry, and business.
3.2.3 How do symbiotic relations develop over time?

Symbiotic relationships can develop and evolve over time through various mechanisms (Skinner and Spira, 2003). The process of developing symbiotic relationships is often influenced by ecological factors, evolutionary pressures, and the specific needs and adaptations of the participating species (Davis and Eisenhardt, 2011). Here are some key mechanisms involved in the development of symbiotic relationships:

- Coevolution: Coevolution refers to the reciprocal evolutionary changes that occur in two or more species due to their interactions over time. In symbiotic relationships, coevolution can drive the development of specialized adaptations in both species (Thompson, 2019). For example, in the mutualistic relationship between flowering plants and their pollinators, the plants may develop specific flower structures and nectar characteristics to attract particular pollinators. In contrast, pollinators may evolve specialized mouthparts or behaviors to access the nectar efficiently (Lyu et al., 2021).

- Dependency and specialization: Over time, species involved in symbiotic relationships can become increasingly dependent on one another. This dependency can lead to the development of specialized adaptations that enhance the efficiency of the interaction (Swarts et al., 2010). For instance, certain insects have evolved specialized structures to live in the nests of social insects like ants or termites, benefiting from the protection and resources provided by the host colony.

- Fine-tuning and optimization: Symbiotic relationships may undergo fine-tuning and optimization through natural selection. Beneficial interactions are favored and more likely to persist and expand, while harmful or unproductive interactions diminish or disappear over time (Jamei et al., 2004). This process can lead to the refinement of mechanisms, behaviors, or traits that optimize the benefits for both species.

- Partner choice and specificity: Symbiotic relationships can be influenced by the selective choice of partners. Over generations, species may develop preferences or adaptations that facilitate the selection of specific partners that provide optimal benefits (Kaltenpoth et al., 2014). This specificity can contribute to the stability and effectiveness of symbiotic interaction. An example is the specificity of certain orchids that rely on specific pollinators with specialized behaviors or anatomical features to ensure successful pollination.

- Environmental changes and pressures: Changes in the environment, such as shifts in climate, resource availability, or the presence of new species, can influence the development of symbiotic relationships (Danovaro et al., 2017). Environmental changes may create new opportunities or challenges that affect the dynamics of existing connections or lead to new forms of symbiosis.

It is important to note that developing symbiotic relationships is a dynamic and ongoing process. The interactions between species continue to evolve and can be shaped by
various factors, including selective pressures, ecological conditions, and the ongoing adaptations of the organisms involved.

3.2.4 How can we explore and understand symbiotic relations?

Exploring and understanding symbiotic relationships involves a combination of observation, experimentation, data collection, and analysis (Yoon et al., 2022). Here are some approaches and methods that can be used to explore and understand symbiotic relationships:

- Field observations: Conducting field observations allows researchers to observe and document symbiotic interactions in their natural environments directly. This involves observing the species’ behaviors, interactions, and ecological context. Field observations provide valuable insights into symbiotic relationships' dynamics, frequency, and outcomes (Ansell et al., 1998).

- Ecological surveys: Conducting ecological surveys helps identify and quantify the presence and abundance of species engaged in symbiotic relationships. Surveys may involve sampling techniques such as transects, quadrats, or specimen collection (Roossinck and Bazán, 2017). By studying the distribution and patterns of species associations, researchers can gain a broader understanding of symbiotic relationships within ecosystems.

- Experimental studies: Experimental studies can help elucidate symbiotic relationships' mechanisms, benefits, and consequences. Researchers can design experiments to manipulate or remove one or more participants in the relationship to assess the effects on both the host and symbiont (Ross et al., 1983). This can provide insights into symbiotic interaction's functional roles, dependencies, and ecological impacts.

- Molecular techniques: Molecular techniques, such as DNA sequencing or fingerprinting, can be used to identify and characterize the species involved in symbiotic relationships (Relman, 2008). These techniques can help determine the participants' genetic relatedness, specificity, and diversity, providing insights into the evolutionary history and genetic interactions underlying symbiosis.

- Microscopic analysis: Microscopic analysis, such as electron microscopy, can be used to examine the physical interactions and structures involved in symbiotic relationships (Pérez-Brocal et al., 2006). This allows researchers to microscopically observe the intimate associations, cellular interactions, or specialized adaptations between species.

- Comparative studies involve comparing multiple symbiotic systems or different stages of a symbiotic relationship to identify common patterns, variations, or underlying principles (Maeyama et al., 1997). By examining a range of symbiotic relationships...
across different species or ecosystems, researchers can identify general principles or ecological factors that influence the development and maintenance of symbiosis.

- Modeling and theoretical frameworks: Mathematical models and theoretical frameworks can be used to simulate and predict the dynamics of symbiotic relationships (Waters et al., 2021). Models can help understand the conditions that promote or constrain symbiotic interactions by incorporating ecological factors, evolutionary dynamics, and population interactions.

These approaches are often used in combination to gain a comprehensive understanding of symbiotic relationships. The interdisciplinary nature of studying symbiosis involves collaboration between biologists, ecologists, microbiologists, geneticists, and other experts to explore and unravel the complexities of these interactions.

3.2.5 The symbiotic business model

The symbiotic business model is the conceptual tool that provides an understanding, analysis, and capture of the development and operations of complex businesses in which multiple actors and stakeholders such as political, societal, institutional, and regulatory bodies are involved and mutually collaborate (Liu, 2019). Figure 13 represents the symbiotic business model.

Figure 13: Symbiotic business model
Source: (Liu, 2019)

Figure 13 represents the symbiotic relationship and collaboration among the actors and stakeholders in horizontal and vertical dimensions. The horizontal symbiotic relationship represents the collaboration between the industry and the potential customers. In contrast,
in a vertical symbiotic relationship, business, institutional and political actors collaborate to develop and accomplish common societal goals and seek business possibilities. The main actors in the symbiotic business model, such as business, political and societal, are dynamically intertwined. Their symbiosis goal is to achieve each stakeholder’s demand within the system mutually. With the help of institutional actors, the symbiotic relationship is formed by establishing a constant dialogue between the political, institutional, and industrial sectors (Liu, 2019).

“In the symbiotic business model, institutional actors function as the lubricant, oiling the system, making the interaction between business and politics smooth and absorbing the frictions between actors. The regulatory forces and actors function as tools of the system, to support the country’s desired decisions and actions of related actors in different domains.” (Liu, 2019)

Electric vehicles require a charging infrastructure, and the charging infrastructure is embedded with the energy system, and the energy system works under government rules and regulations. Thus, developing a charging infrastructure without government support is impossible even though private companies take the initiative to install charging stations; they need electricity to run them. It means that this change is affecting the transportation industry, energy industry, markets, and thus the whole society.

Therefore, the role of politics is significant in the transformation of the transportation system and the integration of new actors and stakeholders in the business model. The business model innovation must collaborate with the external environment to improve its performance (Leppänen et al., 2021). The environment significantly impacts the industry leaders and firm managers to attain and evaluate the market situation before deploying the firm resources (Lippman and Rumelt, 2003). We have a recent example of the political move on the Russia and Ukraine war’s effect on markets, industry, and the world. A sudden peak in energy prices was seen in Europe and worldwide. In May 2022, the European Council decided to ban approximately 90% of all Russian oil imports. In August 2022, the European Council announced new regulations for reducing gas demand by 15% (Council, 2022). This war has created massive instability in the energy industry and market in emerging and developing countries depending on importing fossil fuels from Russia (Borrell, 2022). The environment affects the energy industry and the market and, thus, the performance of the business model.

The symbiotic business model considers the political actors as part of the business model and not as part of the environment. The symbiotic business model provides a high level of interaction and collaboration among the political, institutional, regulatory, and societal actors. All of these actors mutually coordinate and collaborate to achieve their mutual goals. The symbiotic business model can enhance firm performance as it can be adjusted according to the dynamic environment for capturing new value (Liu, 2019). In dynamic environments, it is significant for firms to secure their relationships with beneficial stakeholders and rapidly shape and deploy their resources to prevent rivalry (Sirmon et al., 2007).

The firms that adopt business model innovation can take advantage of enormous market inefficiencies in dynamic markets where the value of resources is uncertain and
changing (Pati et al., 2018). One of the recent examples of market inefficiencies is the turmoil in the oil market internationally. While European and Western countries are boycotting Russia due to the war between Russia and Ukraine at the same time, the Indian private refiner “Nayara Energy” company imported 7,38,024 barrels per day from Russia in August, approximately 18% lower than they imported in July (Standard, 2022). This could not have happened if the “Nayara Energy” private company had not collaborated with the political actors. As a result, the company gained value for each actor and stakeholder in the value chain.

If we look at the electrification of the transportation system, the rivalry has started in the energy and transportation industry since the political leaders have decided to move towards a carbon-free society. New manufacturers are entering the energy and transportation industry and opening new markets. However, if we examine what electromobility manufacturing companies are dominating the world in the electrification of the transportation system, the answer is China. Reason why? Because Chinese government aligned and introduced its business policies that can support the manufacturing industries and markets associated with energy and transportation system electrification. Between the years 1991 and 2000, China had a 2.4% share of all electric vehicle patents in the world. By 2016, that number had risen to 15.5%, and between 2000 and 2016, it had risen to 28.0% (Altenburg et al., 2022). The Chinese government took the emergence of the electromobility paradigm as an opportunity to overtake the established global automotive industry. China promoted more dedicatedly to developing the electromobility industry than any other automotive manufacturing nation.

In a politically unstable environment, there is always the chance that the government can change the "ground rules" for doing business (Butler and Joaquin, 1998). Sudden changes in political policies can potentially affect not only the core companies but all the firms along the value chain. The traditional business model will decay the value of existing resources if the political environments shift dynamically (White et al., 2022). Therefore, we need a new business model that can harmonize with other businesses, activities and integrate new political, institutional, regulatory, and societal actors and potential stakeholders involved in supporting the transformation of the transportation system.
3.2.6 How can we understand the symbiotic relations between politics and industry in China?

In my research, based on my empirical data collection and interpretation, I have come to understand that China is much different from all other countries. As India is a country I understand well from my history, and understanding Western countries has been possible through my master’s and Ph.D. education. However, understanding China has been possible through support and collaboration with my supervisors and being a member of the Sweden-China Bridge (SCB) project. Building upon the research of Liu (2019), I have adopted the concept of symbiotic relations and the symbiotic business model she developed in her work. Thus, certain aspects need to be considered to study the symbiotic relations in the Chinese context, as discussed below.

Understanding the symbiotic relationship between politics and industry in China requires a multi-dimensional analysis that considers historical, political, economic, and social factors. Here are some key approaches and factors to consider:

- **Historical context:** Examining the historical development of China’s political and economic systems is crucial. Understanding the legacy of state control, economic reforms, and the role of the Communist Party in shaping the relationship between politics and industry provides important insights into the current dynamics (Dickson, 2016).

- **State-driven industrial policy:** Recognize the central role of the Chinese government in driving industrial development through policies, regulations, and strategic planning (Chen and Dickson, 2010). Analyze the ways in which political decisions and priorities influence industry sectors, investment patterns, and resource allocation.

- **State-owned enterprises (SOEs):** Explore the unique characteristics and functions of state-owned enterprises in China’s economy. These enterprises often have close ties to political institutions and play a significant role in implementing government policies (Lin et al., 2020). Understanding their structure, incentives, and decision-making processes is important for grasping the politics-industry relationship.

- **Elite networks and guanxi:** Investigate the interpersonal networks and relationships among political elites, business leaders, and key industry figures. The concept of guanxi, or personal connections, is particularly relevant in China’s political and business landscape (Guo, 2001). These networks facilitate collaboration, information exchange, and influence-sharing between politics and industry.

- **Economic incentives and rent-seeking:** Examine the economic incentives that drive political-business relationships in China. Explore how access to resources, licenses, contracts, and market advantages create opportunities for rent-seeking behavior, corruption, and favoritism between political actors and industrial players (Chen et al., 2011).
- Regulatory environment: Analyze the regulatory framework governing industries in China. Assess how political actors can influence or manipulate regulations, permits, and licensing processes, resulting in preferential treatment or barriers to entry for specific industries or companies (Tan, 1996).

- Policy implementation and enforcement: Investigate how government policies are implemented and enforced in practice. Examine the role of local governments and bureaucratic agencies in mediating political and industrial interests. Assess the extent to which local contexts, economic realities, and power dynamics shape policy implementation (O'Brien and Li, 2017).

- Public-private partnerships and state-corporate alliances: Explore the various forms of collaboration and partnerships between the state and private enterprises. Examine joint ventures, strategic alliances, and public-private initiatives that bridge political and industrial interests (Nielander, 2020).

- Media and public discourse: Analyze the role of media and public discourse in shaping the politics-industry relationship. Understand the dynamics of media control, censorship, and propaganda, as well as the ways in which public opinion and social media influence the interaction between politics and industry (Ye et al., 2017).

It is important to approach the study of politics and industry in China with an open mind and a nuanced understanding of the complex dynamics at play. Given the evolving nature of China's political and economic landscape, ongoing research and analysis are essential to grasp the intricacies of the country's symbiotic relationship between politics and industry.
3.3 Ecosystem approach

The concept of "ecosystem" has come from biology. The word 'eco' is associated with the environment, and the term 'system' is related to interconnected parts working together as a single unit (Ianioglo, 2022). One can anticipate a conceptual similarity between an 'innovation ecosystem' and the 'biological ecosystem.' The term 'biological ecosystem' refers to a system in which all of the living species in a region and the area's physical conditions work together as a single cohesive unit (Jackson, 2011). A biological ecosystem is a complex set of interrelated elements such as residents of an area, living resources, and habitats. Collectively, they aim to preserve the stability and functional operations of the habitats to prevent sudden unwanted environmental changes (Anderson et al., 2009).

Before moving towards an "innovation ecosystem," first, we will examine the concept of "innovation." Innovation is "the process of transforming opportunity into new ideas and putting them into widely used practice" (Tidd and Bessant, 2020). Another definition is "innovation is an implementation of a new product, process, services, or a new way of commercialization or external relations or a workplace organization" (Data, 2005).

The preexisting “business ecosystem” literature commonly focuses on competitiveness and value capture, whereas the "innovation ecosystem" concept emphasizes collaboration and value creation (de Vasconcelos Gomes et al., 2018). However, Moore (1993) has equally focused on competitiveness and collaboration, one of the most widely used literature sources on business ecosystems. Firms collaborate and develop their resources around innovation in a business ecosystem. They collaborate and compete with each other to promote innovative technologies and strive to meet customer demands and ultimately support each other for the next wave of innovation (Moore, 1993). The transition from business ecosystem to innovation ecosystem may seem to have changed the emphasis from competition to collaboration. Here are several definitions of ecosystem by different scholars that are listed below in table 5:

<table>
<thead>
<tr>
<th>Author(s), Year</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carayannis and Campbell (2009)</td>
<td>An innovation ecosystem is a combination of several different sets of activities, multiple channels of communications joined together with the various nodes to form a single system of other systems in the 21st century.</td>
</tr>
<tr>
<td>Still et al. (2014)</td>
<td>The term &quot;innovation ecosystem&quot; is related to innovation structures that are technological systems of innovation, political, inter-organizational, environmental, and economic that maintain and support a favorable environment to business growth. Fundamentally,</td>
</tr>
<tr>
<td>Source</td>
<td>Description</td>
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<tr>
<td>Jackson (2011)</td>
<td>The innovation ecosystem is defined by a constant change in synergistic interactions that encourages the system’s harmonious development while allowing it to respond quickly to evolving internal and external influences.</td>
</tr>
<tr>
<td>Nambisan and Baron (2013)</td>
<td>The innovation ecosystem is based on the following components, such as, actors, entities, and intangibles. An innovative ecosystem shapes/simulates the economic complexities of complex partnerships between actors or entities that have the goal of enabling development and innovation of technology. The innovation ecosystem consists of two different economies such as, commercial and knowledge.</td>
</tr>
<tr>
<td>Autio and Thomas (2014)</td>
<td>An innovation ecosystem describes an interrelated network of firms and other entities who collaborate to develop innovative products and services in a shared set of knowledge, technologies, or skills. The main features of an innovation ecosystem are the common goals (unique customer value preposition), interconnected dependencies among actors and a shared set of competences (additional technology and skills).</td>
</tr>
<tr>
<td>Gobble (2014)</td>
<td>An innovation ecosystem is a group of integrated organizations network that focuses on innovation to create new value. This network is established around focal firms and includes both consumers and producers.</td>
</tr>
<tr>
<td>Bomtempo et al. (2017)</td>
<td>The primary foundation of the innovation ecosystem is trust, value creation, and collaboration. Innovation ecosystem focuses on the development of exchanging knowledge, skills, and competencies. Innovation ecosystems are dynamic that interconnect complex societies and organizations for a meaningful goal.</td>
</tr>
<tr>
<td>Tamayo-Orbegozo et al. (2017)</td>
<td>The term innovation ecosystem applies to a group of innovative actors involved in the same network, such as customers, upstream suppliers, and downstream complementors. The focal firms produce products and services, and these actors play a significant role in adding value and enabling market diffusion to innovative products and services.</td>
</tr>
<tr>
<td>Walrave et al. (2018)</td>
<td>The innovation ecosystem is a complex system in which the collaboration of various actors influences and support to enhance the performance of the organizations.</td>
</tr>
</tbody>
</table>
capabilities and complementary resources to mutually develop and offer a broad value proposition for customers and take an appropriate advantage in the process.

| Witte et al. (2018) | The term "innovation ecosystem" refers to the resources and distinct group of contributors involved in the continuous innovation of a modern economy. The ecosystem consists of different stakeholders such as policy makers, business developers, investors, entrepreneurs, researchers, and funding organizations. |
| Tsujimoto et al. (2018) | In the field of innovation and technology management the role of ecosystem is to provide a system for products and services and also support the actors in a managerially constructed multilayer social network that have various beliefs, decision principles and attributes. |
| de Vasconcelos Gomes et al. (2018) | An innovation ecosystem is composed of a group of various actors. It includes actors such as innovators, regulators, policymakers, customers, focal firms, and suppliers. They all are interdependent and interrelated to each other to collaboratively create value for customers. The term “innovation ecosystem” means collaboration and competitiveness among the actors within the ecosystem, and it has a lifecycle that follows a co-evolution process. |
| Ding and Wu (2018) | An innovation ecosystem is described as a network system that is combined of customers, complementary manufactured goods companies, product enterprises, and a group of government institutions that promote innovation to develop innovative products. |
| Granstrand and Holgersson (2020) | An innovation ecosystem is a continuous developing system based on artifacts, activities, actors, institutions, and relations. It is significant to have complementary and substitute relationships for the innovative performance of an actor. |

Table 5: List of definitions of Ecosystem

The above table 5 represents various definitions of an ecosystem. Most definitions rotate around the traditional way of establishing an ecosystem that focuses on developing a network of more than one firm where they collaborate to produce and implement innovations. In traditional ecosystems the main goal of the actors is to cooperate and compete to develop and deliver new products and to meet customers’ demands (Adner and Kapoor, 2010). The most common use of an ecosystem on an organizational level is to describe the mutual understanding of collaboration among firms to share their expertise, knowledge, skills, and technologies in a coherent form to create value for customers. Rubens et al. (2011) stated that a competitive ecosystem supports various organizations and distributed individuals for
concurrent innovations to develop new products and customize their services according to constantly changing market demands (Kukk et al., 2015). Companies develop ecosystems to execute value propositions and merge their values into a unified form to meet the demand of the customers. In traditional ecosystem, a technology platform often serves as the foundation of the surrounding activities, such as interfaces, standards, and a shared set of assets (Dattée et al., 2018).

The innovation is no more restricted and confined within the boundaries of a single firm (Bittencourt et al., 2021). The concept of innovation has developed and moved towards a more network-based approach as innovations are promoted and implemented through a network where organizations collaborate. In the traditional ecosystem, the main components that move around the organizational level network are knowledge, information, and tangible resources. Technology is the primary innovation source. However, not all technologies ultimately result in innovation. The idea of a new product, process, or services may not lead towards innovation until it is commercialized.

The main focus of the traditional ecosystem is on firm-level collaboration. In contrast, some of the new definitions of “innovation ecosystem” focus on adding new actors in the ecosystem such as political, institutions, and regulatory bodies that can support the complex and dynamic changing demand of individual customer, national and even global levels. Several scholars suggested that the innovation ecosystem concept deals with the complexity of the innovation processes by collaborating among companies and countries rather than competing with each other directly or indirectly. Innovation ecosystems are similar to biological ecosystems in which multiple types of diverse actors contribute to the same goal (Brusoni and Prencipe, 2013).

The concept of innovation ecosystem evolves and refers to the mutual symbiosis and collaboration among the firms, governments, and private institutions to enable innovation and technology development (Adner, 2006). The innovation ecosystem identifies the complex and dynamic relationships established among different actors or entities whose main functional objectives are to support innovation and technology development. The most common components used to define the innovation ecosystem are actors, activities and material as represented in figure 14.

The actors consist of entrepreneurs, researchers, industry, government, institutions, financial systems, and civil society and material resources (facilities, funds, and equipment) that form the institutional entities contributing to the ecosystem, such as business firms, local economic development, policymakers, etc. (Jackson, 2011, Rabelo and Bernus, 2015, Granstrand and Holgersson, 2020).

The most significant mechanism of an innovation ecosystem is the collaboration and the feedback among different actors (researchers, customers, suppliers, manufacturers, decision makers, regulators, policymakers, etc.), support of the resources (funds, furniture, and IT services, etc.), and the activities (businesses, diffusion of innovation, etc.) that develop innovative products, complex value for the customers, and the value for each stakeholder within the ecosystem.
In an innovation ecosystem, a symbiotic relationship is created among interdependent firms, politics to develop and deliver products and services (Basole and Rouse, 2008). In a symbiotic relationship, firms, political, institutions and regulatory bodies collaborate and mutually dependent and interrelate to share knowledge, skills, and resources with each other to generate extraordinary results to meet the demand of customers (Liu, 2019). The term “innovation ecosystem” is related to innovation structures that are technological systems of innovation, political, inter-organizational, environmental, and economic, that maintain and support a favorable environment for business growth. Fundamentally, the innovation ecosystem is defined by a constant change in synergistic interactions that encourages the system’s harmonious development while allowing it to respond quickly to evolving internal and external influences (Still et al., 2014). Thus, the innovation ecosystem focuses on research, development, and commercialization through business model innovation that supports adding additional actors such as political institutions and regulators that can derive and support innovation at the customer level, society, country, and even globally.
3.4 Reflection of three approaches in the context of electrification of the transportation system

The transportation sector is now transforming from fossil-based to electric, forming an entirely new ecosystem. This new electromobility ecosystem develops new technological products, equipment, and solutions, establishing symbiotic relationships among new industrial, political, institutional, regulators, societal actors and stakeholders and introducing new ways of doing business that demand new business models which can integrate new actors. Thus, this revolutionary change in the transportation sector makes it a complex and dynamic system that requires new knowledge and a holistic approach to explore and understand the new ecosystem of transportation electrification.

Being from an engineering background, I had always thought that “technology is a solution to all problems.” However, technology is merely a starting point to developing an ecosystem for the existence of that technology. Here, in the case of electrification of the transportation system, electric vehicles are the technology that requires other technological components to manufacture electric vehicles, such as electric motors and batteries. Electric vehicles require a charging infrastructure that can charge the batteries of the electric vehicles. The charging infrastructure requires electricity, which depends on the electricity generation, the distribution system, and the service providers that operate under government rules and regulations. Thus, this new technology, “electric vehicles,” opens new doors for manufacturing industries and service providers where they can collaborate and develop a symbiotic relationship to meet new opportunities.

The electrification of the transportation system is not merely moving from one technology (combustion engine vehicles) to another (battery electric vehicles). It is a completely new shift from a niche model to a dynamic market. The electrification of transportation systems is forming a new ecosystem where the success of electric vehicles is dependent on collaboration and interplay between electric vehicles, charging infrastructure, and electricity distribution systems and relies on customer-oriented ideas and services.

The innovation ecosystem provides a network-based approach where the boundaries of collaboration can be expanded from local firms to international firms to meet the dynamic demand of the market (Bittencourt et al., 2021, Brusoni and Prencipe, 2013). The most significant component of developing electric vehicles is batteries, which is the main factor that increases the cost of electric vehicles. However, not all electromobility manufacturing countries develop batteries on a larger scale. China is the only country till now that has a complete value chain in the electromobility industry, from the initial reception of materials through their delivery to market and everything in between. The prestigious German brands BMW and Mercedes import batteries from China to manufacture their electric vehicles. In 2019, Germany imported 106 million lithium-ion batteries from China, worth almost US$ 1.5 billion (Xinhua, 2020). The import/export tax duties increase the cost of the batteries, and these taxes are imposed according to the rules and regulations announced by government
institutions. The German government applies approximately 19% tax on all items imported from China. This tax increases the price of lithium-ion batteries imported from China which directly impacts the cost of electric vehicles. Thus, this is just one example of the role of government policies that has a direct link to the cost of manufacturing electric vehicles.

Another significant component in the new ecosystem of transportation electrification is the charging infrastructure. The charging infrastructure is not an isolated component that can serve and fulfill the rising charging demand for electric vehicles. Charging infrastructure combines multiple actors such as electricity generation, distribution firms, charging station owners, grid system operators, banking, and payment system and IT service providers. All of these actors work under the rules and regulations provided by government institutions. A considerable investment is required to build charging infrastructure where individual firms hesitate to take the initiative to build charging infrastructure. The government has to take the initiative or collaborate with the firms to develop charging infrastructure. Thus, this discussion has led us to understand the centric and significant role of the political, institutional, and regulatory actors and their collaboration and symbiotic relationship with the potential actors in the manufacturing of electric vehicles and the development of charging infrastructure involved in the new ecosystem of transportation electrification.

However, for new technology to survive, we need society to adopt it. For the adoption of electric vehicles, we need a symbiotic business model that can integrate the role of politics, institutions, regulatory bodies, and potential actors in commercializing electric vehicles and their supporting solutions. Governments, institutions, and regulators can play a significant role in the new ecosystem by using their economic policies to diffuse electric vehicles in society—one of the leading examples is Norway. Norway does not manufacture electric vehicles; it imports electric vehicles and supporting solutions from other countries. However, in 2021 Norway has the highest market share with approximately 64.5% of pure electric vehicles worldwide. One of the main reasons is the government policies of phasing out combustion engine vehicles by imposing high taxes and diffusing electric vehicles by providing high subsidies and rebates to the citizen of Norway on purchasing electric vehicles and its supporting solutions. The symbiotic business model also supports electromobility players in the new ecosystem to diversify their revenue streams from their core business. This happens because of integrating political, institutional, and regulatory actors in the new business model that supports them to reach out to new markets, local and international, improving operations and building stronger customer relationships and better meeting end-users' need. China is a key example of it. The Chinese government promoted its electromobility industry with its supportive policies to become a global market leader and overtake the established international automotive industry. Thus, we understand that the role of politics is like glue in the middle of technology, industry, and society that forms a new system of transportation electrification.

The system approach, symbiotic business model, and innovation ecosystem complement each other. All three approaches focus on collaboration and the integration of new actors, such as political, institutional, regulatory, and societal, for managing complex and dynamic systems to achieve the expected performance of a system. The system approach
discussed human values, where political actors are neglected during the design of a system. These actors might act as 'enemies' and thus hinder the overall performance of a system (Churchman, 1979). The business approach discusses the integration of political, institutional, and regulatory actors that enhances the performance of a business model in a complex and dynamic business environment for capturing new value (Liu, 2019). White et al. (2022) stated that the traditional business model will decay the value of existing resources if the political environments shift dynamically. The innovation ecosystem is also aligned with these two approaches. It focuses on adding political, institutional, and regulatory actors that can support the achievement of the demand of the individual customer, national and even global level in the complex and dynamic environment.

Thus, all three approaches agree that integrating new actors (political, institutional, and regulatory) in the new ecosystem and the new business model are important for achieving a high level of readiness, commercialization, and managing complex and dynamic systems.

In the following sections, the empirical data is used to explore and further analyze the significance of integrating new actors (political, institutional, regulatory, and societal) and their collaboration and symbiotic relationship among them and with the potential industries in the process of transforming the transportation system.
4. Analysis and Discussion

This chapter is intended to present the overall analysis and discussion of my five papers. However, the analysis and discussions are not merely restricted based on the five papers. I have also added my reflection and understanding based on the knowledge developed throughout the research process that goes beyond the content and analysis included in the papers. The analysis and discussion present the rigorous global targets and policies of decarbonizing the environment to lead the development of renewable energy technologies and the barriers to adoption and implementation. Further analysis and discussion present the development of a model that contributes to a new knowledge of exploring, analyzing, and understanding the transformation of the transportation system from a holistic perspective. Finally, it presents the system approach to further explore the symbiotic relationship among the actors that have a high impact on transforming the transportation system from fossil-based to electric.

4.1 Global targets to decarbonize society

The world is moving towards renewable energy sources and non-fossil fuel-powered vehicles to save the environment and human life and be less dependent on the depletion of fossil fuels. For this purpose, based on the Paris Agreement, some countries have set very high targets and adopted rigorous policies to decarbonize society and reduce the use of fossil fuels. The European Union (EU) has set the target to achieve a 32% share of renewable energy by 2030. To achieve the overall goal, the individual European member states have also set targets for their countries.

Sweden has reached approximately 54% share of renewable energy and aims to achieve 100% by 2040 (Ring et al., 2022). In 2019, China consumed 23% of global energy, the world’s largest energy-consuming country, and contributed 29% of global greenhouse gases. In September 2020, Chinese political leader updated their climate goal to peak carbon emissions (to decrease fossil fuels up to the satisfactory level where it is considered safe) by 2030 and reach net-zero emissions by 2060 (Zhang and Chen, 2022).

The above political targets and promises brought a revolutionary change in the development of technology associated with fossil-free products, equipment, and solutions that can transform transportation and electricity generation and distribution systems from non-renewable to renewable and fossil-based to electric systems.
4.2 Exploring the dynamics of technology in the energy system

Electricity generation systems are transforming from fossil-based to renewable and centralized to decentralized distribution systems (Momoh et al., 2012). The old, centralized electricity distribution system does not have the capability to efficiently integrate new decentralized electricity production systems based on renewable energy sources (Feisst et al., 2008). The centralized electricity distribution system, commonly called the ‘traditional grid,’ primarily uses coal boilers and fossil fuels to produce electricity. These coal boilers and fossil fuels emit greenhouse gases that harm the environment and people’s health. In 2018, more than 8.7 million people died globally due to air pollution caused by burning coal and fossil fuels (Burrows, 2021). The centralized electricity distribution system requires high voltage and long transmission wires from the point electricity are generated to the grid and from the grid to the end consumers, which requires massive investment and higher chances of power losses and interruption during electricity transmission (Alanne and Saari, 2006). Figure 15 shows a conceptual representation of a traditional grid.

![Figure 15: Conceptual representation of a traditional grid](image)

Since the transportation sector is transforming from fossil-based to electric vehicles, electricity demand is rapidly rising. Globally, the growth of electric vehicles is approximately 19.9%, predicted every year from 2021 to 2027 (Carlier, 2022). Therefore, it is arduous for the centralized electricity generation and distribution system to achieve the rising demand for electricity due to the transformation of the transportation system and meet the environmental challenges.

In this situation, the advancement of modern and digitalized technology has made it possible for the renewable energy source to efficiently integrate into new electricity distribution system (Hoang, 2006). The new digitalized electricity distribution system is commonly known as ‘smart grid’. The role of smart grid could be decisive in transforming the energy system from a centralized fossil-based to a decentralized renewable-based intelligent system. Smart grid is an electricity distribution network system combined with various
modernized sensors, information, communication, measurement, and smart metering control technologies connected with digitalized electrical infrastructure (Shijie, 2009).

The smart grid system allows for decentralized electricity generation and distribution systems, as the embeddedness of highly digitalized technologies enables the smart grid to efficiently integrate with renewable energy sources and smartly distribute electricity based on the demand of individual consumers (Yu, 2009). These systems are located close to end-users, which reduces energy losses, saves construction costs on centralized electricity generation units, decreases transmission and supply costs, reduces utility services, and provides clean electricity (Vallee et al., 2008). In addition, real-time control technology can improve the efficiency, reliability, security, and operation of a smart grid, and therefore, the hidden faults can rapidly be discovered and eliminated (Atteya et al., 2016). A conceptual model of a smart grid system is shown in figure 16.

![Conceptual model of a smart grid system](image)

**Figure 16: Conceptual model of a smart grid system**

*Source: (Marte, 2018)*

However, it is challenging to transform the old traditional centralized electricity distribution system into a new smart digitalized decentralized electricity distribution system as it is not only implementing technology, but the modification to the grid is associated with economic, legal, and regulatory means, which is impossible without the support of the government (Hoang, 2006). The private industries will hesitate to take the initiative without the ensures of the government in terms of favorable regulations that provide the business benefits to them and the acceptance of the society to accept the new trends occurring in the energy systems due to the electrification of the transportation system.

A British company called “Womble Bond Dickinson” conducted a survey worldwide in September 2021 (Sönneichsen, 2022b). This survey aimed to discover the most significant challenges impacting the energy transition from fossil-based to renewable energy systems. In
this survey, 170 decision-makers in the energy sector responded, including investors, in-house legal counsel, and executives. The challenges the respondents addressed were: 1) 53% of decision-makers acknowledged that infrastructure complexity is the main challenge to switching from fossil fuel to renewable energy sources. 2) 52% agreed on the financial burden of stranded assets. 3) 51% accepted that the government’s rules and regulations should be clear. 4) 48% believed that understanding new technologies is a challenge. 5) 42% admitted the governments’ insufficient support in terms of taxes and incentives. 6) 36% accepted that the lack of customer collaboration or interest is another challenge.

The smart grid is a complete transformation of the new electricity distribution system, challenging the status quo, demanding people, and process improvements, and changing electric utility business models (Vadari, 2019). Smart grid is not a stand-alone technological system. It is a combination of various subsystems such as electricity production, storage, and consumption. These subsystems are deeply rooted in political-economic policies and societal behavior, which rely on each other.

The diversified electricity generation systems, the consumption side of the electric transportation system, and the central smart grid electricity distribution system that ensures the balance between electricity supply and electricity demand consist of a complex dynamic system. The advancement of technology, involvement of multiple stakeholders, and empowering consumers to control the usage of electricity have made the entire system of energy dynamic and complex, often associated with uncertain system behavior. System behavior is influenced by several dynamic uncertainties such as various government policies, consumer choices and reactions, and business decisions made by the industries. In the smart digitalized distribution system, complex interactions and mutually dependent relations exist among the different actors and stakeholders. Therefore, it is significant to understand the symbiotic relationship among the key actors and their interdependencies and dynamic relations for transforming the energy system from a fossil-based to a renewable energy system.

The old traditional electricity distribution system does not have the capability to efficiently integrate renewable energy sources because of intermittent electricity production (solar and wind) and thus meets the promises and global targets of decarbonizing society from fossil-based sources. The development of new digitalized innovative technology has enabled the integration of renewable energy sources into the smart electricity distribution system. However, the smart grid is a disruptive technology, and its implementation requires a revolutionary shift in the political policies, institutional rules, and regulations and a massive investment. The new electricity distribution system empowers consumers, changes their electricity usage behavior, and allows new actors and stakeholders in the value chain, and their integration requires new business models. Thus, new knowledge and a holistic perspective are needed to understand the adoption of the new system that can support achieving the global targets of decarbonizing society from fossil-based systems.
4.3 Barriers to implementing new energy technology

Green energy sources already exist. But converting these sources into a usable format required technological solutions, which have been developed over time, and are now available. However, widely accepted technology and technical system solutions must cross environmental barriers, such as political, industrial, societal, and financial; as in literature, it is called the “valley of death,” represented in figure 17. The new technology needs political support to be widely accepted. If not, the higher risk is that the new technology will be manufactured in a different nation that offers more favorable conditions (Grafström, 2016).

The environment determines the rules and regulations for the new technology and its effects on a sector (energy or transportation). Therefore, Wustenhagen and Teppo (2006) argue that the role of political and societal actors is more significant in establishing and diffusing the new energy technology than the capability of the technology. The actions of government agencies impact the environment and, occasionally, the ability of technology to enter the market; thus, the energy industry is dependent on these actions.

The energy industry is fundamentally different than other industries. A few differences are that the old traditional electricity generation system requires a piece of land where the electricity production plants can be installed, a grid system, and long distribution lines needed to deliver electricity from the production points to the consumers’ end. The old fossil-based electricity generation and distribution system produces greenhouse gases that harm the environment and people’s health. Governments are taking rigorous actions to prevent
greenhouse gas emissions and establishing new laws. Thus, the energy sector is deeply rooted and works under government rules and regulations.

The introduction of new technology also depends on the actors of the industry. The industrial players should be in a position where they have symbiotic relationships with political actors and access to finance through banks and institutions. According to Grafström (2016), customers do not have a high level of confidence in the Swedish electricity market since the expansion is being slowed down more than it should be by consumers' doubt of emerging renewable electricity generation technologies such as solar and wind power and their uncertainty that renewable energy sources can satisfy demand. The policymakers need to ensure that society is included in developing and implementing the new technology, which increases society's trust. Otherwise, this can lead to unequal decision-making and impact the diffusion of new energy technology in society, access to clean energy, and distribution of its benefits (Sovacool et al., 2022, Sonja and Harald, 2018, Carley and Konisky, 2020).

Accelerating the adoption of fossil-free energy technologies is not merely introducing new smart technologies or changing consumer behavior; it also requires other factors to be considered, such as location, income stability, and access to financial capital (Matuszewskaja et al., 2021, Bartiaux et al., 2019, Wilson et al., 2012). Moving towards a sustainable society requires understanding the challenges and opportunities people face and whether they have an opportunity to access environmentally friendly technology or they can practice sustainable energy consumption.

The transition toward a low-carbon economy is not merely a simple technological implementation. It requires an understanding that the new fossil-free technology can lead to economic and societal imbalances as it is deeply rooted in forming broader geographical and societal development (Mulvaney, 2013). The transition is associated with socioeconomic factors based on race, ethnicity, class, and gender, as well as their intersections.

The policy imbalance can be observed across renewable energy supply chains in the case of the individual household. For example, in Germany, only property owners are allowed to mount solar photovoltaics on their property, which creates a barrier for millions of non-property owners to adopt new fossil-free technology (Sovacool et al., 2022). While socioeconomic status is the most important factor in determining who owns the property, other factors such as age, gender, citizenship, ethnicity, and race play a role. Suppose wealthy people are the main beneficiaries of solar panels. In that case, it becomes clear that clean energy could increase inequality because those who do not own property and are thus at risk of rising rent prices are also paying more for electricity (Lukanov and Krieger, 2019). Thus, integrating political policies in favor of society and using economic means are significant to overcome the challenges of diffusing and adopting fossil-free technology on a larger scale.

The following sections guide developing new knowledge and understanding that provides a holistic perspective of seeing, exploring, analyzing, and evaluating the readiness conditions for transforming from the traditional electric system to the electric system with an increased share of renewable electricity production by integrating technological, political, societal, and economic dimensions in one model. However, the model is not explicitly applied
to the transition of the energy sector but the transportation sector of the eight selected countries. The knowledge and understanding obtained by applying the multidimensional readiness index model intend to guide decision-makers and associated industries in making decisions and establishing new policies that favor the transportation system’s transformation processes.

The adoption and manufacturing of technology requires a favorable environment comprising politics, institutions, and society. If the technology does not get a favorable environment, in that case, the higher risk is that the adoption of technology will be slower than expected, and the manufacturing of technology will be in the country where it finds a favorable environment.
4.4 Developing the multidimensional readiness index model

The concept of technology readiness level was first introduced by National Aeronautics and Space Administration (NASA) in the 1970s (Mankins, 1995) when they were developing the rockets to the moon program. It was a political decision embedded with US politics supported by society, and the economy was not considered a restriction. Developing the technology readiness level (TRL) was to monitor the development and readiness of the rocket system before it was sent into space. Later, the technology readiness level became a standardized method of assessing the maturity level of technologies before they were ready for implementation. The basic concept of TRL was adopted by Danilovic et al. (2020) and introduced a model called the “multidimensional model” with four dimensions such as technology, political, societal and economy and with four levels. This model was applied to conductive and inductive road technology to evaluate the maturity level of the specific technology.

In my thesis, I adopted the concept of four dimensions (technology, political, societal, and economic) and further developed the model with its nine readiness levels, as NASA originally introduced it for technology readiness level. The model was named the “multidimensional readiness index model.”

An innovation perspective was adopted to examine the TRL and explore other key components to understand and incorporate into a system approach. Generally, the term ‘innovation’ refers to the introduction of new or recombined ideas or methods (Kahn, 2018), however in the context of this analysis, ‘innovation’ is also about using technology to succeed with the commercialization, value creation, and diffusion in the society via a suitable business model. The technological element is merely one of the essential dimensions of the business concept. The technology requires a proper and relevant context to be embedded and integrated for its commercialization. Economic, societal, and political acceptance are the main elements needed for a potential technological solution to become a successful innovation accepted by a majority of the market. When it comes to some of the most successful innovations in our society, such as fast trains, airplanes, electric vehicles, and smartphones, we can see that they are all rooted in the political, economic, social, and socio-cultural contexts of their respective eras.

The diffusion and deployment of technologies are based on social acceptance; without socially being accepted, technology for technologies’ sake will face endless public resistance. It will be difficult to achieve commercial success for technology and attract investment and partners if political, institutional, and regulatory players do not support it. Therefore, the acceptance of developed technologies needs to be observed and examined in the context of a complex web of interactions that includes technical, political, societal, and economic elements.
Thus, the multidimensional readiness index model consists of four dimensions, technology readiness (TRL), political readiness (PRL), societal readiness (SRL), and economic readiness levels (ERL). These four dimensions form a web and, therefore, create a whole system where no one can be left out to gather a broader understanding of the electrification of the transportation system. Figure 18 represents the multidimensional readiness index model.

![Multidimensional Readiness Index Model](image)

Figure 18: Multidimensional readiness index model
Source: (Bhatti et al., 2022a)

Figure 18 shows that these four dimensions form a web and, therefore, create a whole system that none of these dimensions can be overlooked to attain a broader understanding of the electrification of the transportation system (Danilovic et al., 2020).

I have also developed and classified the economic readiness level (ERL) and political readiness level (PRL) based on empirical observations to fully operationalize the model. For societal readiness level (SRL), I have been inspired by the European societal readiness levels (Büscher and Spurling, 2019) but modified them based on the need that focuses on the adoption of electric vehicles by society. Each dimension consists of nine levels from 1 to 9. Level 1 is considered the lowest, and level 9 is the highest measuring criterion for analyzing, evaluating, and determining technology, political, societal, and economic maturity.
4.4.1 Technology readiness levels (TRL)

Technology readiness level (TRL) is an approach for conducting a logical analysis, assessment, and decision-making process when selecting an appropriate technological solution based on maturity of technologies. TRL has become a standard approach to measuring a particular technology’s maturity. Fundamentally, TRL determines if technologies are ready for adoption by potential consumers (Hirshorn and Jefferies, 2016). Level 1 is considered the lowest, and level 9 is the highest measuring criterion on the TRL scale. Figure 19 represents all nine levels of TRL.

![Figure 19: Technology readiness levels](image)

Figure 19: Technology readiness levels
Source: (Hirshorn and Jefferies, 2016)

Figure 19 explains the nine steps of evaluating the maturity levels of technology that begin with an idea and transform to the fully functional technology that reaches the level where it can be deployed on a larger scale. The levels from 1 to 9 can assist the decision-makers in observing and analyzing the development progress and transitioning of technology into a desired form. It can be noted that the established TRL is focusing on individual technologies and not on system level where different technologies can be combined or recombined.
Table 6 illustrates those 9 TRL levels in more detail.

<table>
<thead>
<tr>
<th>TRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Technology is ready to be deployed on a larger scale.</td>
</tr>
<tr>
<td>8</td>
<td>The evaluation of the evidence proves that technology works and is ready for deployment.</td>
</tr>
<tr>
<td>7</td>
<td>The fully functional technology is tested in the planned operational system and gathered evidence of its success.</td>
</tr>
<tr>
<td>6</td>
<td>The technology is tested in a simulation environment that replicates the natural world and provides almost accurate results. A fully functional representational model is considered a TRL – 6.</td>
</tr>
<tr>
<td>5</td>
<td>Technology at TRL 5 is a continuation of technology at TRL 4. However, TRL 5 is considered a breadboard technology and must undergo more thorough testing than technology at TRL 4.</td>
</tr>
<tr>
<td>4</td>
<td>The initial findings are collected, and multiple parameters are tested.</td>
</tr>
<tr>
<td>3</td>
<td>When active research and design starts on a particular technology.</td>
</tr>
<tr>
<td>2</td>
<td>When basic concepts have been investigated, practical applications may be developed based on those results. However, TRL – 2 could be risky as there is no empirical evidence that the technology exists.</td>
</tr>
<tr>
<td>1</td>
<td>The beginning phase of any technology when the conceptual study is translated and reported for future research and development.</td>
</tr>
</tbody>
</table>

Table 6: Description of Technology Readiness Levels
Source: (Hirshorn and Jeffries, 2016)

The above table 6 illustrates the nine steps of evaluating the maturity levels of technology that begin with an idea and transform to the fully functional technology that reaches the level where it can be deployed on a larger scale. The levels from 1 to 9 can assist the decision-makers in observing and analyzing the development progress and transitioning of technology into a desired form. It can be noted that the established TRL is focusing on technologies and not on system level where different technologies can be combined or recombined.
4.4.2 Political readiness levels (PRL)

We have experienced that technology has been one of the most critical driving forces of societal and industrial transformation. The advancement of technology has introduced various technological solutions for decarbonizing the environment, such as renewable energy, transport electrification, hydrogen-based transport, etc. However, large-scale R&D, implementing new technical solutions, and diffusion of new technologies are almost impossible without political decisiveness and determination to utilize technology to transform and develop society. This is especially valid for the electrification of transport as transport is one of the most harmful environmentally impacting industrial sectors globally. At the same time, it is directly associated with the coal and oil industry, which are an economic engine and a significant employer of many countries and will be the loser when transport is electrified. Some are suggesting that this ongoing electrification of the European automotive industry might lead to about 500,000 people losing their contemporary jobs. Political readiness is seen when the politicians recognize the problems and challenges and provide immediate support in framing new regulations, laws, and policies to support economic, industrial, and consumers for achieving the capabilities of purchasing expensive but desirable technologies that are costly in the beginning. Figure 20 represents nine levels of PRL.

![Figure 20: Political readiness levels](image)

Source: (Author)
Figure 20 illustrates the nine levels to assess the government’s intention, willingness, and firm decisive move towards adopting innovation or invention and implementing new favorable policies for the relevant stakeholders to encourage them to embrace it.

Table 7 illustrates those 9 PRL levels in more detail.

<table>
<thead>
<tr>
<th>PRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The government includes the idea in its national plan and monitors the development and implementation from the top level.</td>
</tr>
<tr>
<td>8</td>
<td>The government sees the impact of the new innovative product/project from a holistic system perspective and integrates other dimensions (economic, societal, and environmental) in their policy rebuilding and deals with it as one system.</td>
</tr>
<tr>
<td>7</td>
<td>The government provides the fund to the relevant stakeholders to begin the work.</td>
</tr>
<tr>
<td>6</td>
<td>The government approves the funds for converting the idea into a physical reality.</td>
</tr>
<tr>
<td>5</td>
<td>The coherence and commitment among the local/regional, provincial governments and institutions on each level in developing the budget planning and planning to monitor the idea to be implemented.</td>
</tr>
<tr>
<td>4</td>
<td>The government makes new policies or reshapes their old approaches to transform the idea into reality. For instance, imposing taxes to eliminate the old product that is not environmentally friendly reduces or eliminates taxes on the new product that the government wants to promote, which is good for society and the environment.</td>
</tr>
<tr>
<td>3</td>
<td>The new innovative idea and benefits are announced in the parliament, where the government and opposition parties mutually approve it.</td>
</tr>
<tr>
<td>2</td>
<td>The idea is discussed in the cabinet meeting where local, regional, and state governments show their willingness to move forward and develop the action plan.</td>
</tr>
<tr>
<td>1</td>
<td>The head of the state publicly expresses his/her interest in moving towards new innovative ideas / new inventions or adopting new technology.</td>
</tr>
</tbody>
</table>

Table 7: Description of Political Readiness Levels
Source: Author

Table 7 demonstrates the nine levels to assess the government’s intention, willingness, and firm, decisive move towards adopting innovation or invention and implementing new favorable policies for the relevant stakeholders to encourage them to embrace it.
4.4.3 Societal readiness levels (SRL)

Societal readiness level is a scale for analyzing and evaluating the readiness level of societal acceptance; for example, a product or a technology to be integrated into society needs to be accepted and desired by its citizens. Suppose we continuously design technologies, infrastructure, and policies in which people are not incorporated and do not see the benefits for them and their lives. In that case, there will be a risk in moving forward towards electrified solutions because it could be a failure (Cardullo and Kitchin, 2019). SRL 1 is the lowest, and the SRL 9 is the highest level of readiness indicating that society has already started adopting new technology or product. Figure 21 represents all nine levels of SRL.

![SRL Levels Diagram]

Figure 21: Societal readiness levels
Source: (Buscher and Spurling, 2019)

Figure 21 demonstrates the nine levels of evaluation of incorporating society in the transformation of an innovative product (electric vehicles) and the citizens’ adoption and diffusion of EVs.
Table 8 illustrates those 9 SRL levels in more detail.

<table>
<thead>
<tr>
<th>SRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The product diffused in society, and many citizens buy the product.</td>
</tr>
<tr>
<td>8</td>
<td>Business development and product commercialization are done, and the product’s initial sales begin.</td>
</tr>
<tr>
<td>7</td>
<td>The citizens and the relevant stakeholders test the first product and confirm the benefits.</td>
</tr>
<tr>
<td>6</td>
<td>Establishing a business relationship by demonstrating the solutions with the customers and the relevant stakeholders.</td>
</tr>
<tr>
<td>5</td>
<td>Customers and stakeholders’ views confirm the success rate of the proposed solutions in the specific area.</td>
</tr>
<tr>
<td>4</td>
<td>The proposed solution is tested by collecting views of the customers and relevant stakeholders through the pilot projects.</td>
</tr>
<tr>
<td>3</td>
<td>Suitable solutions that fit the best for the problems and the awareness are provided to citizens and relevant stakeholders.</td>
</tr>
<tr>
<td>2</td>
<td>To specify the needs or problems of society, some market research is performed mainly based on secondary data.</td>
</tr>
<tr>
<td>1</td>
<td>In the initial stage, problems are identified, such as environmental problems, different customer needs or factors associated with human health, etc.</td>
</tr>
</tbody>
</table>

Table 8: Description of Societal Readiness Levels  
Source: (Büscher and Spurling, 2019)
4.4.4 Economic readiness levels (ERL)

Economic readiness level is a dimension for analyzing and evaluating the readiness levels of cost affordability of a technology or a product by the industry that impacts them and by the large number of citizens expected to adopt electric vehicles. Economic readiness plays an important role in diffusing innovative products (electric vehicles) in society. The consumer's approach is to pay for something less expensive or better than they already have.

The word “economic” is a vast subject divided into microeconomics and macroeconomics. Microeconomics is a bottom-up approach that deals with individuals, business decisions and concentrates on supply – demand and forces that determine the price levels. Macroeconomics is a top-down approach that deals with decisions made by governments and countries. It focuses on the economy, where the government determines the investments in R&D, prices, imposes and reduces the taxes, and provides rebates and subsidies to balance the development and manufacturing cost for early technologies with the price level of the products in the market (Potters and Logan, 2021). After all, the business operators and citizens must afford to buy the new technology and products coming on the market.

The transformation of the transportation system is a national and international matter that involves facing national and international challenges such as global warming, pollution, and depletion of fossil fuels in the world. Being responsible nations, it is countries’ governments’ responsibility to deal with these challenges and support the transformation of the transportation system towards electrification. Therefore, we have used the macroeconomic concept to build the economic readiness levels where the government controls the prices to bring stability and affordability to the market. The government has the mandate to manage and set the minimum or maximum prices for specific products, including gasoline, electricity, and vehicles (Kenton and Potters, 2021).

To develop the economic readiness levels, we have focused on balancing cost of three main factors (manufacturing cost of EVs, energy supply for the transport infrastructure, and operational cost), where governments can support by providing subsidies, rebates, imposing /reducing taxes on the EVs to push the EVs in the market for societal diffusion to achieve certain benefits, for instance, decarbonizing the environment and less relying on fossil fuels. The government can support until the economic readiness reaches the highest level where the price balances for consumers and producers, which means that the consumers can afford the product, and the producers can still capture the value. Figure 22 represents nine levels of ERL.
Figure 22 illustrates the nine levels of government involvement to make economic readiness ready for each stakeholder participating in the transformation of the transportation system. The technology, political and societal readiness levels are more of general readiness levels that can be used for any technology, political and societal context, but the economic readiness levels depend on the development requirement of the product and the context where the product will be used.

Table 9 illustrates those 9 ERL levels in more detail.

<table>
<thead>
<tr>
<th>ERL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The EVs' purchasing and operational costs become equal to or less than gasoline-based vehicles.</td>
</tr>
<tr>
<td>8</td>
<td>The government provides affordable/free charging facilities at public charging stations or affordable/free charging piles at public parking or support installing charging piles at home. This act will reduce the operational cost of EVs for citizens.</td>
</tr>
<tr>
<td>7</td>
<td>The government reduces/eliminates the registration and insurance fees on EVs, which will further support citizens in the cost reduction on purchasing EVs compared to gasoline-based vehicles.</td>
</tr>
<tr>
<td>6</td>
<td>The government provides extra support to encourage citizens to buy EVs by offering subsidies and rebates.</td>
</tr>
</tbody>
</table>
Table 9 illustrates the nine levels of government involvement to make economic readiness ready for each stakeholder participating in the transformation of the transportation system. The technology, political and societal readiness levels are more of general readiness levels that can be used for any technology, political and societal context, but the economic readiness levels depend on the development requirement of the product and the context where the product will be used.

Economic readiness is itself a complex dimension that is interrelated and interdependent on various factors such as government policies related to import/export, manufacturing companies’ capabilities (they have complete value chain capability or need to import the parts for manufacturing the product), and the market behavior. Not all the products require the same or specific infrastructure to operate. For instance, the airline and shipping industry follows international laws, customer segments vary from country to country, and the airplanes manufacturers are limited, so the economic policies are designed by considering these factors, which do not apply to the automotive industry. Therefore, the economic readiness levels are explicitly developed for electrification of transportation systems because economic readiness depends on the import/export policies of the government, requires specific infrastructure and support of energy companies to operate electric vehicles.

The multidimensional readiness index model is an analytical tool that explores, analyzes, evaluates, and determines technological, political, societal, and economic readiness. The technological readiness levels scale evaluates the development processes of technology towards readiness. The political readiness levels scale explores the actions and intentions of the government with their policies and economic support to the industry in developing the technology and diffusing it in society. The societal readiness levels scale examines the willingness and adoption of new technology. The economic readiness levels scale is intertwined with governmental policies and efforts to balance the economic cost of new technology so that the average consumer can afford it. Thus, the model provides a holistic perspective of politics' significance and its fundamental role in developing new technology and its diffusion and adoption by society.

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>The government reduces/eliminates taxes on EV purchase for citizens to control the initial cost of EVs.</td>
</tr>
<tr>
<td>4</td>
<td>The government also supports renewable energy providers by eliminating/reducing taxes for those who provide energy to the EV infrastructure.</td>
</tr>
<tr>
<td>3</td>
<td>The government provides extra support to encourage automotive manufacturers to produce electric vehicles by offering subsidies and rebates.</td>
</tr>
<tr>
<td>2</td>
<td>The government reduces/eliminates taxes for companies producing electric vehicles and charging equipment.</td>
</tr>
<tr>
<td>1</td>
<td>The government revises their tax duties on import/export of EVs, EVs batteries, charging equipment, and equipment supporting renewable energy (solar panels, wind turbines, etc.).</td>
</tr>
</tbody>
</table>

Table 9: Description of Economic Readiness Levels
Source: Author
4.5 Applying multidimensional readiness index model to the eight selected countries

This part of the analysis and discussion is based on the data collected and discussed in papers 4 and 5 on the consideration involved in assessing the state of global readiness for the electrification of all modes of electric transportation equipment and supporting systems in eight countries on three continents, such as Asia (China and India), Australia and Europe (Germany, Norway, Sweden, Slovenia, and the UK). The exploration, analysis, and discussion lead to the understanding that merely relies on technology development, and its analysis will not lead us to the complete system readiness of transportation electrification. We need other such as political, societal, and economic dimensions to explore, understand, utilize, and support the whole system to transform the transportation system towards electrification successfully.

Figure 23 (for further detail of figure 23 is represented in paper 5, see appendix: 1) represents the achievement of the countries in the process of transforming the transportation system towards electrification in all four dimensions (technology, political, societal, and economic) of the eight countries (China, India, Australia, Germany, Norway, Slovenia, Sweden, and the UK) from three continents, Asia, Australia, and Europe.

Figure 23: Multidimensional readiness index model of eight selected countries
Source: (Bhatti et al., 2022b)
As a result, to attain a high degree of diffusion of an electric transportation system, additional factors such as political, societal, and economic readiness also must be considered and balanced alongside the available technology. The research has noted that the major dimension in the public discussions of electrification has been focused globally on technology. Until all the readiness factors have not been given their due consideration globally, the introduction of complete and effective electrification of all modes of transportation equipment and their associated systems will not proceed effectively or expeditiously. From this point of view, all those four dimensions of the states of readiness are complementary and thus equally important. All of them need to be fully integrated and implemented to support the development and diffusion of electrification of the transportation system. Figure 24 (for further detail of figure 24 is represented in paper 5, see appendix: 1) represents the eight countries' position in transforming the transportation system toward electrification.

![Countries Positioned in the Development of Transportation Electrification, 2022](image)

**Figure 24**: Countries positioned according to the readiness index in the development of transportation electrification in the year of 2022
Source: (Bhatti et al., 2022b)

China is the biggest country in Asia, with the largest population in the world of 1.44 billion. It is one of the leading countries in the world in adopting electric vehicles. In 2009, China was the home of the world's largest internal combustion engine (ICE) vehicle market (Teece, 2019). A revolutionary shift was seen in the Chinese automotive technology, industry, and market, and within ten years, in 2019, China had the largest electric car fleet, with 47% of electric vehicles globally. China is historically a landmark of success for automotive companies. China's automotive industry has been flourishing and growing at an average of 15% each year and was acknowledged to have 70% growth globally during the last ten years (Teece, 2019). China overtook the U.S. as the world's largest electric vehicle market in 2015, becoming more than three times larger in 2018 than the U.S. (Richter, 2019).
China is dominating the world in the field of electromobility technology, industry, and market, according to the electric vehicle index in 2021 (Carlier, 2021). China is at the forefront of the transition from fossil-fueled to electric vehicles. China is leading in manufacturing pure battery electric vehicles as well as in battery along with South Korea, which is ranked 1st in innovation, according to Bloomberg (Jamrisko et al., 2021). Of the top 10 fully battery-electric vehicle manufacturers, nine are Chinese companies, and the other one, Tesla, is a U.S. brand also manufactured in China (Kane, 2021a). The strength of China in manufacturing electric vehicles is the collaboration, coordination, and integration of the new actors and stakeholders associated with I.T. and software application development firms such as Alibaba and Tencent (Altenburg et al., 2022). One of the main reasons for China’s booming manufacturing industry of electric vehicles is the government’s policy which is aligned to phase internal combustion engine (ICE) vehicles out and allows generous support to the alternative technologies with the complete policy package and firm-level strategies.

One key system, the most value-added, however technologically complex, for electrified road transportation is batteries. For an electric vehicle to be more attractive than conventional vehicles, lithium-ion batteries must perform well in terms of energy density, cost-effectiveness, safety, and life cycle. These factors make up a significant portion of the cost of an electric vehicle. However, China has an edge in two areas: the geographical advantage, where China finds a substantial portion of the world’s rare earth elements and other essential mineral deposits used to manufacture lithium-ion batteries (Altenburg et al., 2022). Another advantage is that China has achieved a high level of in-house technical expertise in manufacturing lithium-ion batteries for electric vehicles and other electronic devices (Altenburg et al., 2022). Asian companies are leading the electric vehicle battery industry. They are expanding their manufacturing capacity in Europe and the USA to gain profitable contracts and secure market positioning from the international electromobility manufacturers. L.G. Chem and Samsung SDI are the largest South Korean battery manufacturing companies (Park and Koo, 2021). Contemporary Amperex Technology Co., Limited (CATL) and BYD are two of the leading Chinese battery manufacturers. CATL is ranked second with a market share of over 29% (Buchholz, 2022a). CATL is the most significant international electric vehicle battery exporter to BMW, Honda, Hyundai, Tesla, and Volkswagen. Besides Panasonic, a Japanese battery-making company, China, and South Korea are leading in battery manufacturing for electric vehicles. China has a complete value chain in the electromobility industry from the initial reception of materials through its delivery to market and everything in between (Möller et al., 2019).

China started demonstration projects to provide awareness to their society of electric vehicles. In 2008, thirteen cities were chosen, and later twelve more cities were included and rolled out charging infrastructure throughout these cities. By June 2021, approximately 1.947 million charging piles and 716 battery swapping stations were available for charging electric vehicles in China (Danilovic and Liu, 2021). To gain citizens’ trust and motivate them to adopt new technology, the Chinese government took the initiative to shift their public transportation, specifically taxi fleets and public buses. With the help of the Chinese government’s progressive policy initiatives, businesses could develop their technological capabilities and rapidly shift toward being lead manufacturers. Government subsidies have
played a key role in boosting demand for electric vehicles. The incentive programs offered in China are among the most substantial in the world. Therefore, domestic sales in China were considerably more important to manufacturers than exports. The favorable business policies of the Chinese government appeal to foreign investors to invest in China. Some international brands, such as Tesla, BMW, and Toyota, began using China as an export center for electric vehicles as the government allowed foreign manufacturers to use all local production facilities (Altenburg et al., 2022). Therefore, the major international vehicle manufacturers are increasing their electric vehicle production in China.

Norway is a country situated in northwestern Europe. It is the sixth-largest country in Europe, with a total land area of 323,802 sq km but a small population size of 5.4 million in 2021. Norway is renowned for producing oil and natural gas. The Norwegian economy primarily relies on exporting oil and gas. Norway is a small but significant player covering approximately 2% of the global crude oil demand (Petroleum, 2022). In Norway, the sales of battery-driven electric vehicles are continuously increasing due to the subsidies and rebates provided by the government. In 2021 almost 50% of all new vehicles sold in Norway were electric vehicles (Kleesty, 2021).

Norway does not manufacture electric vehicles or electric vehicle batteries, but it imports from other countries such as the US, South Korea, Japan, and China. NIO Norway (Chinese BEV supplier) has also started its sales in 2021 and several other Chinese brands such as XPeng, LiAuto, BYD and other are moving to Europe (Narayanan, 2022). Norway is a small but geographically long country, and people need to travel long distances for their daily life activities. Almost 96% of electric vehicle owners have access to a charging station in their own homes or apartment (Lorentzen et al., 2017). However, long-distance travelers or tourists with their electric vehicles need public charging stations, which presently lack in number and distribution. The government has started funding to construct at least two multi-standard fast-charging stations at every 50 km along all of Norway’s major highways.

Germany is situated in Central Europe. It is the sixth-largest country in Europe with a total land area of 357,114 sq km. Germany has the second biggest population in Europe, with 83.24 million people in 2020 after Russia. Germany is a well-recognized country for its excellence in the automotive industry. It is the home of producing the most innovative and luxury automobiles. In 2018, almost 426 billion euros (approximately $442 billion) were generated by the automobile industry in Germany (Koptyug, 2020).

Germany is the most prominent country in Europe in manufacturing fully battery electric vehicles, with its top five selling brands such as Volkswagen, Mercedes-Benz, BMW, Smart, and Audi (Koptyug, 2021). However, Germany imports batteries from Asia, especially China and South Korea, to manufacture luxury electric vehicles like BMW, Mercedes-Benz, and Audi. Germany imported 106 million lithium-ion batteries worth approximately US$ 1.5 billion from China in 2019 (Xinhua, 2020). Germany also aims to become the center of European battery production. The federal government is funding around $ 506.7 million (€ 436.8 million) for the project (Manthey, 2021). In 2020, the German and French governments collaborated “German French battery consortium” to initiate a pilot plant and establish a factory in Germany and France (Rivet, 2019). Even though Germany is working to develop its strength
to produce batteries for electric vehicles domestically, this process is still in its initial phase. At the end of 2020, the total number of public charging stations was 44,669, of which 37,213 were slow and 7,456 were the fast-charging stations available in Germany (Koptyug, 2023). However, Germany is still lagging behind in its charging infrastructure. The charging stations are not evenly distributed in Germany. Hamburg is the second biggest city in Germany with 1.9 million people, whereas Munich is the third biggest city in Germany with 1.5 million people. However, as of 2021, Munich has the highest number of charging stations than Hamburg, approximately 1,327 and 1,214, respectively (Statista Research, 2023). Germany has introduced its first electric road of about 10 km long in the south of Frankfurt. The electric road charging solution faces standardization issues, and the road charging technologies are still in their early testing phases.

Sweden is situated in northern Europe bordering Denmark, Finland, and Norway. It is the fifth-largest country in Europe, with a total land area of 450,295 sq km. The population of Sweden is double the size of the Norwegian population of approximately 10.35 million in 2020. Sweden is one of the top innovative countries in the world and the number one in EU (Buchholz, 2022b). According to the Bloomberg innovation index 2021, Sweden is ranked 5th in the innovative countries worldwide, while in the EU Innovation Scoreboard, it is ranked as 1st.

However, in the field of electromobility, Sweden still lags behind, despite manufacturing its own electric vehicles in Belgium and China. The Swedish Volvo manufactures its prestigious electric vehicle (Polestar) in China. The new Volvo XC-40 launched in 2021 is manufactured in Belgium and China. However, Sweden yet does not have its own battery manufacturing and thus Swedish EV manufacturers purchase batteries mainly from Asia, Europe, and the US. Volvo in the majority, manufacturers hybrid vehicles rather than fully electric vehicles. Scania and Volvo have launched their first electric trucks in 2020/2021 (Vilhelmsson, 2020). In Sweden, several charging technologies are in the testing phase, such as electric roads (conductive and inductive), and the government is considering to further looking into battery swapping solutions. Static cable-based charging is considered a relatively mature technology that is primarily used to charge passenger vehicles. However, static charging faces a standard technical problem in that there is no standardized charging plug (Hasselgren and Näsström, 2021).

The United Kingdom (UK) is located on the northwestern coast of mainland Europe. It includes the entire island of Great Britain. The UK consists of England, Scotland, Wales, and Northern Ireland. The total land area of the UK is around 242,495 sq km. The population of the UK was recorded at about 67.22 million in 2020. The UK is renowned for manufacturing prestigious brands of automobiles. The UK automobile industry was the second largest in the world in the mid-20th century. The automotive industry has a significant role in the UK economy. In 2020, it contributes 15.3 billion British pounds (approx. $18.6 billion) to the country’s economy and employs more than 860,000 people working (Placek, 2021). The UK automobile industry was the second largest in the world in the mid-20th century. However, in the field of electromobility the UK is lagging behind in manufacturing its own electric vehicles. The British brand MINI was founded in 1969 but is now owned by
German automotive company BMW since 2000 (Chinn, 2022). The other MG British automotive company was founded in 1920 but is now owned by SAIC Chinese motor corporation limited since 2007 (Jordon, 2022). Among the top ten selling brands of electric vehicles in 2021, only Vauxhall Corsa is the British brand (Herincx, 2022). The other nine brands are imported from the US, South Korea, Germany, and Japan. The UK also imports batteries from China and South Korea to fulfill the demand for British electric vehicle manufacturers. The UK has lately considered developing a Gigafactory to establish itself as a future battery leader. The "Envision AESC UK Limited" is currently the only British EV battery manufacturing company with an annual production capacity of 2GWh (Hill, 2021). The other two British start-ups, "AMTE Power" and "Britishvolt," have announced building the first large-scale battery factory to supply batteries for the domestic electric vehicle manufacturers (Statista, 2020). The UK is catching up in its charging infrastructure with approximately 28,458 charging points, including 3,874 fast chargers and 1,290 ultra-fast chargers were available at the end of 2021 (Statista, 2021). However, 32.3% of the total UK chargers are installed in London (Kirby and Bawden, 2021), whereas according to the County Councils' the other 36 county areas are lagging behind in the charging infrastructure.

India is the second-largest country in Asia, with a 1.39 billion population. It is spread over 3.287 million square kilometers. India is different when it comes to the electrification of transportation as the most common mode of transportation in India is two and three-wheelers. Indians prefer to have two-wheelers as they are convenient for short distances and efficient transport on narrow and busy roads with heavy traffic. India is the largest two-wheelers manufacturer in the world. In 2019, approximately 295 million two-wheelers were registered in India (Sun, 2021b). Hero MotoCorp is the market leader in producing two-wheelers and has taken the initiative to produce electric bikes and scooters. In 2021, approximately 5,600 electric bikes were sold by Hero MotoCorp (Sun, 2021c). Honda Motorcycle & Scooter India is also catching up with India’s electric two-wheeler market share, with approximately 3,868 electric bikes sold in 2021 (Sun, 2021c). An Indian automotive manufacturing company, TATA, has also introduced Tata Nexon and Tata Tigor electric vehicles. These two TATA brands had the highest sales among the electric cars, with approximately 4,214 electric vehicles sold in India in 2021 (Sun, 2021a). However, India does not manufacture batteries for its two, three, and four-wheelers but instead imports from China, Hong Kong, and Vietnam. The most significant challenge for India is to have a suitable charging infrastructure. India only has 1,640 public electric vehicle chargers installed, of which 940 chargers are only installed in 9 megacities (Ministry, 2022). These chargers are not enough for the country with the second biggest population in the world. Even though the Indian government has taken some initiative to expand the public electric vehicle charging stations, these efforts are not enough until now.

Australia is the smallest continent in size, and the entire country occupies this continent. It is the sixth-largest country on earth and 2.4 times bigger than India but 1.2 times smaller than China. The total population of Australia was about 25.69 million in 2020, which was much lower than China and India.
Australia is far behind in the electrification of transportation systems compared to the other developed nations such as China, Germany, Norway, Sweden, the UK, etc. Australia does not manufacture electric vehicles but imports from the USA, Germany, South Korea, Sweden, and Japan (Misoyannis, 2022). Australia is rich in lithium mines production. In 2021, approximately 55,000 metric tons of lithium came out of Australian soil. In contrast, Chile and China ranked second and third in producing lithium, with approximately 26,000 and 14,000 metric tons, respectively (Garside, 2022). However, Australia has not been manufacturing lithium-ion batteries till 2021. In 2020, the Australian government funded $28 million for the first time to start a lithium-ion battery manufacturing facility in Australia (Hartmann, 2020). In 2021, Australian Prime Minister Scott Morrison announced additional funding of $1.5 billion to boost Australian battery production (Carroll, 2021). The battery production facility is still at an early stage in Australia. Australia is lagging behind in electric vehicle charging infrastructure. At the end of 2021, approximately 3,017 public charging stations were available in Australia, of which 1,017 were only in New South Wales (Council, 2019). Charging an electric vehicle is a challenge for people who cannot charge their vehicles at home, especially for tourists who travel from one state to another. Therefore, highways, metropolitan areas, and tourist attractions need public charging facilities in Australia.

Slovenia is a country situated in the south of Central Europe, which is one of the smallest countries in Europe, with a total land area of about 20,273 sq km. Slovenia is also smaller in population size in Europe, with approximately 2.1 million people in 2021. The share of electric vehicles in Slovenia is comparatively low than in the northern European countries.

Slovenia is lagging behind its goal of decarbonizing the road transportation sector. The Slovenian government has set the goal to have 130,000 battery electric vehicles and 70,000 plug-in hybrid vehicles on roads replacing fossil fuels (Union, 2021). To achieve the goal, Slovenia should have been 5,311 battery electric vehicles and 6,033 plug-in hybrid vehicles on roads by the end of 2020, whereas 3,678 battery electric vehicles and 944 plug-in hybrid vehicles were registered as of December 31, 2020 (Europe, 2022). Slovenia does not manufacture electric vehicles. All of the top-selling electric vehicle brands in 2018 were imported from Japan, France, Germany, and South Korea (Watt, 2020). Slovenia is planning to gain in-house battery manufacturing capability. For this reason, Slovenian battery manufacturing company Tovarna Akumulatorskih Baterij (TAB) collaborated with a Chinese company Haidi Energy Technology (Raiev, 2021). However, this project is not ready yet to produce batteries on a larger scale. Slovenia does not have a suitable public charging infrastructure yet, that supports the transformation of fossil-based to clean transportation and enables the government to achieve its targeted goals set for 2030 of replacing gasoline-based with electrified vehicles. Slovenia only had 308 public charging stations by the end of 2021 (Kmetec and Knez, 2022). These charging stations are mainly available in the populated cities of Ljubljana, Maribor, Kranj, and Koper. It is difficult for the people driving across Slovenia or tourist to find public charging stations on the main highways.

The above analysis of the eight countries drew my attention to the system approach. It guided me to explore further the driving factors and their symbiotic relationship for the countries to lead in the field of electromobility and become a lesson for other countries in
transforming transportation systems from fossil-based to electric. The following section leads to exploring the dynamics of the electrification of transportation systems from a system perspective.

Based on the analysis of the above eight countries, we can see that only China has complete control over manufacturing electric vehicles, batteries, equipment, and system solutions for transportation electrification. In contrast, Germany is catching up with its five prestigious brands of electric vehicles and gaining the capability to start in-house battery manufacturing along with Sweden and France. The other five countries, Australia, Norway, Sweden, Slovenia, and the UK, are mainly buyers of electric vehicles and their supporting equipment and systems for the electrification of transportation. India has been stuck in the middle with its few electric two-wheelers and one known TATA electric vehicle manufacturer. China is leading in technology, industry, and market because of adopting a system approach in establishing its policies toward electrification. The system approach can be seen through the actions of the Chinese government, where technology, industry, and all levels of society are integrated into comprehensive policy packages. In contrast, although a variety of policies are announced in Germany, Norway, Sweden, and the UK, they are more general and fragmented, where not all associated industries and all levels of society are considered in the policies that can significantly impact the transformation of the transportation system. Australia, India, and Slovenia are far behind and need to revisit their policies toward technology, industry, and society if they want a high level of transformation of the transportation system.
4.6 System approach to Exploring the Dynamics of Electrification of Transportation

The old fossil-based transportation is facing transformational challenges towards the electrification of the transportation system. Electrification of the transportation system is not a single technological element that can be understood or treated as an isolated technical system. It is a combination of various technical elements such as electric vehicles, batteries, and charging infrastructure. These elements are deeply rooted in social systems such as political, societal, and economic, which cannot easily be mathematically modeled to predict their behavior as a single technological system (Churchman, 1979). However, to attain the expected objective, the system can be understood and managed if we see it in a larger picture. In section 3.1, it has been discussed that the system approach advocates that problems should be seen as a whole rather than in parts (Senge, 1990). Therefore, the system approach is adopted to explore and understand the dynamic behavior and significance of the various actors and their symbiotic relationships based on their role in transforming the transportation system.

Predicting the behavior of a system requires understanding the system structure, which is the combination of elements and their interconnections (Ossimitz, 2000, Richmond, 1994). To examine the behavior of transforming the transportation system in a larger picture, all four aspects: technological, political, societal, and economic are adopted from papers 4 and 5 (see: appendix – 1). In papers 4 and 5, these four aspects are used in developing the multidimensional readiness index model, and each of these aspects is represented as a dimension, whereas in the context of the system approach, these aspects are interpreted as domains. The concept of domain has come from a computer engineering perspective, which means representing a group of multiple elements communicating together for a specific purpose (Moffett, 1989, Wang et al., 1989). A group of elements forms a domain, and a collection of organized domains which are highly integrated form a system that accomplishes an overall goal (Meadows, 2008).

Figure 25 represents four domains, such as technological, political, societal, and economic; the technological and societal domains are placed vertically, whereas the political and economic domains are placed horizontally. The domains placed vertically represent the symbiotic relationship and collaboration between technology and its adoption by potential customers. In contrast, the horizontal domains represent the symbiotic relationship and collaboration between political and economic. Government policies generally influence the economic domain, and their rules and regulations apply to industries and businesses that affect the cost of developing and selling new technologies or products. Thus, the political and economic domains are intertwined with each other. Whereas for technology to be diffused and accepted on a larger scale requires favorable political decisions and economic means. Thus, all four domains have a symbiotic relationship that requires each other feedback regarding surviving and thriving to attain objectives and deal with challenges.
Figure 25 illustrates technological, political, societal, and economic domains and the chosen elements of each domain.

Each domain holds various elements, as shown in figure 25. The elements support the development of a system structure (Ossimitz, 2000, Richmond, 1994). The concept of identifying these elements has come from papers 4 and 5 (see: appendix – 1) during the exploration and analysis of the readiness conditions for electrification of transportation in the eight countries (Australia, China, India, Germany, Norway, Sweden, Slovenia, and the UK). These elements have shown their significance for the countries in achieving a higher readiness positioning in the process of transforming the transportation system towards electrification. Thus, these elements have been chosen to explore further and analyze their symbiotic relationships and collaborations within and across domains.

In the following sections, from the perspective of each domain, conceptual models are developed to explore and understand the non-linear relationships (Hopper and Stave, 2008, Plate and Monroe, 2014) between the domains and their elements through feedback loops. These elements and their non-linear relationships lead to understanding the dynamic behavior (Plate and Monroe, 2014, Arnold and Wade, 2015) of the electrification of the transportation system.
4.6.1 Exploring the dynamics of technology in the transportation electrification system

The advancement of technology has made it possible for the transportation system to be transformed from fossil-based to electric. However, this transformation is not merely a matter of replacing fossil fuel-propelled vehicles with electric vehicles. Electric vehicles require batteries that can store energy for propelling vehicles, and these batteries need to be charged, which requires charging infrastructure. Thus, all these elements, such as electric vehicles, batteries, and charging infrastructure, are interconnected and interdependent to perform a function; these elements are illustrated as the technological domain elements, as shown in figure 26. This section mainly focuses on exploring the dynamic relationship and feedback from the technological domain perspective to understand the dynamic behavior of developing the technological domain elements in the eight countries.

![Figure 26: Technological domain and its elements](image)

The development of the technological domain has a non-linear relationship with the political, societal, and economic domains, as technological development depends on the feedback of these domains. Developing technology such as electric vehicles, advanced batteries, charging equipment and establishing new charging infrastructure is costly. So far, China is the only country with a complete value chain in EV technology, which means that electric vehicles, their components, batteries, and their associated materials are mined and manufactured within China (Altenburg et al., 2022). This results from more than 20 years of continuous effort in developing EV technologies and the value chain. As early as 2001, China launched a major technology project for EVs, with the main goal of establishing new energy power systems, including pure battery based EVs, hybrid EVs, and fuel cell EVs, with three technical routes. In 2005, the Outline of the National Medium - and Long-Term Science and
Technology Development Plan established the strategy for developing energy-saving and new energy vehicle technology. In 2009, new energy vehicles were established as one of the national strategic emerging industries by the State Council of China, and a demonstration and promotion project for applying ten thousand of new energy vehicles in ten cities was launched. Since 2011, Chinese mining companies have consciously acquired the raw material mines needed to produce automotive lithium batteries, becoming the world’s largest lithium and cobalt minerals supplier. In 2012, the State Council issued the Energy-saving and new energy vehicle industry development plan and recognized battery-based pure EVs as the major technical route. In 2015, the National Development and Reform Commission set the target for China’s new energy charging stations to meet the changing needs of 5 million new energy vehicles by 2020 (Zhang and Bai, 2017). By 2018, the whole domestic-based EV industry value chain had been established. By the end of 2022, 5.21 million charging piles had been established in China.

The EV technology, charging infrastructure, and industry value chain are co-explored and co-created in collaboration between the state and industry actors in a holistic and parallel approach. Therefore, Chinese electromobility manufacturers do not necessarily have to import equipment from other countries to manufacture electric vehicles as all the associated components are easily available in China. However, Chinese batteries and electromobility manufacturers are depended on government policies to get government support in terms of getting subsidies or rebates or reducing or eliminating taxes on manufacturing electric vehicles and batteries to become a price competitive compared to petrol or diesel-based vehicles. Over the past decade, the Chinese government supported electric vehicle and battery manufacturers with over $60 to $100 billion to produce cheap electric vehicles and lithium battery manufacturers to build refining infrastructure (Goldman et al., 2019). The Chinese government provided $100 million in loans to CATL from state-owned banks to expand its battery supply chain operations in China (Pike, 2022).

The feedback loop in figure 27 represents that the development of the technological domain is not an isolated process; it requires support from political policies, economic means, and societal acceptance. Each of these domains is explored and discussed in the coming sections.

Norway does not manufacture electric vehicles and batteries but imports its top 10 selling brands from the Czech Republic, Germany, Japan, South Korea, and the USA (Kane, 2021b). Without having technology, i.e., electric vehicles, Norway is leading as a top country with more than 86% of the market share in 2021 for electric vehicles (Paper: 5, appendix: 1). The secret behind it is the role of the political system, which made it possible with its economic policies to diffuse electric vehicles in Norwegian society. Germany, Sweden, and the UK, even though these countries have in-house manufacturing capability, these countries import batteries and components to manufacture electric vehicles. The cost of the batteries depends upon the governmental import and export tax duties. The initial price of electric vehicles is higher than the fossil-based vehicles in Germany, Sweden, and the UK. The role of the government system with its economic policies is significant to balance the prices with its counterparts of fossil-based vehicles to diffuse the electric vehicles in the society.
One example of a weak system is the electrification of the transportation system in Australia, India, and Slovenia. Australia does not manufacture electric vehicles and batteries but imports its top 10 selling brands of electric vehicles from Germany, Japan, South Korea, Sweden, and the US (Council, 2019). The prices of these imported electric vehicles are higher than those of fossil-based vehicles. One of the reasons is the lack of coordination and collaboration between technology and political systems. The import tax duties are high, which increases the initial price of the electric vehicles compared to their counterpart, petrol, or diesel-based vehicles. Australia, India, and Slovenia are far behind in manufacturing electric vehicles. At the same time, the coordination between the technological and political systems is weak to promote even imported vehicles within their countries by providing subsidies and rebates that compensate for the price of the fossil-based vehicles.

Charging infrastructure is a complex element embedded in the technological domain within the system of transportation electrification. The charging infrastructure depends on various charging solutions such as cable charging, battery swapping, etc. These charging solutions depend on electricity generation, distribution, and consumption systems connected with IT systems as they are digitalized automated and intelligent systems in various nations. Developing charging infrastructure is heavily dependent on the political domain as it requires funds and lands to be built. Thus, all these systems are entirely reliant on political policies and support. If the political support is weak, the entire system may function but with a prolonged transition from fossil-based to electric transportation.
4.6.2 Exploring the dynamics of politics in the transportation electrification system

Moving from fossil-based to electric transportation systems is a global challenge where governments of each country have to take the initiative to deal with this challenge. Electrification of transportation is a complex system as it combines various industries such as electromobility, energy, IT, and socio-economic systems. These industries and systems operate under government-influenced institutions and are dependent on government policies. The technological, political, societal, and economic domains are intertwined and function with the feedback of their dependent domains, as shown in figure 28.

Figure 28: Relationship of various domains within the transportation electrification from political perspective

Source: (Author)

Figure 28 represents that the speed of transformation of the transportation system towards electrification is primarily dependent on the government actions and policies introduced in favor of associated industries and society. The political role in the system of transportation electrification is like an “enabler” to start taking the initiative to interact with the technological and societal domains by using its economic means to enable the entire system to function. Figure 28 represents the correlation and coordination with its feedback.
loop among the political, technological, societal, and economic domains within the whole system of transportation electrification.

The political role is significant for the development of society, transformation processes, and diffusion of system solutions for transportation electrification. Without firm government support, transportation transformation towards electrification is complicated and probably impossible. The government can take the initiative and introduce policies by imposing heavy taxes on petrol or diesel-based manufacturing companies, discouraging them from manufacturing vehicles which are harmful to human health and the environment. In the meantime, raise favorable policies by reducing or eliminating import/export taxes for mobility manufacturers who want to shift towards manufacturing or are already manufacturing electromobility. Governments can also support in-house battery manufacturing companies by reducing or eliminating import tax duties on the materials used in manufacturing batteries which will encourage battery manufacturers to manufacture batteries on a larger scale. Governments need to take the initiative to provide funds or have a mutual understanding to cooperate with the companies interested in developing charging infrastructure. The charging infrastructure is dependent on the electricity generation, distribution, and consumption systems. These systems in most countries work under government-influenced institutions where governments can play an essential role in easing the taxes or providing subsidies or rebates to the energy-providing companies to decrease the electricity prices for the electric vehicle manufacturing companies and the electric vehicle consumers. Governments can reduce the initial price of electric vehicles and the charging price with their policies and strategies, encouraging societies to shift from fossil-based to the electric transportation system.

Government engagement at both the rhetorical and action levels is key to success in the rapid transition from fossil fuels to electric transportation. A clear government and institutional enforcement power are the main success factors behind China's rapid development of electrification of the transportation system. Political actors in China create sustainability transition missions to set the selection criteria in the social-technical landscape and deploy strategies for developing sustainable mobility solutions (Development Plan for the New Energy Vehicle Industry (2012-2020), (2021-2035)) to create positive and stable investment expectations. Termination policies toward fossil-driven vehicles are implemented, and adopting renewable energy-driven vehicles in public-influenced agencies and organizations is encouraged to develop markets for the new solution. The state also provides flexibility and space for industry and institutional actors to co-explore and co-experiment on the sustainable mobility solution when the regulations and standards on the solution are not available yet, set up demonstration projects, and provide subsidies to support the utilization of the new solution. In 2009, the State Council of China launched a demonstration and promotion project for thousands of new energy vehicles in ten cities. It started the diffusion of EVs in China in scale.

However, government policies can have an adverse effect on the other parts of the system of transportation electrification. In 2019, China decreased a subsidy on electric vehicles with 20%, and the purpose was to force electric vehicle producers to become more
independent and be prepared for pure market-based competition. However, that decision affected the sales of electric vehicles that year. The political, technological, societal, and economic domains are interrelated and interdependent. If any domain or element within the system of transportation electrification is not handled correctly, it will negatively affect the other domains. Finally, the entire system will not work as expected.

The Norwegian government has taken bold decisions and enabled the entire system of transportation electrification to work according to the desired expectation. Norway does not manufacture electric vehicles, batteries, and equipment for charging infrastructure. Norway imports electric vehicles and charging equipment from other countries and facilitate Norwegian buyers by eliminating import taxes and providing subsidies and rebates to introduce electric vehicles and their associated charging solutions comparatively at a lower price than fossil-based vehicles. The societal acceptance in Norway is leading in the world, with more than 86% of the market share of electric vehicles in 2021. The technological domain of the entire system of transportation electrification is weak in Norway of having no in-house manufacturing. However, the Norwegian government has filled the gap by importing technology from other countries and proved with their policies that the countries could accelerate the transformation of the transportation system from fossil to electric by using its economic means to encourage the society to adopt electric vehicles.

Germany, Sweden, and the UK have adopted almost similar traditional approaches for transforming the transportation system towards electrification. Germany is ahead of Sweden and the UK in electric vehicle manufacturing technology with its top five selling brands, Audi, BMW, Mercedes, Smart, and Volkswagen. In contrast, Sweden is slowly catching up with its in-house manufacturing brands, such as Volvo Cars and Polestar. The UK brand Vauxhall Corsa could secure a place among the top ten selling brands in the UK in 2021. However, these three countries import batteries from China, South Korea, and Japan to manufacture their top-selling brands of electric vehicles. In 2019, the European Commission decided to focus on the entire battery manufacturing value chain from acquiring, processing raw materials, designing battery cells, and recycling used batteries. For this purpose, the European Commission took the initiative called "important project of common European interest" (IPCEI). Under the initiative of IPCEI, these three countries have also started or supported the companies establishing in-house battery manufacturing solutions. Another thing common in these three countries is the higher initial price of the electric vehicles than their counterparts of petrol or diesel vehicles and the lack of charging infrastructure on the highways and within the rural areas. However, the governments of these countries have an opportunity to use their economic means to enhance the charging infrastructure and decrease or balance the initial price of electric vehicles compared to their counterparts of petrol or diesel-powered vehicles. We can see that the technological, political, societal, and economic domains are loosely connected in the entire system of transportation electrification in Germany, Sweden, and the UK. Therefore, the speed of shifting from fossil-based to electric transportation systems is prolonged in these three countries.

India, Australia, and Slovenia are far behind in transportation electrification. One common thing that can be seen in these three countries is the fragmented government
policies and the lack of coherence among the political, technological, societal, and economic domains within the entire system of transportation electrification. The most common mode of transportation in India is two and three-wheelers. “Hero MotoCorp” and “Honda Motorcycle & Scooter India” are the famous Indian brands in India. India imports battery materials from China and assembles them in India. However, India imports batteries from China, Vietnam, and Indonesia to fulfill the demand. Australia and Slovenia do not manufacture electric vehicles but import electric vehicles from other countries. Australia is the second-largest country in the world in the production of lithium. However, Australia does not manufacture batteries on a larger scale but exports lithium to other countries. These three countries lag behind in the charging infrastructure within rural and urban areas and on highways. The price of electric vehicles is higher than their counterparts of petrol and diesel vehicles with less charging infrastructure support. Therefore, India, Australia, and Slovenia are far behind in the development progress of the electrification of the transportation system.
4.6.3 Exploring the dynamics of society in the transportation electrification system

The societal domain is one of the significant domains of the entire electrification of the transportation system. The diffusion of transportation electrification in society fundamentally depends on the four elements mentioned below based on the data of the eight countries discussed in papers 4 and 5.

1) Feasible charging facilities,
2) Environment friendly vehicles,
3) Electric vehicles should have a lower price than fossil-based vehicles and
4) Lower charging and operational cost, as represented in figure 29.

These four elements are embedded in the societal domain; if these elements are supported and coordinated by the technological, political, and economic domains, then the outcome would be in the shape of higher sales and a larger market share of electric vehicles in the country. The higher sales and a larger market share of electric vehicles indicate society’s active engagement in the system of transportation electrification.

Figure 29: Relationship of various domains within the transportation electrification from societal perspective
Source: (Author)
The better-charging infrastructure (multiple charging solutions that better fulfill the system challenges and demands) and better vehicles (provide long-range driving on a single charge) are dependent on the technological solutions and, at the same time, interrelated with the governmental policies for the funds to develop and innovate new technology. The initial cost of an electric vehicle depends on manufacturing cost and battery cost; these costs are deeply rooted in economic solutions. These economic solutions are dependent on governmental policies in terms of imposing and eliminating import duties and adding and reducing taxes for manufacturing electric vehicles. The operational cost primarily depends on charging price, parking, insurance, and annual tax fees; all these costs are firmly linked to governmental policies. Thus, these policies can either be favorable or undesirable for the diffusion of transportation electrification in society.

The data of the eight countries discussed in paper 5 (see appendix: 1) shows the variation in the governments’ actions to transform the transportation system in their countries. The countries took firm measures and introduced favorable policies for the diffusion of transportation electrification; in that case, the positive outcome can be seen in those countries’ electric vehicles’ sales and market share, as represented in figures 30 and 31.

Figure 30: Total sales of battery and plug-in hybrid vehicles in the year of 2019, 2020 and 2021
Source: Based on the data collected in papers 4 and 5 (See appendix: 1)

China has the biggest population globally, with 1.4126 billion in 2021; therefore, the size of the automotive market is bigger too. In 2021, approximately 21.48 million passenger vehicles were sold in China (Statista, 2022a). Meanwhile, the market size of electric vehicles is also expanding in China. The sales of electric vehicles are continuously increasing in China.
compared to every previous year between 2019 – 2021 as shown in figure 30. In 2021, approximately 3 million battery and six hundred thousand plug-in hybrid cars were sold in China. Chinese society is rapidly moving towards BEVs.

Figure 31: Market share of the battery and plug-in hybrid vehicles in the year of 2019, 2020 and 2021
Source: Based on the data collected in papers 4 and 5 (See appendix: 1)

Figure 31 represents that from 2019 to 2021, the market share of electric vehicles in China increased from 3% to 15%, meaning that the market share increased by approximately 12% in merely three years. The success behind China’s leading in electromobility is the Chinese government’s implementation power of favorable electric transport policies and strategic positioning of EVs in upgrading the automotive industry, communication technology, and smart-city development. Regarding EV applicant promotion, the Chinese political actors have adopted a promotion strategy of starting with the public sector vehicle market and then developing to the private passenger car market. In this process, public sector EVs, especially electric buses, have played an important role in facilitating the EV technological progress and industrial value chain maturity of power batteries (Ouyang, 2022). At the same time, the large-scale application of EVs in the public sector has also provided education and consumer awareness preparation for the public to understand and accept EVs. Customers need EV solutions that work all the way for them. Successful diffusion of EVs needs the support of infrastructural facilities and green electricity from the grid. Cross ministries’ working mechanism is carried out to make sure synergy in EV industry policy and regulation making. EV development strategies, policies and action plans are often co-developed and supported by the Ministry of Industry and Information, the Administration of Energy, the Ministry of Transportation, and the Ministry of Housing and Construction. The Chinese government focused on developing charging infrastructure for EVs as early as possible and as much as
possible. By 2022, among the global top 20 cities with the most installed charging piles, 17 are Chinese cities (Jin et al., 2020).

The Chinese central government considers it a vital national policy matter to promote the country’s development and diffusion of electric transportation. The Chinese government provides rebates, subsidies, and tax exemptions and keeps the charging rates low for electric vehicles to promote clean electric transportation in China.

In Norway, the sales of electric vehicles are rapidly increasing over those of fossil-fueled vehicles, with a staggering 54% of new cars sold in 2020 being powered by electricity. At the end of 2021, the sales increased, and the total market share of battery and plug-in hybrid vehicles reached 86.4%, which is the highest market share of any country worldwide. The reason behind it is the Norwegian government policies which are the game-changer positioning Norway as the global leader in EV adoption despite lacking in electromobility technology. The goal of the Norwegian government is to sell 100% electric cars by 2025. The cost of purchasing and operating fully electric vehicles is more reasonable than fossil-fueled or hybrid vehicles. Even though Norway is an oil-producing country, the government has imposed high purchase and CO\textsubscript{2} taxes on fossil-fueled vehicles; in contrast, electric vehicles are exempted from purchase, VAT, and road tolling taxes, and have free parking. The dedication of the Norwegian government in the ways that it has introduced electric transport in society is maintaining Norway’s position as a successful global leader in the world in the transformation of a clean transportation system.

Sweden has maintained its second position in the market share of electric vehicles since 2019 among the five leading countries in the sales and market share of electric vehicles. However, Sweden has crossed Norway since 2020 in the market share of plug-in hybrid vehicles. In 2021, the market share of plug-in hybrid vehicles in Sweden was higher than in Norway, approximately 26% and 22%, respectively. There is a considerable gap between Sweden and Norway in the market share of battery electric vehicles. Sweden stands at 19.1%, and Norway is leading globally with 64.5% in 2021. One reason is that Sweden has double the population size with 10.41 million people than Norway with 5.39 million people in 2021. Norway has the edge over Sweden to gain a higher market share in less time with its less than half population size. To achieve a significant market share, Sweden requires multiple charging solutions (fast charging stations, battery swapping) that encourage vehicle buyers to buy fully battery electric vehicles to cover longer distances without considering finding charging facilities on the highway or thinking of longer charging duration. However, purchasing an electric vehicle and operational costs are still expensive in Sweden despite government rebates and the exemption of taxes.

Germany has changed its market position among the five countries, in electric vehicles' sales and market share during 2020 and 2021, represented in figures 29 and 30. In 2019, Germany had 3% of the total market share, including battery and plug-in hybrid vehicles. Germany stood at the fifth position among the five leading countries in the market share of electric vehicles. In 2020, a rapid increase can be seen in the market share of batteries, and plug-in hybrid vehicles, which reached 13.6% due to the subsidies for purchasing electric vehicles provided by the German government under the scheme of 'environmental bonus.' At
the end of 2020, the German government announced giving grants for leasing and used cars and further offered a 19% tax reduction on the purchase of new electric vehicles. After this, the market share of electric vehicles increased and reached 26%, which doubled the market share size compared to 2020, and Germany changed its position from fifth place to third place in 2020 and 2021 and reached after Norway and Sweden. Thus, the German government policies and actions played a significant role in adopting electric vehicles in Germany. However, Germany is still lagging behind in its charging infrastructure, and variations in the charging prices from place to place create uncertainty for the consumers to buy electric vehicles.

The UK stands continuously at the fourth position since 2019 among the five leading countries in electric vehicles’ market share, shown in figure 30. In 2019, the UK had 3.1% of the market share of electric vehicles, including battery and plug-in hybrid vehicles. In 2020, the sudden increase can be seen in the market share of electric vehicles when the British government announced to ban on the sales of new fossil-based powered vehicles. Additionally, besides purchasing subsidies for EVs, the British government reduced 8% taxes on electric vehicles and provided green number plates to the electric vehicle owners to benefit from local incentives. In 2021, the market share of electric vehicles increased and reached 18.5%. The UK’s adoption rate of electric vehicles is slow compared to Germany, even though the conditions are similar and have no significant difference in the size of the population between these two countries. Even though the British government has included the development of electrification of the transportation system on its national agenda, the UK is still lagging behind in its charging infrastructure. The initial cost of electric vehicles is higher than fossil-based powered vehicles.

We can see that governmental policies and actions can change the game to decarbonize road transportation and gain a higher market share of electric vehicles even if a country lags behind in technology, e.g., Norway. On the other hand, if a country has both, China is an example of its technology and government support. The country can reach a larger market share by selling many electric vehicles worldwide and dominating the electromobility industry. Based on the analysis done above, we can see that Australia, India, and Slovenia are far behind in the technology associated with the electrification of the transportation system and lagging behind in the sales and market share of electric vehicles. One pervasive thing in these countries is the lack of governmental support and actions. It can also be seen by not having supporting charging infrastructure for electric vehicles on a larger scale and enough support from their governments to strategically deviate the purchasing price of electric vehicles in favor of vehicle buyers.
4.6.4 Exploring the dynamics of economic in the transportation electrification system

The economic domain has a symbiotic relationship with the government domain. Both domains are deeply rooted in societal and technological domains in the system of transportation electrification, as represented in figure 32.

The government has to use its economic means to invest in R&D to innovative manufacturing capability of electric vehicles, processes, and the development of the new charging infrastructure that meets the new demand of society. The manufacturing cost of electric vehicles is higher than the cost of petrol or diesel-based vehicles because it directly relates to the cost of the batteries. Some countries import batteries, such as Germany, Sweden, and the UK, from China, South Korea, and Japan, and they have to pay import taxes which increases the cost of the batteries. Therefore, the price of electric vehicles has become higher than fossil-based vehicles. The electric vehicle manufacturers require governmental support, either reducing or eliminating taxes or providing subsidies or rebates to balance the
cost of electric vehicles for the customers. Society also requires government economic support in terms of having supportive charging infrastructure for their electric vehicles and having lower electric vehicle prices than petrol or diesel-based vehicles.

China is the only country globally to obtain all the industrial categories listed in the United Nations Industrial Classification (Yang, 2019). This makes China the world leader on the industrial economy scale and provides the foundation for cost efficiency in the Chinese EV solution. China overtook the United States as the largest single-country new car market since 2011. With Chinese political actors’ strong and continuing policies and strategies pointing out EVs as the transformation direction, creating a market for EVs in the public vehicle application first, then expanding to the passenger vehicle market, facilitating synergized development of EVs, EV charging infrastructures and green electricity access, industry actors developed a total value chain of EV industry in 20 years. On the list of worldwide top 10 best-selling battery EVs in 2022, seven EV models belong to Chinese brands. Among the top 10 EV battery manufacturers in 2022, 6 are Chinese companies, making up 56% of the EV battery market (Venditti, 2022).

Since 2015, the sales volume of new energy vehicles in China has been ranked first worldwide for eight consecutive years (Xinhua, 2022). In 2022, the penetration ratio of new EVs in China has reached 27.6% (Zhongnan, 2023). It is foreseeable that with the scale of the economy, the cost efficiency of EVs in China will improve rapidly.

Figure 33 represents the positive and adverse effects of the governments’ economic policies on the entire system of transportation electrification.

When governments use their economic means, invest in charging infrastructure, and provide subsidies and rebates on electric vehicles, the sales or demand increases. Norway is an example of it.

Investment in infrastructure and providing or reducing subsidies and rebates are the political domain's elements directly related to and dependent on the governments' economic policies. An increase/decrease in sales depends on society's adoption of electric vehicles, which rely on the government policies to react. The technological, political, societal, and economic domains are interconnected and interdependent and should be seen from a holistic perspective. If any domain is not handled correctly, it will have an adverse effect on the entire
system of transportation electrification. Therefore, transforming the transportation system from fossil to electric will not be possible according to the desired expectation.

The elements of the societal domain are intertwined with the elements of the technological and economic domains, and these domains are deeply rooted in the political domain. Thus, success in transforming the transportation system depends on the collaboration and coordination of all four domains, as these domains have a symbiotic relationship that cannot be neglected. Political and societal are the main domains that significantly impact the transformation of the transportation system. Governments can use their economic means to increase/reduce taxes, subsidize industries, and provide rebates to society so that all levels of society can participate in the transformation of the transportation system. Thus, the system approach leads us to understand that higher collaboration among the technological, political, societal, and economic domains can lead us to higher readiness in transforming the transportation system.
The purpose of this research was to explore and understand the ongoing transformation of energy in society from fossil-based to renewable energy and the transformation of the transportation system from fossil fuel-powered vehicles to electrification and identify major obstacles and opportunities in the ongoing transformation. The role of empirical phenomena has been significant in achieving the overall goal of this research. The study started from the technological perspective to explore and understand the transformation of centralized to decentralized electricity generation and distribution systems.

The entire process led to the following main conclusions:

1) Electrification of transportation is a radical industrial and societal transformation.
2) The electrification of transportation is a mission-driven process.
3) Understanding the transformation of the transportation system toward electrification requires a holistic approach.
4) The electricity supply system needs to be decentralized.
5) The electricity needed for electrification requires supply and distribution to be robust.
6) Electrification of transportation needs complementary solutions.
7) The multidimensional readiness index model visualizes the readiness for transformation between countries.
8) Political decisiveness is probably the most critical aspect of achieving transportation electrification transportation.
9) The key to the electrification of transportation is value chain control.
10) From installing to developing.
11) The symbiotic collaboration between the key actors can lead to a higher level of readiness for transportation electrification.

In the following section, I provided detailed explanations for each main conclusion mentioned earlier.
1) Electrification of transportation is a radical industrial and societal transformation

The electrification of the transportation industry represents a significant and disruptive change primarily driven by political motives rather than industrial or business interests. While companies like Toyota initially introduced hybrid vehicle technology with a business-oriented approach, pure electric cars, brought to the West by Tesla, were also driven by business motives. However, the broader societal transformation towards electrification and the shift to green energy production, including the phase-out of nuclear power, is primarily shaped by political motivation. This understanding has significant implications for the roles of key stakeholders involved in this process. Political and institutional actors are fundamental in guiding and leading the transition, rather than relying on industry to achieve political targets based on business logic. The industrial sector, bound by its inherent business logic, is not equipped to undertake a political role in this context. Therefore, the responsibility of achieving the ambitious targets set out in the political sphere cannot be solely entrusted to industry. Ultimately, the successful transformation of the energy and transportation sectors requires active leadership from political and institutional actors.

The electrification of transportation is not merely associated with automotive technology of shifting from combustion engines to electric motors, but it also has a symbiotic and complementary relationship with the energy system. The electricity demand is increasing as the transportation sector transforms from gasoline-based to electric. The findings of articles 1 and 3 (see Appendix – 1) show that the traditional grid does not have the capacity to bear the maximum load if it exceeds its projected demand. Fundamentally, a traditional grid has a one-way communication system. Thus, neither can it be integrated with the electric vehicles to enable them to perform a function like a storage point and return the electricity to the grid whenever needed, nor can the grid receive immediate information if the electricity is terminated at the consumers’ end. The traditional grid depends on the centralized electricity generation system, primarily using coal boilers and fossil fuels emitting greenhouse gases. Thus, the centralized electricity generation and distribution system are incompetent in achieving the rising electricity demand and decarbonizing society from greenhouse gases.

2) The electrification of transportation systems Is a mission-driven process

The ongoing electrification of transportation and the greenification of energy is a mission-driven transformation where the energy industry needs to transform from a centralized to a decentralized electricity generation and distribution system to meet the rising electricity demand and decarbonize society from greenhouse gases. The findings of articles 1 and 3 (see Appendix – 1) show that the smart grid enables the concept of a decentralized system as the innovative technologies embedded in the grid increase the capability of the grid to integrate efficiently with renewable electricity generation technologies (solar PV and wind turbines). The smart grid provides a two-way communication system that enables electric
vehicles to perform an additional function like an energy storage device. When an electric vehicle does not consume electricity, it can be returned to the grid. The grid can receive and balance electricity and transmit it where required. The battery swapping for charging electric vehicles (articles 4 and 5, see Appendix – 1) is a decentralized concept as the battery swapping stations need to be installed close to the end users. The smart grid enables the potential of the battery swapping concept to serve in two ways: 1) to swap charged batteries with uncharged batteries for electric vehicles and 2) to store electricity in the batteries and return the electricity to the grid if it is urgently required to other places.

3) Understanding the transformation of the transportation system toward electrification requires a holistic approach

Transportation transformation from fossil fuel to electric vehicles involved multiple interconnected aspects such as technological innovation, infrastructure development, governmental policies, consumer behavior, and market dynamics. For instance, deploying EVs requires not merely the development of electric vehicle technologies but also the installation of charging infrastructure, the availability of affordable and reliable electricity supply, the implementation of supportive policies, and the acceptance of consumers towards EVs. These interconnected aspects influence each other, making it necessary to consider the whole system when analyzing the transformation of transportation electrification (articles 4 and 5, see Appendix – 1). Thus, the electrification of the transportation system is more than merely a technological change.

Although technological advancements, such as battery technology and charging infrastructure, play a significant role in the electrification of transportation, these advancements alone are insufficient for the transformation. The transformation's social aspect involves changing consumers' behavior and attitudes toward electric vehicles. Understanding consumers' concerns and motivations to promote electric vehicle adoption is essential. Along with it, the economic aspect involves considering the cost of ownership, the availability of incentives, and the profitability of businesses in the electric vehicle market which are difficult to achieve without the involvement of the political aspects (articles 4 and 5, see Appendix – 1). Therefore, the transformation of the transportation system towards electrification is a mission-driven transformation that requires the commitment of political leadership.

4) The electricity supply system needs to be a decentralized

However, moving from a centralized to a decentralized electricity generation and distribution system is not merely a technological change. Articles 1 and 2 (see Appendix – 1) represented the significant challenges for implementing and commercializing the smart grid system. One of the key challenges is finance, as the energy firms do not have sufficient financial resources to invest in installing the new system. Thus, the governments of individual
countries are expected to take the initiative to transform their energy sector. The smart grid is a disruptive innovation that can empower energy users to have more control over electricity usage with its innovative technological features, such as smart meters, proper electric grid management techniques, and time-based rate applications. These options encourage energy users to use electricity during off-peak hours, saving them from additional charges. Thus, energy-providing firms need to change their business models to commercialize the features of the smart grid through which energy firms can create, deliver, and capture values.

Therefore, the transformation to electric transportation is not merely a technological change but also involves changes in the financial aspects of the industry, the way businesses operate, the consumers use and interact with the technology, and the government policies that shape the industry. All of these aspects need to be considered and addressed for transportation electrification to become a reality.

5) The electricity needed for electrification requires supply and distribution to be robust.

The volumes and the balancing. Energy storage and balancing solutions.

The traditional electrical grid operates under the presumption of a balanced supply-demand relationship. However, as the transportation sector moves towards electrification, this balance is being disrupted, with thousands of electric vehicles requiring charging at different times throughout the day, week, and month, imposing an unpredictable disruption to the electricity grid and production side. This variation is challenging for the supply side of the system. Integrating renewable energy sources such as photovoltaics (PV) and wind makes the situation even more complex as these sources depend on the weather conditions to produce electricity that fluctuates their output, adding a layer of unpredictability to the energy system. These intermittent sources create variations that the grid must absorb and manage effectively.

One way to address this is using energy storage and balancing systems like batteries. However, having too many batteries could reduce the environmental benefits of electric vehicles. Thus, implementing energy storage solutions and grid balancing techniques to manage these new challenges and ensure a sustainable transition is essential.

6) Electrification of transportation needs complementary solutions

I see differences in approaches to electrification in my international comparative study.

China started the electrification of transportation more than 20 years ago. They have experienced different stages of evolving technology. Europe is a latecomer, and Europeans seem to see electrification differently. In comparison, the Chinese see it as an ongoing development process with parallel technology routes that compete and complement each
other. Europeans seem to see the process as more fragmented and already start to make decisions with severe impacts in years to come.

The EU stresses that all vehicles in cities and along roads shall be recharged via cable charging regardless of the needs of different markets and customers. Chinese see it as more scenario-based and try to find best practices that complement each other. In papers 4 and 5, an illustration demonstrates that the Chinese consider cable charging, battery swapping, and hydrogen complementary and supportive solutions.

No technology solution fits them all. It is obvious that the variation of needs and the electricity available and distribution of electricity is a bottleneck to electrification. Thus, those three main technologies of today should rather be seen as suitable for different scenarios. Private cars, short-distance trucks, long-haul and bus transport, and construction vehicles all operate under different operational conditions and need different solutions. Based on my research, I am stressing that it is a necessity to have a complementary approach to developing and implementing recharging and refueling technologies.

7) The multidimensional readiness index model visualizes the readiness for transformation between countries

The multidimensional readiness index model was developed to understand the transformation from a holistic perspective that integrates technological, political, societal, and economic dimensions into one model. The model was applied to eight countries for exploring, analyzing, and evaluating the readiness positioning of these countries in transforming the transportation system.

The findings by reviewing the literature guided that the innovative technologies have made it possible to transform the fossil-based centralized to renewable-based decentralized electricity generation and distribution system. However, the key challenges are the implementation and diffusion of new technology, which is deeply rooted and associated with political support, economic means, and societal willingness to adopt new technology and trends. Thus, a multidimensional readiness index model was developed to understand the transformation from a holistic perspective that integrates technological, political, societal, and economic dimensions into one model. The model was applied to eight countries for exploring, analyzing, and evaluating the readiness positioning of these countries in transforming the transportation system. In this kappa, the analysis was taken one step further and applied the system approach for exploring and understanding the dynamics of the key actors and their symbiotic relationship with each other that significantly impact the new ecosystem in transforming the fossil-based transportation system to electric.

Governments and policymakers play a significant role in driving the transformation towards electrification by creating policies, regulations, and incentives promoting electric vehicle adoption. Governments can also invest in charging infrastructure to support the widespread adoption of electric vehicles. By expanding the charging station network, governments can alleviate concerns about range anxiety and make electric vehicles more
practical for everyday use. The analysis shows that China is leading in the electrification of the transportation system globally because of its strong government and institutional execution power that has enabled its industry to advance in technology and become robust, which leads China to have complete control over the entire value chain. China has integrated all levels of society into its policy and developed favorable policies for industry, market, and people that have encouraged the citizens to be highly willing to adopt clean technology.

Norway is leading globally with the highest market share of electric vehicles, even though Norway itself does not manufacture electric vehicles and charging equipment. The secret behind this is the discouraging Norwegian policies on purchasing combustion engine vehicles by imposing a high level of taxes, while favorable policies on purchasing electric vehicles by providing a high level of subsidies and rebates, encouraging Norwegian citizens to adopt new purchasing trends of electric vehicles.

Germany, Sweden, and the UK have adopted traditional policies to transform their transportation system from fossil-based to electric. Germany is leading in the manufacturing industry of electric vehicles in Europe with its five prestigious brands of electric vehicles. However, Germany depends on China and South Korea to import batteries for its electric vehicles. Even though Germany is working to develop its strength to produce batteries for electric vehicles domestically, this process is still in its early phases. The charging stations are not evenly distributed in the states, and charging prices vary even within the states, which develops uncertainty among consumers and holds them back from adopting new technology. Sweden and the UK are primarily buyers of electric vehicles, with a limited industry size of electric vehicles. Even though both countries have announced various policies for the buyers of electric vehicles, there are no clear and revolutionary policies that can be seen from both the governments for industry and society that can push them to adopt electric vehicles.

Australia, India, and Slovenia are far behind and need to revisit their policies toward technology, industry, and society if they want a high level of transformation of the transportation system.

The analysis of different countries demonstrates critical differences seen in the degree of electrification. Thus, the electrification of the transportation system is a mission-driven transformation that requires a holistic approach to understanding all the aspects (technology, politics, society, and economics) of the transformation process. By adopting a holistic approach, businesses, consumers, and policymakers can make informed decisions where governments can play a significant role in creating the policies, regulations, and incentives necessary to accelerate the adoption of electric vehicles, which can ensure a successful transformation toward electrification.

8) Political decisiveness is probably the most critical aspect of achieving transportation electrification

The role of politics is decisive in achieving the electrification of transportation, arguably the most critical aspect of this transformation. Transformation to the electrification
of transportation systems requires a solid political ‘will’ and decisive actions. Policymakers need to recognize the urgency of reducing carbon emissions and tackling the environmental challenges of fossil fuel-based transportation. By demonstrating firm commitment and making bold policy decisions, governments can drive the necessary changes and create an enabling environment for the widespread adoption of electric vehicles.

The success of adopting and manufacturing technology depends on a favorable environment encompassing politics, institutions, and society. In this regard, the electrification of transportation is a key example of how such an environment is crucial for driving transformative change. Transitioning to electric vehicles and sustainable transportation systems requires a convergence of factors, with strong political will and decisive action playing a significant role.

Nevertheless, if the technology does not find a favorable environment, there is a higher risk of slower adoption and manufacturing than initially projected. In such cases, manufacturing may incline toward countries that offer a favorable environment for technology development and production. Therefore, it becomes necessary for governments to create an environment that supports both the adoption and manufacturing of technology. By doing so, they can attract investment, raise industry growth, and ensure technology’s successful integration into society.

However, political decisiveness alone is not sufficient. The success of transportation electrification relies on symbiotic relations and collaboration among key actors, including governments, industry stakeholders, and consumers. Through this collaborative approach, the resources, knowledge, and expertise of these actors can be pooled to overcome challenges and accelerate electrification.

By adopting collaboration, the primary actors in the electrification of transportation can exchange ideas, share best practices, and engage in joint investment, research, and development efforts. This collaborative environment nurtures the conditions necessary for the rapid adoption and diffusion of electric vehicles, ultimately leading to a cleaner and more sustainable transportation system.

9) **The key to the electrification of transportation is value chain control**

To achieve complete control over the entire vertical value chain in the electric vehicle (EV) industry, it is necessary to have influence over various components, including minerals, battery cells, battery hardware, and software systems. This control extends from manufacturing EVs to operating transportation companies and serving final customers. Additionally, the horizontal value chain in the electricity sector needs to be arranged to generate and distribute renewable energy to EV consumers.

Based on my research, the most critical aspect of the electrification process is the political determination to engage in research and development, experimental learning, and establishing industrial support by developing suitable subsidiary systems. These efforts are
essential, particularly in the early stages of diffusion when market actors may not be fully equipped to take over.

Recognizing the potential risks of relying on a single supplier for key minerals, the International Energy Agency (IEA) is developing guidelines to limit import dependence among its members (Chiba, 2023). Currently, China and a few other countries dominate the supply of minerals such as lithium and cobalt for electric vehicle batteries. For example, the EU heavily depends on Chile for 79% of its lithium, Congo for 63% of its cobalt, and China for over 85% of its rare-earth metals. By 2030, the goal is to reduce dependence on any one country to less than 65% of consumption while increasing supplies from within member countries to at least 10%.

To address this issue, the Western World needs to choose whether to develop collaborative strategies with countries that possess significant mining capabilities for crucial minerals and metals or to develop their own mining industry under their own control. The example of batteries is merely one illustration, as similar discussions can arise concerning extensive data management, electric motors, software control systems, and 5G for interconnectivity.

10) From installing to developing

The countries taking a leading position in the electrification process are achieving it by purchasing electric vehicles (EVs) from other countries and relying on them for parts, systems, and manufacturing. I call this approach the “Installation of an EV” method, where one country buys the EVs while others handle the production. To fully understand the impact of EVs, it’s important to take a holistic perspective that considers the entire value chain.

The actual creation of value lies with those who control the EV value chain and engage in manufacturing. This represents the real economy, generating jobs and economic value for the countries involved. While the financial economy plays a role, the real economy drives growth and prosperity.

Technological advancements in the EV sector are happening rapidly, and we are merely witnessing the beginning of a technological revolution in this field. New technologies are constantly emerging, and only those actors and countries with advanced research and development capabilities or who can establish strong collaborative relationships with such entities will likely succeed in this transformation process. Comparisons to past transformative technologies like Kodak, the Internet, and Apple/iPhone are relevant here. Importing technologies for immediate needs is feasible, but for long-term value creation and survival, being a key player with advanced knowledge is essential.
The symbiotic collaboration between the key actors can lead to a higher level of readiness for transportation electrification

The success of transportation electrification heavily relies on the collaborative and coordinated efforts of key actors across various domains. Among these domains, the technological aspect has its own significance as it drives the development of new and advanced technologies such as electric motors, battery storage, and charging infrastructure. However, it is important to recognize that achieving advancements in the technological domain requires a supportive environment from the political domain.

For instance, establishing a robust charging infrastructure is a complex and expensive process requiring considerable investment. This is where the government can play a significant role in overcoming these challenges by facilitating the establishment of charging infrastructure, providing financial incentives, and offering regulatory support to the associated companies. By establishing mutual agreements, the public and private sectors can collaboratively work on developing the necessary charging infrastructure.

The societal domain also plays an important role in the electrification of transportation systems, as public awareness and acceptance of electric vehicles ultimately determine the industry’s success. Factors such as accessibility, affordability, and charging infrastructure availability influence electric vehicle adoption. Governments and associated industries need to invest more in developing and implementing electric vehicles to encourage societal change toward electrification.

It is important to acknowledge that the electric vehicle domain is still evolving, and no dominant solution exists. Therefore, a symbiotic collaborative approach is crucial, emphasizing the need for complementary technological routes to coexist until we understand which solution will prevail, if ever. This necessitates an experimental mindset, where key components are research and development, experimentation, learning, and continuous improvement.

The cost of electric vehicles remains high due to the high cost of battery production and limited economies of scale. Government can use its economic means and provide subsidies that can encourage research and development and incentivize automakers to produce affordable electric vehicles and reduce the initial cost of electric vehicles. Also, governments can introduce new policies that offer tax incentives and rebates to electric vehicle owners and can encourage people to switch from traditional gasoline-powered vehicles to electric ones. Norway is one of the examples of it.

Thus, these technological, political, societal, and economic domains have a symbiotic relationship with each other and cannot be separated for achieving higher readiness levels in the electrification of the transportation system.

These findings enhance our current understanding of the transition to electrification in the transportation system. They offer valuable insights that can be utilized by academics, researchers, industrialists, and policymakers to accelerate the transformation process and encourage further exploration in this field.
6. Implications

This study introduces the major theoretical and practical implications that might significantly affect transforming the energy and transportation system. In this section, those implications are discussed and recommended to the academician, decision-makers, and practitioners to consider when dealing with a complex system integrated with technological and social systems.

First, the significant contribution of this study is the development of the "multidimensional readiness index model" that integrates technological, political, societal, and economic dimensions in one model. The aim of developing the model was to achieve a holistic understanding by exploring, analyzing, and evaluating the selected countries' readiness to observe the transformation of these countries towards electrification based on their conditions and context. The analysis shows that achieving a higher level of readiness demands a higher level of collaboration among the four dimensions. The technological element is merely one of the essential dimensions of the business concept. Technology requires a proper and relevant context to be embedded and integrated for commercialization. Economic, societal, and political acceptance are the main elements needed for a potential technological solution to become a successful innovation accepted by most of the market. The diffusion and deployment of technologies are based on social acceptance; without socially being accepted, technology will face endless public resistance for technologies' sake. It will be difficult to achieve commercial success for technology and attract investment and partners if political, institutional, and regulatory players do not support it. Therefore, the acceptance of developed technologies needs to be observed and examined in the context of a complex web of interactions that includes technical, political, societal, and economic dimensions.

Second, the contribution of this study leads to an understanding that attaining the objectives of a hybrid system (combination of technological and social systems) requires the political domain as part of the system, not as part of the environment. The hybrid system combines technological, political, societal, and economic domains that collaborate to achieve the system's objective. Operating and managing the hybrid system requires resources (finance and new rules and regulations) and management that can allocate the resources and measure the system's performance. Industries cannot take the initiative to allocate a huge number of resources without knowing the outcome of the system, and industries are not allowed to establish policies for the social systems. The role of politics is significant in developing new policies, rules, and regulations and implementing them for society by using their institutional rights. Governments can allocate resources to industries, businesses, and markets that enable them to achieve the expected demand of consumers. Governments can also manage the allocated resources, measuring the system's performance that can support them in observing
the direction towards the desired objective. The analysis shows that in the context of electrification of the transportation system, the countries with higher collaboration among the technological, political, societal, and economic domains achieved a high level of transformation in the transportation system. Thus, the political domain is like an ‘enabler’ empowers the entire hybrid system to function to attain the system’s expected objective.

Third, the traditional centralized electricity generation and distribution system must shift to a digitalized decentralized electricity generation and distribution system. This transformation introduces disruptive technologies, new actors, new stakeholders, and new customer segments that demand new business models. To survive and thrive with the new trends of digitalized decentralized electricity generation and distribution systems, the decision-makers of energy firms have to think about changing their business model. The existing business model does not have the capability to integrate political, institutional, and regulatory actors into the business model. Thus, they need to change or adopt a new business model that can incorporate new actors and stakeholders into the business model, which can support them in collectively working together and meeting the dynamic trends of the electricity market.

Fourth, the emphasis has been and continues to be on various electrification technologies. The analysis of this research guides us that merely focusing on technology development and finding new technological solutions will not lead us toward a higher level of electrification transformation. We live in a time where technology has already been developed, and it’s debatable whether or not we need any further technological advancements. Yes, technology is constantly improving and most likely will continue to do so. This study draws the attention of policymakers toward the most significant factors that have been neglected during the transportation transformation system. The political actors are expected to take the initiative and determine and use their economic means to push the transformation process. Industry cannot take the lead due to risk levels. Political decision-makers do this to open up a market for the sector to enter and make a profit. The typical market forces can only drive it to growth and dissemination after markets and technology are established. Politics open the market and encourage market development through subsidiaries when an industry is at high risk. Only decision-makers may decide to spend on R&D. Politics must gradually modify subsidiary and involvement levels.
In the introduction of my dissertation, two barriers to electrification were identified by the former CEO of Volkswagen, Mr. Dies. The first one was that Volkswagen cannot go all the way to electrification due to the lack of the value chain of the electrical technology route, and the second one was that there was a lack of developed charging infrastructure for vehicles.

In my dissertation, I have contributed to exploring the international condition in electrification and identified three clusters of countries (paper V). The main difference between them is the political aspects. The dominant countries, China and Norway, show solid political support for electrification and readiness to create conditions for a high level of electrification. I have also demonstrated that China took an approach to electrification more than twenty years ago and thus has taken a strong position in the entire value chain, mainly regarding battery technologies and related material and component production.

Suggested new research directions:

1. Exploring the value chain: Several countries in the EU are working on developing the value chain for electric vehicles. Two main directions have been noticed. Batteries are one critical component of electric vehicles which China and other Asian countries such as Japan and South Korea control to a substantial degree. From this follows reflections on how the EU and particularly Sweden can develop battery manufacturing capacity in an independent way regarding minerals and basic materials, battery cell production, and cover the entire
value chain of the life cycle of batteries from materials to recycling, and this way become independent from the global value chains.

Figure 34 shows China has a strong position in several critical minerals such as magnesium, rare-earth metals, graphite, and other non-ferrous minor metals. Thus, the EU and Sweden have to elaborate on the approaches to create the needed value chain for the industry in the EU. One possible direction is to develop the required new value chain through strategic collaboration with those countries that have the position to be suppliers and to build their own mining and processing industry to support their industry to develop and control their value chain. The first one is possible in a short time, while the second one will probably take a much longer time. Until those issues are addressed, the EU automotive industry will not be in control of its value chain.

2. Exploring the system approach: I have noticed a significant difference between the countries that are leading the electrification, and those lagging behind, which is the chosen approach to developing and implementing technologies for electrification. The leading countries have a more developed system approach to developing and implementing technologies. The system approach is very differently managed in China and the Western world.

To accomplish a high level of transportation electrification, I suggest expanding future research into the design and development of system solutions rather than fragmented, isolated solutions that are not complementary to each other.

One such direction is the development of charging infrastructure, where China sees available charging solutions as complementary to each other. At the same time, the EU seems to see single technologies as solutions for all needs, such as cable charging. Another example is that China integrates offshore wind power-based electricity production with desalting seawater and produces hydrogen based on that. Thus, wind power, desalting, and hydrogen production are integrated and show higher efficiency and lower production cost.

I suggest that we explore barriers and solutions to how countries and the EU can develop a more elaborated systems approach to electrification of transport from minerals to final products and also in the combinations of technologies to enable new solutions lowering the barriers for technology entering markets.

3. Exploring the collaborative conditions of the new eco-system for electrification: I have noticed that another important difference between the leading countries in electrification is China and Norway, while the less developed countries are India, Australia, and Slovenia. The most critical difference is the political decisiveness to accomplish electrification. Thus, I propose that we direct research in the area of collaboration between politics, institutions, and industry, where increased collaboration needs intensive cooperation between key actors. Questions arise as the process design of collaboration
between politics, institutions, and industry, integrated policy-making and decision-making that direct industry in the political sphere and the politics to support industry to be capable of achieving the desired targets. These symbiotic relations, and symbiotic development processes, can be established and developed.

I suggest we explore deeper the processes between politics, institutions, decision-making, policymaking, and the industry, and the regulatory barriers that might enable close and symbiotic relations between those key actors of the European automotive industry.

4. Exploring the electricity value chain: We can see several value chains in the electrification of transportation. One is along the battery, and another one is related to electricity. Both are critical. Electrification of transport is very much meaningless if the energy grid and electricity supply system cannot match the consumption side both regarding volumes and quality of electricity provided. The grid system is one of the critical systems. Electrification of transportation is placing higher demands on electricity production, and the grid is a bottleneck.

As I demonstrate in my papers 1 and 2, the grid systems are designed during the old technology paradigm and thus are centralized controlled systems. To enable a high level of electrification, the grid system needs to be developed in a more decentralized solution that enables efficient localized electricity production and consumption. To accomplish this, we need to understand how smart grid systems can support the decentralization of the grid system.

How can we design a “system of systems” from energy production, electricity distribution, and consumption that is decentralized and adaptable to local production and needs that vary during the day, week, and months to enable balanced electricity production in a stable and balanced way, and how can the smart and intelligent grid system solutions support this process of development of decentralized systems?

5. Exploring the complementary solutions: As I have shown in my papers 4 and 5 the charging technology for developing the infrastructure for battery-based solutions can be cable charging, battery swapping, and industrial charging. In the future other solutions will be introduced. Hydrogen-based energy is one new technology that is underway needed new refueling infrastructure. All those recharging and refueling solutions must be seen from a system perspective in terms of how they can complement each other based on the specific needs of different markets and scenarios of users.

How can we develop processes, decision-making systems, and technical solutions that can integrate complementary systems of cable charging, battery swapping, inductive charging, and hydrogen refueling systems? How can we create a supportive charging system solution that can support electrical vehicles based on both battery- and hydrogen-based energy storage that are underway?
6. Exploring the European Electrification from a System perspective: The concept of four dimensions (technological, political, societal, and economic) I have developed in papers 4 and 5 shows that there are different patterns in the electrification of transportation in different countries. The development in Europe is dependent on the implementation of electrification in all European countries. Some small countries, such as Norway, Sweden and Netherlands, have taken the lead. But many countries in southern and eastern Europe have a slower pace of adopting renewable energy and electrification solutions. Europe needs to take a balanced approach to support climate changes and challenges. To support this, the framework of the four dimensions can be taken as starting point to develop a simulation-based model using system dynamics modeling tools on the European level.

The system dynamic model can support the understanding, evaluations, and predictions of the individual countries’ progress in transforming the transportation system based on the respective countries’ existing political and economic policies for the next five or ten years. Such research could contribute to and support the policymakers in understanding the path they should select for the successful integration of social aspects, including manufacturing industries and market that leads to a higher adoption rate of electric vehicles in their respective countries.

The transportation industry is a global industry. Many trucks operate across European countries besides the local and regional governments. The transportation system in Europe must be seen as one system. Thus, European countries need to collaborate and develop shared systems, standards, and regulations within electrification that are unified and supportive.
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Appendix – I

Journal and Conference Papers

Harrison John Bhatti
Paper – I
Making the World More Sustainable: Enabling Localized Energy Generation and Distribution on Decentralized Smart Grid Systems

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Abstract

Smart grid is an idea of upgradation of the traditional electric grid infrastructure. The efficiency of the existing electrical grid can be automated by integrating with innovative technical equipment such as: high-tech forecasting system, digital sensors, advanced two-way communication and two-way power flow systems. Smart grid establishes an interface between utility and consumer which helps to use energy, based on the preferences of price, eco-friendly and without technical system issues. It empowers the grid to be more secure, reliable and efficient. The peer-reviewed articles and published government reports have been reviewed, based on the analysis of technical characteristics of power generation systems, eco-friendly sources of power generations, cost reduction, functionality and design of traditional grid versus smart grid. Furthermore, the innovative technologies that enable the grid to integrate with decentralized power generation system efficiently have been considered. This paper claims that in this modern era, it is arduous for traditional grid to fulfill the rising demand of electricity, along with sustainable, eco-friendly and stable power supply, as it cannot be efficiently integrated with decentralized and localized power generation systems and renewable energy sources. The result of this paper shows that decentralized and localized power generation systems are located close to end-users which decrease the transmission and supply cost of electricity. Innovative technologies allow the decentralized and localized power generation systems to be integrated with renewable energy sources which help to reduce the cost of utility services and provide clean energy. Moreover, technological advancement played a decisive role in enabling the electrical system to be more efficient. Electrical reliability can be improved, greenhouse gas emissions can be reduced, renewable energy sources can efficiently be integrated, and rising demand for electricity can be
met by embedding advanced applications and technological equipment in the electrical grid.

**Keywords**

Smart Grid, Traditional Grid, Centralized Power Generation, Decentralized Power Generation, Innovative Technologies

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**1. Introduction**

Nowadays, the world is facing critical challenges, such as: uninterrupted power supply, saving organic fuels, growing population, rising unemployment level and the improvement of living standards. Further challenges are the contribution of sustainable development in distant areas specifically in mountainous territories and deserts. One of the reasons is the depletion of fossil fuels which is a threatening call for the energy sector and drives them to explore alternative ways for energy sources. The energy sector is highly dependable on oil which is unsustainable and very limited in the world. The main reason of greenhouse gases is the burning of fossil fuels which is directly impacting on the climate change of the world [1]. The solution of all challenges is connected with the development of renewable energy system [2]. Furthermore, according to Bergmann et al. [3], numerous jobs could be created in village regions by developing and using the system of renewable energy.

One of the central factors of economic development in all countries is electricity. Always on demand for electric power generation is challenging both developing and developed countries. Continuous producing electricity gives immense pressure to the infrastructure of electrical energy. In developing countries, almost half of the population live in rural areas. For these regions, electricity delivery is very costly which local people cannot pay, and it causes social inequality and low living standard [4]. Bhattacharyya [5] gave an example of India, where more than 70% of the population live in village areas. Furthermore, in India over 40% of the total population do not have electricity. According to Kaundinya et al. [4], the triple growth of electricity delivery and the fivefold growth of electricity generation are required for satisfying electricity demand growth. Almost 3% of global GDP should be invested per year for facing the electricity demand and generation challenge. Due to new employment, migration from rural areas to cities will decrease and reach a minimum level. Hiremath et al. [6] and Ravindranath et al. [7] stated that in village regions, one of the best, reliable and environmentally secure ways for satisfying electricity demand and making electricity less costly, is the implementation of renewable energy with decentralized generation. It is difficult for the centralized power generation system to fulfill the growing demand for electricity without burning fossil fuels and emitting greenhouse gases. The evolutionary concept of smart grid technologies is driven by these complex challenges [8]. According to Li et al. [9], the term “smart grid” is
primarily considered as an electric grid which is capable of delivering electricity from points of generation to consumers in a smart and controlled way. Consumers can modify their purchasing patterns of electricity according to the need and demand based on the received information from smart grid. Xiang et al. [10] and [8] explain that compare to a traditional grid system; a smart grid is the combination of digitalized innovative communication devices, circuit breakers, and transformers which enhance safety, efficiency and operational performance of the grid. It is recommended to have a robust and highly reliable network connection which can support the interaction between application software and electrical services. Furthermore, Mohani et al. [11] describe that specialized processors, automated metering systems, sensors, communication systems and intelligent devices are required for the complete integration of smart grid. These energy management technologies help to save energy as well as exploiting the sources of renewable energy.

Hiremath et al. [12] stated that reliance on centralized power generation system causes high costs for electricity delivery and inflexibility. This system is using mainly fossil fuels for functioning, and huge capital is required for installing transmission and distribution grids in distant regions. Outflows of obnoxious gases create burning of fossil fuels, which are dangerous for local climate and health problems. Solving these challenges an alternative power generation and distribution systems are required. With comparison to centralized systems of energy, decentralized energy systems are using sustainable sources of energy, in conditions of grid presence or absence the systems run on lower scales, such as kilowatt scale.

Moreover, decentralized system of energy generations gives access to remote locations because power generation is matching with demand. Thus, implementing decentralized systems of energy could solve the problem with electricity delivery in village areas. The solution is fruitful because decentralized systems provide reliable and renewable energy delivery. According to Kaundinya et al. [4] in 2004 total share of a decentralized system of electricity generation reached to 7.2% by growing 0.2% from 2002. Decentralized generation gives more potential for electricity generation. From the point of electric power generation, decentralized energy had rapid growth in the world by reaching 25% in 2005 from 13% in 2001. Furthermore, the ratio of decentralized power generation system increased 11% within a year and reached up to 36% in 2006 [13]. Kim et al. [14] state that there is positive prognosis about the future growth of decentralized systems due to benefits, which it gives. According to calculations, global cost reduction from electricity generation could reach $2.7 trillion by 2030 if decentralized systems are embraced [15].

According to the today’s demand for electricity, the traditional grid is getting obsolete and is required to be re-engineered, redesigned and equipped with innovative and modern technologies. Smart technologies which can be embedded in the electrical network made the transformation process possible for electric grid into a smart grid. Reliability and energy security are the significant eco-
nomic challenges of the 21st century for the grid to integrate with renewable energy sources. The basic concept of smart grid is, the innovative technology can be integrated at all phases of grid actions and management. Implementation of digitalized and intelligent functions into the grid will increase the general efficiency of energy. Furthermore, this transformation of the grid would establish better interaction between consumer and grid [16]. Therefore, it is significant to explore the sustainable energy management system which can efficiently be integrated with renewable energy sources and decentralized power generation systems that support to reduce the usage of fossil fuels along with achieving the rising demand of electricity.

This paper is categorized into five main segments: such as renewable and non-renewable energy sources, power generation systems, traditional grid, technological development and smart grid.

Purpose of the Study
The purpose of this paper is to explore the state of the art of grid systems focusing on the evolution of innovative technologies which transform traditional grid into smart grid and enhances its performance. Moreover, the comparison between energy sources, power generation systems, traditional grid and smart grid systems have been executed based on their availability, efficiency, cost and operational performance to explore the proper distribution system of energy which can fulfill the rising demand of electricity and can provide clean energy in low price.

2. Research Methodology
In order to explore the transformation process of energy distribution system, a review on the "electricity" and "smart grid" literature was conducted. Data had been obtained from various databases, such as; IEEE, ACM digital library, Scopus, Web of Science, Science Direct and published government reports. The use of these databases allowed to achieve the comprehensive list of peer-reviewed articles and reports on smart grid and power generation sources. Three major steps had been taken to conduct the research: 1) identification and skimming 2) filtering and screening and 3) analysis of filtered data.

The first step is associated with identifying scientific articles and reports based on the topics of smart grid, renewable energy sources, centralized and decentralized systems of power generations. The search started with the set of different keywords, such as: "traditional grid," "smart grid," "renewable energy" and "centralized and decentralized systems of power generation." These keywords were used with various combinations by joining with "AND" parameter in the title bar of each database webpage. The "AND" parameter assisted in shortening down the search and bringing up the closest article related to the given topic. The articles and reports were selected by skimming the abstract and seeing the keywords mentioned in the articles. Further filtration criteria were the focus on
technical articles while business articles on smart grid were excluded. 

The second step related to further narrow down the articles and reports by screening each of them based on the technical characteristics, innovative technologies, advantages and disadvantages of smart grid. Further screening was applied to the following group of articles: 1) renewable and non-renewable energy sources and 2) articles that discussed centralized and decentralized systems of power generation. After screening and reading all those articles in detail, a valuable data had been found that leads towards analysis which can respond to the purpose of this study.

The final and third step was an "analysis" which was completed after filtering the data. The analysis is based on the following criteria: 1) performance, technical, and functional capabilities of traditional and smart grid and 2) Integration of renewable energy sources with the grid. The comparison had been performed between old and new energy systems to explore the modernized energy management system which can be adopted in the future. The criteria of this comparison were: 1) comparison between non-renewable and renewable energy sources based on the cost differentiation and eco-friendly and 2) comparison between centralized and decentralized of power generation systems based on cost differentiation and their functional capabilities. The analysis is a crucial component of this research which help to explore the transformation process of energy management system that can be exploited by the governments or energy providing companies. It enables them to fulfill the rising demand for electricity at comparatively less price without harming the environment.

3. Comparison between Non-Renewable and Renewable Energy Sources

Presently, renewable energy is a favorite subject of research. Population and energy demand are growing simultaneously. Non-renewable sources of energy are restricted, and fluctuations in non-renewable energy production have huge. Therefore inflation is high. Renewable sources of energy are plentiful, ecological and sustainable. In comparison with fossil fuels, renewable sources are self-restored. Renewable energy sources have their disadvantages identical to fossil fuels. The weather has a tremendous impact on renewable energy. The energy generated from this source could be decreased as a result of weather changes. Thus, people cannot shift entirely into renewable sources yet. Nevertheless, they can satisfy main part of energy demand by using renewable sources, which are advantageous for environment and economy [17]. Table 1 shows the differences between non-renewable and renewable energy sources.

According to Carolyn J. Randall [18], the climate of the Earth is changing; global temperature is going up because fossil fuels are burnt to produce electricity. The changes in climate and temperature are leading to the growth of sea level and melting of polar sea ice. Thus, renewable energy sources are a coming wave. Nowadays numerous countries are presenting special programs for
development of renewable energy and for lessening emissions of carbon-dioxide. Research and development of renewable energy aim to increase efficiency and decrease electricity costs. In future, new technologies can transform to manage the power generation sources to meet the growing demand for electric energy. Finding resources of energy and plans for the development of sustainable energy needed to be maintained by the local community.

### 3.1. Demand for Renewable Energy

Tanaka [19] stated that the demand for electricity is rapidly increasing in the world. From 2007 to 2050 the projected consumption of power is estimated to increase by 115%.

The demand growth of electricity varies between regions to regions. As Figure 1 shows that the demand growth of electricity in “organization for economic cooperation and development” (OECD) countries, is much more modest than the developing countries. OECD countries have higher demand, which causes higher growth rates. Due to declining the losses of transmission and distribution, as well as the development of infrastructure, smart grid technologies give advantages to OECD countries. Smart grid systems could be part of the new infrastructure in developing and fast-growing regions by providing efficient operations and better capabilities for market-function. Smart grid makes the delivery system more efficient in all areas. Smart grid has its role in demand reduction as well by providing consumers with data they can use to consume electric power more efficiently [20].

On the other hand, the demand for renewable energy is also increasing to fulfill the shortage of electricity. According to Kiefer [21], electricity delivery, utility market, and the traditional business models are being affected by the customer preferences. For instance, the amount of electricity has been reduced required from power companies by increasing the use of energy-efficient appliances, the massive growth of installing rooftop photovoltaic arrays. Banerjee et al. [22] use

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**Table 1.** Comparison between non-renewable and renewable energy sources.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Non-renewable energy resources</th>
<th>Renewable energy resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetitively used energy sources</td>
<td>One-time use</td>
<td>Can use again and again</td>
</tr>
<tr>
<td>Perpetual sources</td>
<td>Vanish one day</td>
<td>Available for perpetual use</td>
</tr>
<tr>
<td>Eco-friendly sources</td>
<td>Emits gases and pollute the environment</td>
<td>Do not emit gases and does not pollute the environment</td>
</tr>
<tr>
<td>Availability</td>
<td>Limited quantity</td>
<td>Unlimited quantity</td>
</tr>
<tr>
<td>Production cost</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Production quantity</td>
<td>Large</td>
<td>Less</td>
</tr>
<tr>
<td>Area required</td>
<td>Require less space to install energy plant</td>
<td>Require large space to install energy plant</td>
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</tbody>
</table>
a word “prosumers” who both utilize and produce electricity. Furthermore, Banerjee et al. [22] claim that consumers are progressively becoming “prosumers.” For instance, solar photovoltaic panels have been installed in the number of homes in the United States. It has been recorded that the solar photovoltaic installation has surprisingly increased from 15,500 in 2004 to more than 600,000 before the finish of 2014. It has been estimated that the solar photovoltaic system produced 1460 megawatts electricity for the residential use and more than 80% of that has been increased in the last four years.

As stated in Association [23] report, the rapid change and growth have been noticed of electro-mechanical to electronic-based devices, such as; offices, factories and home appliances which has directly been affecting on the requirement of energy and the grid operations. In this current era, 92% of transport is fueled by petroleum. However, the immediate rise of electricity demand has been predicted in the transportation sector, as the concept of plug-in electric vehicles is rapidly increasing. The 18.6% annual growth rate of the electric vehicle is being predicted from 2013 to 2022 if this prediction of electric vehicle sale continues then the demand for electricity will remarkably be increased. Concurrently, Banerjee et al. [22] suggest that the rise of electricity demand can be mitigated by installing smart meters, utilizing proper electric grid management techniques and time-based rates application. It encourages consumers to use electricity during off-peak hours which will save them from additional charges.

3.2. Challenges
The mindset of most of the stakeholders has been changed due to inefficient grid
infrastructure, rising fuel cost, climate change, and the latest technologies used for power generation. Feisst et al. [24] raised some questions which have become challenges for the power suppliers:

- The most prominent issue for the electric supplier is to reconsider about the future electrical system, as the centralized electric generation system becomes the primary cause of emitting around 25 percent of global greenhouse gases.
- Another important thing is to consider, the role of distributed electric generation and the integration of renewable energy with the electric grid will remarkably be prominent in the reduction of greenhouse gas emissions.
- Next challenge rises at the demand-side management to reduce power consumption and enhance power proficiency.
- Constant monitoring of grid performance can improve blackouts, utilization, and grid reliability. Furthermore, constant monitoring would be a challenge, but it will rapidly return the financial investments on the grid.
- The remarkable rise of electricity demand, the emitter of greenhouse gases and dependence on fossil fuel which are against eco-friendly have become noticeable challenges. Renewable energy sources have been addressed to generate electricity as the usage of fossil fuels pollutes the environment [25].
- Traditional grid does not have an appropriate capacity to fulfill the increasing demand for electricity. Massive modification and improvements are required to integrate renewable energy sources with traditional grid to generate electricity [26].

3.3. Opportunities for Improvement

Technology plays a decisive role in enabling the electrical system to be more efficient. Electrical reliability can be improved; greenhouse gas emissions can be reduced by just implementing advanced applications and technology [24]. Some of the opportunities where improvements can be made in the electrical system are mentioned below:

- Advanced technology and application software can help reducing power usage during peak hours by robotically turning off specific home appliances, office equipment, and factories machinery.
- Instant feedback can help reducing wastage of energy consumed by the consumers.
- Usage of energy can be reduced by producing smart appliances by the manufacturers.
- Power blackouts can be controlled by installing sensing equipment and detaching turbulences in the grid.

It is not hidden that non-renewable energy sources are restricted and fluctuation is huge during energy production whereas renewable energy sources are unlimited, ecological and sustainable. Furthermore, the remarkable rise of electricity demand, the emitter of greenhouse gases and dependence on fossil fuels have become noticeable challenges. Meanwhile these challenges have created tremendous opportunities for the improvement of power generation and distribution systems which can be restructured, modified and equipped with innovative technologies that can satisfy the rising demand of electricity and mitigate greenhouse gas emissions in better and efficient way.
4. Power Generation Systems

Decentralized decision making enters the higher level of the power system, which is caused by continuous reformation of the electricity industry. The planning of long-term growth is influenced by the trend of improvement because now private investors with smaller centralized direction are making significant decisions [27]. The power plants have been centralized and using heavy and costly components to produce electricity. According to Alanne et al. [28], the generation of distributed energy leads to this new tendency, which means that heavy power generation components are switched into smaller components, and energy generation elements are near to end-users of the energy. The term distributed generation of energy includes self-operating buildings as well, which could provide themselves with electricity, cooling and heat energy. Alanne et al. [29] state that the alternative of the original system of electricity is the system of distributed electric power, which is more reliable, efficient and sustainable. For instance, hospitals have implemented this concept since continuous electricity distribution is crucial for them. Another example of generation of distributed energy is automobiles [30].

4.1. Centralized Power Generation System

The electricity was produced by big power generators in the 1900’s, which were located in central areas. In this period, electricity reached to end-users through networks of transmission and supply. Alanne and Saari [28] bring an example of a classic centralized system (Figure 2) of electric energy, which includes a large number of end-users located in big distribution zone.

Figure 2 represents the complete scenario of centralized power generation system. Energy is produced at the central point and then it is transmitted through the high voltage electric wires to the grid and from there electricity is distributed to its consumers. The transportation of electricity is costly and are more chances of interruption during power supply.

The generation of electricity through central power generators is called centralized generation (CG). These generators provide the power of bulk. To get steam necessary for operating generators of the turbine, most of the power generators use coal boilers or fossil-fired gas, or nuclear boilers. Sometimes large hydro is used as well. Costly execution of large infrastructures is needed for these massive power plants. Unpredicted events and uncertainty are the serious issues for CG power plants. Thus, CG power plants are unprotected from errors and attacks.

Momoh et al. [31] state that CG power plants’ efficacy, security, and benefits are not sufficient for this modern era, which intensifies the efforts of authorities and researchers to look for sources of renewable energy.

4.2. Decentralized Power Generation System

The generation of electricity, which is located close to end-users, is called decentralized generation (DG). Sources of DG contains technologies, which are
small-scale and ecological, for instance, photovoltaic and wind technologies. These technologies are originally installed and made for serving in a specific location of the individual consumer [31]. Alanne and Saari [28] argue that even though energy transmission and supply are based on the location of electricity generators, naturally the consumption of energy is decentralized or distributed. The concept of “decentralized” or “distributed” is connected with the way separated units are combined and form the entire system, as shown in Figure 3.

Figure 3 shows that even in the small area electricity can be produced and utilized in each separate unit. These units are combined through one central control system where information can be exchanged and energy can be stored and distributed according to the demand of the consumers.

Decentralized power generation systems contain reciprocating engines working on traditional fossil fuels or gas turbines to enhance the quality and reliability of the electric grid [31]. The connection between electrical grid and DG is creating reliability and security issues for utility. DG could decrease the demand for traditional utility services. For incumbent utilities and end-users DG creates economic risk as well. This risk could be managed only with procedures for cost recovery or with proper rate structures. Occasionally, DG which is arranged and designed efficiently gives numerous advantages to society and end-users. For example, cost savings due to subsidies from government and a cleaner environment. DG is installed in multiple utility systems, and it has its significant role in the development of new technologies [31].

4.3. Localized Power Generation System

The localized units do not have a connection with other units. Thus, they are stand-alone and independent [32]. It is significant to realize that all localized generation (LG) systems are decentralized or distributed, whereas not always decentralized or distributed systems are localized as it is mentioned in Figure 7.
that decentralized systems are the combination of small units. Therefore, in energy systems context, using the word “decentralized or distributed” is more rational. Figure 4 clarifies the localized energy system example.

Figure 4 shows an example of the localized power system. As represents in Figure 4, it is possible that the whole chain of electric power could be combined in one place. For example, it could be a building, which is in countryside regions and the building is not connected with the network of public energy. The building contains solar electricity system, electricity distribution including storage of electricity and heating system which is a good picture of a localized generation of power [33].

4.4. Comparison between Centralized, Decentralized and Localized Power Generation Systems

In order to design a series of activities for future grid, the comparison has been done based on the criteria which is mentioned in Table 2.

It gives an opportunity for designing a workable grid, which will satisfy increasing global electricity demand. Moreover, essential requirements, development of abilities and arrangements of institutions are combined into special road map. The road map has an objective to increase the engagement of population in new smart grid [31].

As per Table 2, the measurement standard for CG/DG and LG comparison contains combined infrastructure resiliency assessment, the effect on sustainability through CG/DG and LG because it is concerned with energy decreasing, environmental effect reduction and emission declining. The criteria include the finding of efficient CG/DG and LG combination as well, which will satisfy the needs of future grid. The installation of DG is affected by obstacles, such as: problems with quality of power, generation of power and high cost, because subsidy from government or local sources may be not sustainable.
Figure 4. An illustration of a localized power system [28].

Table 2. Comparison between centralized and decentralized power systems [31].

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Centralized Generation</th>
<th>Decentralized Generation</th>
<th>Localized Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uninterrupted Power Supply</td>
<td>Although CG system provides uninterrupted power supply, but the attributes of CG are showing the following results: • Because of high losses at the system of transmission, electric effectiveness is low. • Emissions are high.</td>
<td>DG allows buildings to generate their own permanent electricity. Essential DG features for uninterrupted power generation gives following results: • Electric effectiveness is high. • Emissions are low.</td>
<td>LG permits pump stations/hospitals or any isolated building to generate their own electricity. • High efficiency. • Low emission required.</td>
</tr>
<tr>
<td>Premium Power</td>
<td>Reliability of power supply is low. There is no assurance of high quality power because power losses are high.</td>
<td>Electricity generation and delivery are more reliable and have higher quality than usual electricity which provided by grid.</td>
<td>Supply of power is reliable as power generation is very close to end user. No chances of losses.</td>
</tr>
<tr>
<td>Cost</td>
<td>• Changing cost is high. • Maintaining is very costly.</td>
<td>• Changing costs are low. • Maintaining is not costly.</td>
<td>Low charging and maintenance cost.</td>
</tr>
<tr>
<td>Peaking Power</td>
<td>Has unstable functioning at different peak levels of power.</td>
<td>Functioning from 50 to 3000 hours every year for decreasing costs of electricity.</td>
<td>Same as decentralized generation.</td>
</tr>
<tr>
<td>Resiliency</td>
<td>Have less resiliency but meets high demand of power.</td>
<td>Are more resilient due to satisfying low demand of power.</td>
<td>Same as DG.</td>
</tr>
<tr>
<td>Sustainability</td>
<td>Less sustainable due to power sources.</td>
<td>Are sustainable due to renewable sources of Sustainable as solar panels depend on sunlight.</td>
<td></td>
</tr>
</tbody>
</table>

4.5. Cost Differences for Centralized, Decentralized and Localized Power Generation Systems

Comparison of costs based on typical design, required for CG/DG and LG is now becoming very important since DG/LG engage new technologies. Expansion of DG role in the future grid could be built on whether DG/LG costs are lower than CG because DG/LG is permanent energy providing source. DG/LG power would be closer to the retail price of produced electricity, and it would be more efficient for satisfying the demand of small power markets due to the same location of electricity generation and usage. DG and LG replace the power pro-
vided by the utility which is less probable for DG and LG to affect users of land negatively [34].

Table 3 represents the cost in cases of using centralized, decentralized and localized power generation systems. The power supply area is the same in these cases. DG/LG systems are based on technology which has the lowest cost if heat loads and permanent electricity are accessible. Through limiting technologies which are accessible to the model, efficient solutions for DG/LG using system can be compared with a system using electricity-only and heat-only technologies [31]. The question is, will DG/LG systems provide cost savings?

The installation and maintenance are very costly for CG systems. The usage of CG is based on central location. From installation and maintenance perspective, CG is less costly than DG but LG is much more lesser than CG. In the same area, power distribution through CG is cheaper than DG whereas LG is within an isolated or standalone building so no distribution system required. However, DG/LG have less power losses than CG [35]. Moreover, CG and DG/LG combination would have more cost savings. Areas with huge population should be a priority for using both CG, DG and LG. In the regions with huge population, CG could be used for reducing power losses by locating it very close to the areas or DG/LG could be used for lessening the losses. Therefore, capital costs could be decreased due to less installation capacity of CG or DG/LG systems.

Table 3. Cost differences between CG and DG systems [31].

<table>
<thead>
<tr>
<th>Component Cost</th>
<th>Centralized Generation</th>
<th>Decentralized Generation</th>
<th>Localized Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>Per unit low cost</td>
<td>• Cost is high for every unit.</td>
<td>• Per unit cost is high.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cost saving through system design and capacity reduction.</td>
<td>• Life time cost savings from utility bills.</td>
</tr>
<tr>
<td>Maintenance and Operational cost (Fixed)</td>
<td>Higher</td>
<td>Lower</td>
<td>Lower</td>
</tr>
<tr>
<td>Maintenance and Operational cost (Variable)</td>
<td>Lower</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Fuel</td>
<td>Highly required</td>
<td>Not required</td>
<td>Not required</td>
</tr>
<tr>
<td>Transmission</td>
<td>• Mandatory high voltage transmission</td>
<td>• Only distribution is needed</td>
<td>• Production is close to end-users.</td>
</tr>
<tr>
<td></td>
<td>• Failure of transmission and high losses</td>
<td>• Decreased cost of capital</td>
<td>• Cost saving on distribution.</td>
</tr>
<tr>
<td>Unnecessary Expenses based on unserved energy</td>
<td>High</td>
<td>Low</td>
<td>Very low</td>
</tr>
</tbody>
</table>
4.6. Analysis and Reflection

Centralized, decentralized and localized grid systems have advantages as well as disadvantages. Thus, the purpose is to discuss the advantages and disadvantages as well as to identify problems, which grids could create. This debate leads to explore the proper solution in upgrading existing mechanism of grid which makes the grid more secure and efficient.

In general, some decentralized and localized systems of generation are distributed geographically. Thus, it is possible to place them very close to areas where end-users are living which decreases the cost of supply and transmission of electricity. Strong terms build on multiple separate generators and their reliability, in comparison with CG, shrink the transmission and supply costs [36]. In the system of CG, power transmission goes through a long way to reach end-users. At the final stage of generation, various sources should produce electric power. For example, thermal power, nuclear power, hydropower. The need for transforming CG into DG is high especially in areas, where CG system is very far from consumers. This approach decreases power transmission losses [31].

An alternative method exists for saving costs. It is localized DG. Part of electric energy, which used to be lost during energy transmission in CG, is now saved because of generating the energy close to the place where it will be used. The quantity and size of needed power lines are decreased as well due to this approach. The preservation of distributed energy sources in a Feed-in Tariff (FIT) scheme is low.

They have low contamination, and they are efficient. Nevertheless, the quality of electric power and security become critical issues in this case, because of most of FIT’s need using renewable resources, which are discontinuous. For less pollution, DG and LG require complicated plants and professional engineers. Due to sustainable resources (sunlight, geothermal, wind energy) and automatic functioning, contemporary embedded systems can face these challenges. This approach decreases the number of power plants, which could give profit [37].

The rapidly growing demand for electricity requires reliable power grid. The grid is using various modern power generation mechanisms to make the electrical system influential, sustainable, protected and flexible where technology needs more Distributed Generators. The same could be said regarding the CG. Nonetheless, the installation of CG becomes more difficult and costly because of higher installation, permission and location barriers. Therefore, with growing electricity demand, the implementation of DG and LG is inexpensive than installing CG. Moreover, during new power generation place construction, using CG is very expensive and economically ineffective (costs for power transmission). DG and LG, which is not intermittent, does not require a system of transmission. Thus, it completely removes costs for transmission. Therefore, for new power plants construction, it is evident that DG and LG show more efficacy and cost savings compared with CG [38].
The centralized power generation system uses coal boilers and fossil fuels which emits gasses. Cost of transmission and execution of heavy power generation plants is high, completely insecure and not able to be efficiently integrated with renewable energy sources. On the other hand, decentralized and localized power generation systems are located close to the end-users which decrease the transmission and supply cost, it can easily be integrated with innovative technologies and renewable energy sources, reduces the cost of utility services and providing clean energy.

5. Early Electric Grid

Thomas Edison’s Manhattan Pearl Street Station was the earliest electric complex in the world. It started to run in 1882. Originally, Edison’s electrical complex was a microgrid, which contained 100 V coal-fed electric engine. It was providing electricity to few hundred lamps. Thus, electric grid was compact and limited in the early stages [39]. Power plants were located near to their power sources in the first instance of electric complexes. Figure 5 is a reflection of an early electric grid.

They were within close range of their ultimate users as well. Nevertheless, throughout time, the demand for electricity has been grown up. Thus, these small grids were evolved into larger and more compound systems. Appropriately, electric grids were transformed into interdependent systems. Now we are using these systems, and they are connecting the stations of power generation, load centers, supplying channels and lines of transmission [40].

6. Traditional Grid

The word ‘grid’ is usually used for an electrical system. Traditional grid supports typically four operations, such as electricity generation, transmission, distribution, and control. The primary function of traditional grid is to carry electricity from the point of generations and distribute it to many of its consumers by using transmission lines [41]. Banerjee et al. [22] explain that the architecture of traditional grid was constructed on the extensive amount of electricity generation, passive loads, centralized and one-way control.

Most of the electricity grid or power supply system in the world was built when the cost of electricity was reasonably low. The grid has still been functioning as it had been functioning almost hundred years ago, to fulfill the rising demand for electricity, minor upgradation has been done. Energy is generated at the central electricity plants then it flows over the grid to consumers, and there is no proper storage surplus capacity [26]. Hossain et al. [42] add that more likely traditional grid would not have the sufficient capacity to fulfill the future demand for electricity. Furthermore, the existing grid system emits greenhouse gases, consumes lots of fossil fuels which is completely a useless and environmentally extravagant system. Thus, it is not suited to distributed, wind energy and renewable solar sources.

6.1. Traditional Grid Design

According to Banerjee et al. [22], a decade ago, organizational principles and system design models were used to design and build traditional grid system. It
should have been restructured to achieve the demand of digital economy, low-carbon and environment-friendly. Traditional grid design was depended on a large scale generation, passive loads, energy storage with limited capacity, minimal feedback due to hierarchical control structures and remotely located from consumers. Figure 6 shows the graphical view of traditional grid architecture.

Traditional grid does not have the capability to adapt the upcoming technology, such as; power generation sources with low inertia, the demand for greater flexibility and the distributed power generation resources of rising diffusion.

The latest studies reveal that a smart grid is fully equipped with agile, robust and more flexible. Resources and grid operators can dynamically be optimized in a smart grid system; disturbances can rapidly be detected and mitigated, diversely integrated with energy generation sources and able to protect against cyber and physical risks. Moreover, consumers are in-charge to manage the use of the electricity and finally, smart grid can response the demand and the energy resources can efficiently be integrated according to the need [22].

6.2. Analysis and Reflection

The analysis and reflection of traditional grid have been done based on its characteristics. As it is demonstrated in Figure 7, traditional grid is a rigorously hierarchical electrical supply system. In this system, the central generation is at the top of the chain where electricity is produced, and the customers’ loads are at the bottom of the chain where electricity is supplied [43].

Traditional grid does not have two-way communication because it is fundamentally a one-way channel system. The source does not have immediate information if the electricity is terminated at the customers’ end. Furthermore, the grid is incompetent to bear maximum load if it exceeds its projected demand. Thus, it is integrally an ineffective system.

Additionally, the system stability has been decreased because of the ineffective infrastructure of power delivery system and the tremendous rise in demand for
electricity. Finally, terrible blackouts can be activated because of the failures of the components which could be the cause of irregularities in distributing power supply.

In this modern world, traditional grid has now become a "stupid," ineffectual and environmentally extravagant system, because it is fundamentally a one-way channel system. The power distribution system cannot receive immediate information if the electricity is terminated at the customers’ end. The grid is incompetent to bear maximum load if it exceeds its projected demand. Moreover, it is not suited to integrate with decentralized/localized and renewable power generation sources. Therefore, traditional grid does not have sufficient capacity to fulfill the increasing demand for electricity.

7. Technology Development

Innovative technology has made it possible that traditional grid can be transformed into smart grid. This technology can be divided into three main segments: generation, transmission, and distribution. Technology that belongs to generate and transmit electricity is rapidly developing and improving as it is
controlled by the utility companies whereas, distribution segment is facing a huge struggle on some of the improvements, some stakeholders are involved in this part of the process [44]. According to Kang et al. [45], energy efficiency is directly associated with the technology. If the technology is advanced, then the better level of energy services can be achieved by using less energy. Hi-tech equipment which contains efficiency measures is useful for energy saving and long-lasting use if they are used at the consumer’s end. Kempener et al. [46] stated that embedding smart equipment into the grid is the only way to transform the electricity system, as shown in Figure 8.

Figure 8 shows that the present grid has an only one-way communication system. It does not have system that consumers can send information to grid or its utility providers. On the other hand, the future grid is a fully integrated two-way communication system and has various types of distributed power generation system. Future grid is fully equipped with smart technologies which enables its consumers to send or receive information from the grid [46].

Furthermore, Prabhu et al. [8] stated that major changes are required in the distribution network, specifically for residential and commercial consumers. Main technology requires for distribution networks are special charging equipment for an electric vehicle, transformers that has a built-in high efficiency of the distribution system, smart meters, low voltage inverters that have the capability to integrate with solar systems, automation systems for homes or buildings and automatic fault detecting sensors. Other significant technologies which brought smart grid into existence are mentioned below:

**Communication Technology:** Communication technologies made possible for different smart electronic devices to integrate and interact with each other. It includes protection, data transfer and allows consumers to communicate with the intelligent devices [47]. According to Luan et al. [48], smart grid systems can use ethernet based networks to communicate with different devices. However, Ethernet-based networks are not suited to establish everywhere because it is a wired system network [49]. Furthermore, as per Deb et al. [50], cloud computing has brought great evaluation in communication technologies. Fuzzy controllers have the strength to enhance the robustness of the system.

**Sensing Technology:** Sensing technology plays a significant role in measuring and evaluating the integrity and health of electric grid. Sensing technology has the capability of preventing energy theft, eliminating the billing estimation system and automatically taking meter reading [47]. Furthermore, complex energy
system data can be converted into a readable format with the help of sensing technology which can easily be comprehended by grid operators.

**Fault Detection Technology**: Fault detection technology enables the grid to indicate the disturbance and faults in the grid. In case of any disruption, this technology helps the system to restructure the grids in affected areas and re-adjust rapidly with the newly assigned network topology which allows the system to reduce the severity of the disturbance and faults of the grid. Furthermore, in case of any major disruption in the power system which leads to an emergency, the system should take prompt action and redirect the power to normal and secure paths [51].

**Power Storage Technology**: Innovative technology has brought an evolution in grid systems. Power storage technology is one of the great examples of it. According to Katiraei et al. [52], renewable energies such as photovoltaic battery, wind power, storage components and fuel battery required more control functions. Power electronic converters are used to connect these energy sources with the large-scale power grids. Prabhu et al. [8] stated that Energy storage technologies have a high capability to integrate with renewable energy sources which help to mitigate the demand for electricity. Operations can be optimized, efficiency can be increased, and distribution systems and flexible transmission can accommodate fluctuations in supply. Furthermore, disruptions of electricity can be prevented before they occur with the help of strict control system and automatic monitoring system.

**Weather Predicting Technology**: Some of the sources of renewable energy are based on weather. Therefore, the demand for cutting-edge technology in weather forecasting is mandatory. To accurately predict the changes in power generation of renewable energy, it is required to enhance the precision of climate forecasting technology. Thus, the instability of renewable energy in producing power will be reduced [9].

**Other Advanced Technologies**: Some of the other innovative technology helps to build up a complex smart grid system. It also assists to monitor the performance of the grid. The advanced methods are the algorithm that allows to predict, diagnose and analyze grid conditions which are used to take rapid actions against blackouts, power quality disturbance and mitigate power shortage [47]. Furthermore, Li and Yao [9] say that even though the access of renewable energy distribution system is complicated but the advanced technology made possible to monitor, control and schedule in stable operation, safe and improving efficiency.

Innovative technology has brought marvelous revolution in an electrical industry. It made it possible for the grids to integrate with centralized and decentralized power generation systems. With the help of digitalized technology traditional grid can be transformed into smart grid which enables smart devices to interact with each other, measuring and evaluating the integrity and health of electric grid. Technology has the capability of preventing energy theft, eliminating the billing estimation system, automatically taking a meter reading and enabling the grid to indicate the disturbance and faults. Furthermore, energy storage technologies have a high capability to integrate with renewable energy sources which help to mitigate the demand for electricity.
8. Smart Grid

The aging of traditional grid, the lack in responding to the increasing demand of electricity, instability in fuel cost and no automation system for power restoration has brought an idea of “Smart Grid” (modernized electric distribution system). Smart grid can be fully equipped with innovative technologies and be able to fulfill the future demand for electricity [16]. Forte [53] added that smart grid is a system, combination of innovative sensors, two-way communication system, automatic metering, intelligent electricity supply equipment and completely computerized system. Smart grid has the capability to improve choices and awareness for the consumers, consistency in the performance of electric supply and enables utility providers and consumers to take independent decisions in delivering and receiving services. Figure 9 shows the complete overview of smart grid.

According to Chang et al. [54], smart grid system can quickly adapt revolutionary enhancements in economics, reliability, efficiency, and sustainability of different electricity services. Advanced metering infrastructure is considered as a central point of information flows in smart grid systems. Furthermore, Horowitz et al. [55] explain that the beauty of smart grid is that, networked intelligent sensors can be integrated with long-distance transmission lines which can be profited in increasing efficiency, improving operations and synchronizing alternative and even small power sources.

Forte [53] stated that, by enabling the core functionality of plug-in electric vehicles, renewable sources, micro-grids and of other technologies would make it possible for smart grid to penetrate and integrate with these technologies. Finally, Prabhu et al. [8] say that smart grid can fulfill the future demand for electricity and the need for power for electric vehicles. Moreover, it is well capable of keeping environmental concerns.

8.1. Conceptual Model of Smart Grid

According to Li and Yao [9], the primary function of the electric grid is to deliver electricity from the generation point to consumers. The delivery of electricity network mainly works through the transmission and the distribution systems. Electricity is transmitted through transmission system from electric generation plants to distribution substations whereas electricity is distributed to consumers from distribution substations through the distribution system, as shown in Figure 10.

The conceptual model of smart grid is represented in Figure 10. It is a combination of a different set of domains, and each domain has its function according to its communication and electrical interfaces. Besides that, smart meter plays a vital role in overall communication between electrical grid and consumer interfaces; it consists of the communication link and an electronic box. A smart meter electronically records the necessary parameters and the consumption of electricity consumed by consumers, then time to time it transmits the recorded
Figure 9. Smart grid benefits [25].

Figure 10. Conceptual model of smart grid system [9].

information over a communication network to the billing providing companies. Similarly, the information can be supplied through end-user devices to the consumers for informing them regarding the related costs and the energy consumption [11]. Moreover, YIN et al. [56] stated that smart meters could be differentiated according to their features and capabilities, such as; one or two ways communication types, meters that can measure the storage data or the meters that can be connected at the energy suppliers’ end.

8.2. Integration of Smart Grid with Renewable Energy

The over-reliance on fossil fuels and the growing demand for energy are becoming significant problems presently. Thus, for generating electricity, there is a huge tendency for switching to renewable energy. However, to adapt and combine these disconnected natural sources, important developments and adjustments for current electric grids would be required [25]. Renewable energy sources, including solar, wind and others, cannot be distributed naturally. Furthermore, changes in weather have a giant impact on the renewable energy
sources. These create gaps and instabilities, which will affect original grids, as they have quick changes and alteration of voltage, as well as regularity changes. Nonetheless, smart grids will launch a computerized network of data due to smart detectors, automatic systems of transmission and resolution [51]. According to Papavasiliou et al. [57], nowadays the adoption of sustainable sources of energy by smart grid system is becoming supreme and significant, which is gaining more attention of researchers.

Atteya et al. [58] argue that smart grid has more essential functions besides sustainable energy unification and depository of energy in a system distribution. Other principal tasks are monitoring, smart metering, systems of communications, as they help to get data about power usage and send it to electric services through a wireless network of communication to execute and examine the information for making effective decisions for consumers and utilities. According to Vallee et al. [59], combining sustainable sources of energy into smart grid is allowing to save the sources costs regarding construction of additional generators. Moreover, it is enabling to enhance the quality of power, fulfills needs of customers and makes the system reliable. Gaviano et al. [60] combined data and analyzed smart grid’s role in generating renewable energy and its potential for future studies. The authors state that central and crucial element in connecting and adjusting renewable energy for construction of future grid is the interaction between digital devices.

Ultimately, Smart grid control allows to sustain functioning of the system, foresee expected performance of it, manage resource supply, safety, demand, efficient reply to digital devices, and decrease the operation costs [61]. According to Liserre et al. [62], the future of security and execution systems is smart grid, which is auto-controlled, reliable and stable.

8.3. Techniques Apply in Smart Grid

The techniques that make smart grid “smart” are expressed here. According to Li and Yao [9], smart grids, which are systematized, have to respond to power variations and forecast the defects of operating systems. Multiple remote sensors are developed to reach this point. Communicating grids are being inserted in the original transmitting grids. The method of communication has an accurate and flexible standard of measuring because every inadequacy in the system should be fixed swiftly [63].

Automated Metering System: Smart grids must manage consumer changes for holding the stability of consumers and providers. The electric meters are forming the improved metering system by intelligent system of data-execution at the supplier end. According to Yu et al. [64], the nexus which links them has the following tasks: maintaining adaptable price for the electricity power, automate control of electric load based on current time price, computing actual time information for users, power quality and voltage remote control.

Computerized Electrical Devices: The smart digital devices, machines of power supplying with adaptable systems of transmission and the solid-state con-
trollers, which are multifunctional, are all technical devices. They have vital roles in generating, transmitting, providing and utilizing of electricity. According to Li et al. [9], the most widespread controller of power grids is silicon switches. In smart grids, they will be used as integrated instruments with multiple functions and with real control for making the ability of transmission to the maximum.

**Digitalized Transmitting and Distributing System:** The improved mechanization contains generators with an efficient measuring system of large zones and other vital processes. This mechanization can upgrade functioning and execution of smart grids. Yang et al. [51] state that the developed automation of transmission and supply could preserve grids' performance, self-recovering, and management throughout swift and updated programming.

### 8.4. Characteristics of Smart Grid

As per Xie et al. [65], smart grid uses the self-scanning technique to inspect, identify, as well as to repair its elements or units of the network. By these operations, smart grid preserves safety, accessibility, quality of power and its state of energy-saving. Smart grid allows separate and professional customers to have principal roles in the system of electricity. Both independent consumers and authenticity of the system are getting advantages from active customer engagement. The modern grid must have dynamic protection system and provide combined and stable procedures for operation. Entire loads of power system are growing in the form of sensitive loads. For fulfilling the demands of responsive loads, the quality, which smart grid is delivering, must be enhanced. The loads could be more flexible for power delivery by getting design upgrades. Furthermore, the next feature of smart grid is the ability to unite markets of electricity and create an efficient system of electric power. Functioning, reliability, costs, and arranging are based on the structure of markets, which are easy to access. Appropriately, smart grid will brace electricity markets and restructure them. Finally, the management of assets through smart grid will allow getting high performance with minimum expenditures. For instance, advance diagnosis of the problem, as well as problem-fixing activities will be available throughout developed sensing system and dynamic communication system.

### 8.5. Advantages and Disadvantages of Smart Grid

Some of the main advantages and disadvantages of smart grid are described below: [9] [11] [16] [53].

**Advantages**

- Access to natural and sustainable sources of energy.
- Benefits for society due to depletion of waste from disruption of power.
- Growing amount of electric energy resources.
- Advanced protection of energy due to providing customers with data.
- The development in energy distributor sector will decrease the decrease the utility cost for the consumer.
• Pressure on assets is decreasing by fulfilling the demand, which is minimizing failure likelihood.
• Capital funds rearrangement due to lessened loads of peak.
• Reduction of oil consumption due to decreasing ineffective generation requirements in top usage phases.
• Making available to shift from oil to electric energy for the transport system, which includes buses, cars, trains.
• Electric Greenhouse gas reduction due to stimulating machines with electricity and sustainable energy sources.

**Disadvantages**
• The critical issues are protection and seclusion.
• Hackers could crack some meter types.
• Hackers could:
  o Gain access to thousands or millions of meters.
  o Make the electricity demand to grow or to lessen.
• Despite to traditional grid, smart grid consists of multiple components.
• Diverse technical elements—the engines of power, integrators of system, programs, etc.
• The installation is very costly and requires a big budget.

**8.6. Comparison between Traditional Grid and Smart Grid**

Contemporary electric grid complexes are being described by expressive vocabulary, for example, “traditional” or “smart.” According to Mohd et al. [66], smart grid mechanisms, as well as the allowance of consumption data in real-time amplify the effectiveness of production, transmission, and usage. The energy classes relationships start to change due to this productiveness enhancement. Smalley [67] states that the process of switching from stockpiled fuels (natural gas, oil, coal, nuclear) into sustainable and renewable systems is becoming agiler through means for linking end-users and energy services. Accordingly, the traditional energy grid is becoming insufficient, which is starting to be more visible. Decentralized and ineffectual value chain limits traditional grid’s potency and productivity. In opposition to traditional grid, the structure and design of smart grid give superior control over energy distribution and usage. Furthermore, it provides instant feedback for energy consumption. Thus, the mechanism of smart grid enables higher effectiveness and less wastage of resources. Table 4 gives a quick image of the traditional and smart grid.

Makansi [68] describes traditional grid by using five classes of assets: Source, Generation, Transmission, Delivery, and Distribution. This categorization is highlighting the value chain. At the same time, it emphasizes decentralization mentioned above of value chain. Makansi’s energy value chain portrait indicates significant elements, such as Source of energy, Generation, Transmission, Supplying, the ultimate user. Different energy storage types and excess with the dump-load form were added by the revised model, which is shown in Figure 11.
Table 4. Traditional grid vs smart grid.

<table>
<thead>
<tr>
<th>Traditional Grid</th>
<th>Smart Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fewer detectors</td>
<td>Fully equipped with detectors</td>
</tr>
<tr>
<td>Electromechanical devices</td>
<td>Computerized devices</td>
</tr>
<tr>
<td>Manual observing system</td>
<td>Automatic observing system</td>
</tr>
<tr>
<td>Centralized power generation system</td>
<td>Decentralized/Distributed power generation system</td>
</tr>
<tr>
<td>Manual healing system</td>
<td>Automatic healing system</td>
</tr>
<tr>
<td>One-way communication system</td>
<td>Two-way communication system</td>
</tr>
<tr>
<td>Breakdowns and dark</td>
<td>Robust and islanding system</td>
</tr>
<tr>
<td>Fewer options for customers</td>
<td>Many options for customers</td>
</tr>
<tr>
<td>Restricted system</td>
<td>Extensive system</td>
</tr>
<tr>
<td>Less control over grid</td>
<td>Good control over grid</td>
</tr>
</tbody>
</table>

Data and the mono-directional flow of energy are the principal attributes of the grid mechanism.

The distribution is the only repeating circle around feedback. The reason is the surplus of discarded loads, which is redirecting the energy from the end user. The discarded loads cause more losses of revenue, which makes all costs and no income. Thus, grid operators have a stimulus for maximum reducing these incidents and keep the supposition of delivery, as well as high level of energy service quality. The technology, which collects usage information from end users and sends it to the operator of the grid, is used for describing smart grid. The collection and sending of data enhance the performance of grid, as well as informs users about real-time prices from generators. The information flow is described, which is another direction from the same assets category. The description is shown in Figure 12.

The dump loads are replaced with better information flow from electricity production. Smart grid mechanism illustration does these changes. Consequently,
it provides energy generator with demand based on real time. Moreover, the supply and customer needs are overlapping with each other, which is multiple times advantageous and efficient from the calculation of demand at any time. The limited suiting ability of feedback loop is the disadvantage of this system. The feedback loop suits only with energy generation. Thus, it makes the distribution less efficient because generators ramp up and down according to consumer demand, which fluctuates swiftly. Upgraded engines of energy generation are partly solving the problem. However, the level of the solution is not enough (i.e., residential use of solar energy). The differentiation between smart grid and traditional grid concentrates on increasing efficacy by improving the level of understanding. Makansi et al. [70] argue that more valuable information creates an opportunity for enhancing the operations. Meanwhile, consumer costs could be decreased by more accessible and balanced distribution system. In this value chain, the storage of energy has more additional position instead of central position (see Figure 12). Thus, it restricts energy storage service value, as well as makes administration of storage possession more complex.

8.7. Future Challenges for Smart Grid

Hoang [47] stated some of the prominent challenges for implementing smart grid:

**Finance:** From business-perspective it is efficient to have the ability to automate restoring, especially if it gives advantages to society. However, for investing in new technology, authorities will demand evidence, mainly if the technique depends on benefits for the community.

**Assistance from Government:** The industry sector does not have sufficient financial resources for funding new system installment. Therefore, it is necessary to get support from the government in the form of individual programs and activities to motivate new investments. Although the industry contains capital, which equals to $800 billion, it experienced financial problems, which caused
economic rankings’ reduction.

**Competent Apparatus:** Older technologies are not well-suited with smart grid, and they cannot be reinstalled for suiting. Thus, the old equipment must be changed, which could cause obstacles regarding laws and controllers. Maintaining the old machinery more than its optimal service time decreases the spending of customers. At the same time, early exit of the apparatus could be a problem.

**Technical Advancement Speed:** 50 years ago, people predicted the solar gravel, chimney wind turbine and the fuel cell of an underground room. They described these technologies as inherent in future house design. This historical evolution should be reinforced.

**Rules and Regulations:** The providers of utilities often take into consideration new projects and plans of construction. The crossing state border of first circuit tie has always faced refusal. The government authorities who give the funds for the program are not ever getting advantages from the project. Thus, the utility providers will only invest in smart grid if the returns are high and sufficient.

**Collaboration:** The collaboration of 3000 various utilities is required for establishing critical circuit ties and spreading the information about integrating and implementing the concepts of smart grid.

9. Discussion
The primary objective of this discussion is to explore and exploit the sustainable and eco-friendly power management system. The term “distributed energy system” means a system in which electric energy generators are near to end-users. Moreover, distributed energy system contains the change of decision-making place, changes in control and possession of electricity distribution. In the future system of energy is going to be a combination of distributed and centralized sub-systems, which will operate simultaneously [28]. Multiple analysis of electric technologies and its mechanisms are focused on finding the special method for using centralized generation (CG), decentralized generation (DG) or localized generation (LG) to satisfy the increasing demand. As per Momoh et al. [31], distributed energy system is a useful choice, especially for a long term.

According to Association [23] report, the rapid change and growth have been noticed of electro-mechanical to electronic-based devices which have directly been affecting the requirement of energy and the grid operations. In this modern era, 92% of transport is fueled by petroleum. However, the immediate rise of electricity demand has been predicted in the transportation sector, as the concept of plug-in electric vehicles is rapidly increasing. The 18.6% annual growth rate of the electric vehicle is being predicted from 2013 to 2022 if this prediction of electric vehicle sale continues then the demand for electricity will remarkably be increased. Moreover, Tanaka [19] stated that the consumption of electricity is expected to grow by over 115% from 2007 to 2050.

On the other hand, it is difficult for a traditional grid with old technology to
meet the rising demand for electricity. Zame et al. [70] added it has become more visible that traditional grid is an inadequate power distribution system. As per Hossain et al. [42] traditional grid depends on centralized power generation system which consumes lots of fossil fuels and emits greenhouse gases, that makes traditional grid ultimately a useless and environmentally extravagant system. Feist et al. [24] comment that centralized power generation system has become a primary cause of emitting around 25% of global greenhouse gases. Furthermore, Banerjee et al. [22] explained that traditional grid cannot adapt the upcoming innovative technology, such as; power generation sources with low inertia, the demand for higher flexibility and the distributed power generation resources of rising diffusion. Therefore, Hossain et al. [42] stated that traditional grid is not suited for distributed, wind energy and renewable solar energy sources.

Nonetheless, the advancement of innovative technology has changed the scenario and played a significant role in transforming traditional grid into smart grid. Modern electrical technologies have empowered intelligent devices to interact with each other, measuring and evaluating the integrity and health of electric grid. Similarly, to prevent energy theft, eliminate the billing estimation system and automatically take meter reading [47]. Climate forecasting technology can accurately predict the changes in weather conditions which effects on power generation through renewable energy sources [9]. Furthermore, digitalized technology allows the grid to indicate the disturbance and faults in the grid. In case of any disruption, technology helps the system to restructure grids in affected areas and re-adjust rapidly with the newly assigned network topology which allows the system to reduce the severity of the disturbance and faults of the grid [51]. Finally, energy storage technologies have a high capability to integrate with renewable energy sources which help to mitigate the future demand of electricity [8] [52].

The latest studies reveal that a smart grid is fully equipped with agile, robust and more flexible techniques and technologies [16]. Power generation sources and grid operators can dynamically be optimized in a smart grid system; disturbances can rapidly be detected and mitigated, capable of protecting against cyber and physical risks [22]. According to Papavasiliou and Oren [57], nowadays the adoption of sustainable energy sources by smart grid system is becoming supreme and significant, which is gaining more attention of researchers. Attaya et al. [58] added that smart grid has more essential functions, besides sustainable energy unification and depository of energy in the distribution system. According to Vallee et al. [59], combining sustainable energy sources into smart grid is allowing to reduce greenhouse gases and decreasing the usage of fossil fuels and to save the cost, regarding constructing more centralized power generation units. Moreover, Banerjee et al. [22] stated that consumers are in-charge to manage the use of electricity, and finally, the smart grid can efficiently be integrated with renewable energy sources and decentralized power generation sys-
tems which can respond the rising demand for electricity.

10. Conclusion

Finally, we have come to the point that decentralized and localized power generation systems are the better options for generating power, as both systems are closed to the end-users which save the cost of transmission and supply of electricity. Integration of renewable energy sources with decentralized and localized systems is possible which helps to provide clean and inexpensive energy without emitting greenhouse gases. Similarly, with the help of digitalized technology traditional grid can be transformed into smart grid which enables smart devices to interact with each other, measuring and evaluating the integrity and health of electric grid. Smart grid is a two-way communication system which is fully equipped with innovative technologies that can improve choices and awareness for the consumers, consistency in the performance of electric supply and enables utility providers and consumers to take independent decisions in delivering and receiving services. Moreover, energy storage technologies have a high capability to integrate with smart grid and renewable energy sources which help to store and distribute electricity according to the required need. The rise of electricity demand can be mitigated by installing smart meters, utilizing proper electric grid management techniques and time-based rates application. It encourages consumers to use electricity during off-peak hours which will save them from additional charges. Finally, smart grid is loaded with the core functionality of plug-in electric vehicles which has the complete capability to fulfill the demand of power for electric vehicles. Thus, the mechanism of smart grid allows higher effectiveness and less wastage of resources which enable it to achieve the rising demand for electricity. However, smart grid still faces some challenges such as; government support is required which is not easy in some cases; the initial massive investment need to install the automated system; replacing obsolete equipment with new digitalized systems; and facing different rules and regulations imposed by individual governments.

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https://doi.org/10.1109/MPE.2009.935554


Paper – II
Business Model Innovation Approach for Commercializing Smart Grid Systems

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Abstract

How to cite this paper:

Received: August 28, 2018
Accepted: September 27, 2018
Published: September 30, 2018

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1. Introduction

In this modern era, on the one hand, the demand for electricity is increasing while on the other hand, fossil fuels are depleting which are used for power generation. Therefore, Bhatti et al. [1] and Grace [2] stated that one of the reasons for high-cost electricity delivery and inflexibility is the dependence on a centralized system of power generation and old technology in energy distribution systems. The centralized power generation system mainly relies on non-renewable energy sources to produce electricity. The installation, transmission, and distribution of electricity with a centralized system are costly in distant areas and cannot handle the increased variation of energy sources and new consumption patterns among consumers. Fossil fuels are one of the causes of harmful gas pollution which negatively effects peoples' health and the local climate. Therefore, a different method for electricity generation and delivery is necessary to face these challenges. According to Allen et al. [3], traditional energy market economics have been moving towards decentralized energy systems. For instance, residential level solar photovoltaic and storage is used, and on a community level there are numerous ongoing sizeable projects of renewable energy. These trends are creating "risks" for traditional energy system, and energy companies are already making strategies for further investment in the industry of renewable energy. McDonough et al. [4] stated that all these components of energy system evolution create new and better ways of electricity generation and distribution. Making smaller systems and industry may be a new way of electricity supply since effectiveness will be higher. For making the new systems, redesigning is needed, which can make systems recharge and maintain themselves.

A decentralized system of electricity is based on handling localized renewable energy sources which provide clean and eco-friendly energy. The decentralized system is an alternative option to reach the rising demand for electricity in distant regions. Therefore, electricity delivery problem in village regions can be electricity system which will give them more control over electricity. CO₂ production will be reduced, helping to create a clean environment and will enable operators to improve grid security and network stability. Finally, demand response services will provide multiple electricity package options to the consumers in which they can select an appropriate package according to their need which will give them more control over their electricity bill. System operators can optimize their grid operations to provide better power quality, and service providers can increase their income by offering additional services.

Keywords

Smart Grids, Electricity Firms, Business Models, Disruptive Technology, Sustainable Energy
solved by integrating localized renewable energy sources with the decentralized and intelligent power distribution system (smart grid), which is capable of managing variations in energy sourcing and energy consumption. In the world, the adoption ratio of decentralized electricity generation systems was 13% in 2001, and it increased by 12% within four years, reaching 25% at the end of 2005, and a year after in 2006, it reached 36%. Based on the benefits of decentralized electricity generation systems, more growth is expected in the future. Calculations show that by 2030, the cost of electricity generation may reduce to $2.7 trillion, due to the efficient integration of renewable energy sources with intelligent, decentralized electricity generation systems and energy distributed through a digitalized smart grid system [1].

According to Christensen [5], the term “disruptive technology” refers to new products or services which transform markets and businesses. Disruptive technologies bring changes in market structure and in value delivery. Usually, the concept of “disruptive innovation” is used as an alternative phrase for “disruptive technology”. Furthermore, the business model enables the impact of disruptive technology. Bower et al. [6] defined and made widespread the concepts of “disruptive technologies” and “disruptive innovations”. The center of economic innovation is innovation in technology. New knowledge, products, and services create the resources for better life quality, value creation and problem-solving. Due to innovation, technologies are continuously evolving. According to Bower and Christensen [6], technologies which cause structural changes in the market, as well as affect market-leading organizations, are called disruptive. During the market entry, disruptive technologies have limited effect. However, after a short period, disruptive technologies are entirely changing existing technologies. Unlike dominant technologies, disruptive technologies are straightforward, low-priced and more reliable. Nevertheless, consumers do not care about some characteristics of disruptive technologies [5]. Disruptive innovation has been noticed in the energy industry in the last decade. Power generation sources and the distribution system have been the focus of innovation as to mitigate the rising demand for electricity. The distribution structure and the transmission part of the energy sector remained untouched [7].

In this age, the smart grid is an emerging technology in the energy industry, and it has the potential to revolutionize, integrate and enable all the different parts of the energy value chain [8]. Inage [9] explains that the smart grid is an electricity network. It uses advanced, innovative and digitalized technology to manage and monitor the distribution and generation of electricity from different sources to fulfill the demand of consumers. Therefore, the question arises, how can grids be made smarter? The answer is, by intervening in information and communication technology, because information and communication technology (ICT) has the potential to embrace distributed energy, enhancing and corresponding with the electricity network and offers control over sustainability and energy savings. The goal of smart electric grids is to provide sustainable, reliable, safe, as well as inexpensive electricity to consumers. Future...
1.1. Problem Statement

In recent years, the advancement in information and communication technology (ICT) and the involvement of ICT firms in the electricity industry have brought tremendous disruption. The concept of a centralized power generation system with the usage of fossil fuels is rapidly shifting towards decentralized and localized power generation systems with the utilization of renewable energy sources such as wind, solar PV, hydro and biogas. Similarly, the distribution of power generation system is moving from traditional grid systems to smart grid systems. This emerging change in the electricity industry can meet the future demand for electricity and provide clean energy at a low price and flexible solutions to the consumers[1].

However, this disruption in the electricity industry has a direct impact on the business models of energy providing firms. The main problem is that energy
providing firms are hesitant to change their established business models. They want to commercialize the new system (Smart grid) of electricity with their old business model based on the assumption that the entire value chain remains as it is. However, the smart grid system enables the integration of energy sources and energy consumption in different ways and different combinations, demanding the dynamics of the value chain and thus demanding for a new business model, enabling the creation of new value to consumers. Therefore, Bocken et al. [19] stated that although electricity firms are strategically trying to rebuild themselves towards sustainable energy, they are still experiencing uncertainty about business model design, which will be both profitable and sustainable. Mah et al. [20] insisted that many smart grid technologies are ready for use, but electricity firms are still failing to generate profits from them because they want to commercialize disruptive technology with the old business model. Shomali et al. [21] stated that ICT firms have a high impact on smart grid when smart grid is introduced in the market, the utility providing firms need to upgrade their business model regarding capturing profit from third parties. Furthermore, as per Amit et al. [22], utility providing firms have incentives for updating their business models to integrate smart grids and include solar PV and storage as well. However, for incumbents, there are several challenges, such as the market entrance of new players, uncertainties with government support, enrollment of customers, as well as an unwillingness for business model innovation caused by a fear of losing streams of revenue. Thus, Sosna et al. [17] stated that the primary challenge for electric utilities is to find better ways of commercializing the technologies of renewable energy. Researchers have determined that established firms have problems with changing their business models. The companies are getting profits by using their current business models, but in the future, the situation could change due to technological development or environment changes. Finally, Christensen and Bower [18] clarify that many companies are losing profits to their competition not because of new technology, but because they are failing to change their current model and implement new business models with new technologies.

1.2. Purpose of the Research

This study explores the impact of disruptive technology (intelligent and decentralized smart grid systems) on energy providing and energy distribution firms. Further exploration is focusing on the need for a new business model to commercialize the new intelligent and decentralized energy distribution grid systems in order to create, deliver and capture value for the mutual benefits of consumers of energy and renewable energy producers and energy distribution firms.

2. Research Methodology
new systems of power generation and distribution, which demands a new business model to commercialize the new system. The smart grid is a relatively new disruptive technology which is expected to transform the energy industry. Being as it is a new technology, there are no real implementations that can be seen in real life and real business. Thus, this research is tentative in which literature has been reviewed and indicative of a possible future revolution in the energy industry.

In order to perform the research three databases were mainly focused on in the literature review. ABI/Inform Global is one of the wide-ranging databases that cover broad areas of research, such as; business, corporate strategies, economic conditions, management techniques and business trends. Furthermore, not only are peer-reviewed articles or other databases just indexed, but it provides the full text. Emeralds journal also covers broad areas of research. It has been categorized into subfields, such as; accounting, finance and economics, business, management and strategy, education, engineering, health, social care, library studies, and marketing. It provides holistic research sources to the researcher. Science Direct which is operated by Elsevier covers engineering and business peer-reviewed articles. Furthermore, international energy agency (IEA) reports published by the French government have been considered to get a deeper understanding of the involvement of different governments in the energy industry.

To identify the relevant articles, the search has been divided into two segments. The first search is based on disruptive technology in general and energy in particular, and its impact on business models for commercialization of energy providing and distribution firms. The second search is related to the business model innovation approach for commercializing a smart grid system. The selection of the keywords was: "disruptive technology" AND "smart grid", "disruptive innovation" AND "smart grid", "business model" AND "smart grid", "impact of smart grid" AND "business model", "business model innovation" AND "commercializing smart grid". The keywords were used in the form of phrases and were quoted with quotation marks. To refine the search "AND" operator has been used in the middle of the phrases in the advanced search bar.

The selection of peer-reviewed articles and reports has been an iterative process, screening, and filtering which is divided into three steps. In the first step, only titles of all the articles were screened, and articles with irrelevant titles were removed. In the second step, the abstracts of all the remaining articles were skimmed, and duplicate and irrelevant articles were removed. In the final step, filtration was based on skimming the full-text of the remaining articles from the second iteration. Further exclusion criteria were if the articles were too technical or had no relation to a business model for smart grid or disruptive technology. The criteria of analysis of the data and obtaining the results vary according to each section. The first section explores the transformation of the electricity system which is further divided into three sub-sections. In the sub-sections, 1) Non-renewable to renewable energy sources, the analysis is based on the availability of renewable energy sources.
3. Transformation of Electricity System

3.1. Non-Renewable to Renewable Energy
In the 19th century, people switched to coal, while in the 20th century, people shifted to natural gas and oil. In the middle of the 20th century, nuclear power had its debut in the energy industry [24]. Every economic development era included the process of switching from one main energy source to another. Presently, the central sources of energy are fossil fuels (coal, natural gas, and oil), which are the major sources of energy generation in developing countries (see Figure 2). Nonetheless, the 21st century is establishing a new era of energy sources by attempting to switch energy production from fossil fuels to renewable sources. This changeover is reinforced by several aspects, such as fossil fuel delivery restrictions, costs, environmental safety (especially changes in climate and temperature) and evolution in technology [25].

Figure 2 shows that the economic infrastructure, as well as stock capital, depend on the usage of fossil fuels, as non-renewable energy sources produce 81.6% of global energy. Any changes in this situation will require substantial capital investments and severe infrastructural change. Even though private capital has the most impact on these changes, governments and authorities must adopt rules and regulations in order to legitimate and promote shifting of energy sources. The key point is renewable sources of energy, which could give numerous benefits to the economy and to the environment [24]. As non-renewable energy sources are producing electricity at the lowest cost, about 81.6% of world energy supply is provided by fossil fuels. Nevertheless, in recent years, fossil fuels' advantage in costs is being reduced since many types of renewable energy can provide power at a price, which is almost similar to or even lower than fossil fuels' energy price. Moreover, in the future, costs of renewable energy will be reduced more, while costs of fossil fuels are expected to grow. Thus, economic tendencies are going towards renewable sources [24].
Comparison of costs of various sources of energy is based on determining the levelized cost of energy (LCOE). Levelized costs show the current price required for a building or plant operation throughout the presumed time period. Real terms demonstrate LCOE to discard inflation influence. The assumption for fuel-based energy sources is built on future expected prices of fuel. Total energy cost contains operations and levelized construction prices, which makes it easier to compare costs of various sources of energy [26].

Figure 3 presents the cost comparison between fossil fuels and renewable sources of energy. Renewable energy sources need to have a similar price to power plants of fossil fuels in order to sell electricity to the grid. This price is called wholesale price of electricity. Hydropower and biomass have already reached this price. Figure 3 highlights that costs of geothermal and wind energy are almost identical to prices of fossil fuels but solar energy is expensive. However, the solar photovoltaics (PV) price requires being equal to retail power price paid by end users, because end-users of energy can easily install solar PV. The PV price exceeds the wholesale price [26].

Prices and Volumes

Past and expected price tendencies of solar and wind energy are represented in Figure 4 and Figure 5. Even though prices may reduce curve shape of price shows that prices decline slower than in the past. Furthermore, Figure 4 and Figure 5, suggest that the difference between prices of wind and photovoltaic energies will shrink. Therefore, the renewable energy costs become more foreseeable, while the situation with fossil fuels is entirely different. According to Energy report of U.S. Department from 1998-2011 costs for U.S. PV system, every year declined 5%-7%. From 2010 to 2011, PV prices declined 11%-14%, and it is likely to see future decreases as well [27]. According to Timmons et al. [24], future market prices of renewable energy sources will not necessarily be lower than prices of fossil fuels, although prices of renewable energy are reducing. The net energy of renewable sources, the intensity of capital and their discontinuity are present in main cost issues for Figure 3.
renewable energy generation. Solar and wind energy have lower operating costs because once facilities for energy production are constructed, little cost is required in order to generate energy yearly. However, Timmons et al. [24] stated that higher capital investments are needed for building renewable energy plants, the total price of which is equal to the price of fossil fuel plant construction plus the price of purchasing all of the energy which the plant will generate for a long time. For example, fewer numbers of consumers would buy a gas furnace and all the gas which the furnace will use during its lifetime, this much money is required for implementation of renewable energy sources. The introduction of renewable energy sources such as solar and wind power is localized in many different locations, thus being scattered. To fully use the potential of renewable energy sources such as solar and wind power, new systems should be developed that enable renewable energy sources to be integrated into the grid systems which is hardly done in today’s old technology used by centralized grid systems. In the next session, we will elaborate on those aspects.
3.2. Centralized to Decentralized/Localized Power Generation Systems

Centralized, decentralized and localized systems of power generation have their merits and demerits. Showing the merits and demerits, as well as the reasons for shifting from centralized to the decentralized and localized systems, is the purpose of this section. In decentralized and localized systems, the electricity is distributed to specific geographic areas. Therefore, if electricity is generated in the same place where consumers live, the distribution and transmission costs will be reduced. Meanwhile, in a centralized system of power generation (CPG), there is a long distance between consumers and generation places (Bhatti, H.J. and Danilovic, M., 2018). The electricity moves through all the way, which makes the distribution costly. Thus, switching from CPG to decentralized power generation (DPG) and localized power generation (LPG) becomes necessary, particularly in distant regions, where generation places are too far from end-users.

Electricity should be generated from different sources, such as nuclear power, thermal power, and hydropower. A decentralized system of power generation reduces costs and power losses during the distribution [29]. In case of DPG and LPG, electricity generation and its usage are in the same region, which reduces the number of power transmission lines, annuls electricity losses and saves cost. The pollution level of distributed energy is low. The electricity quality and safety have great significance because Feed-in-Traffic (FIT) system requires intermittent and renewable energy. Skilled engineers and advanced power plants are needed for having lower contamination level in DPG system. Modern electrical technologies can give a solution to pollution problems, since they are fully automated and use renewable resources, such as sunlight, wind power and geothermal energy. With today’s technologies, less power plants are required, which increases potential revenues [30].

A decently developed power grid can face increasing electricity demand. Different generation procedures are used by up-to-date Distributed Generators to have a more efficient, secure and advanced electric system. Although a CPG mechanism has similar features, its construction and usage are expensive, and in some regions, electricity distribution through CPG is complicated. At the same time, DPG is discontinuous and has zero transmission costs. Thus, the integration of a DPG system becomes cheaper and more efficient in comparison to CPG [31].

3.3. Traditional Grid to Smart Grid

Due to growing electricity demand, further usage of the existing traditional grid becomes a difficult task. The traditional grid is old, and does not contain appropriate and safe generation and distribution mechanisms [32]. Moreover, the traditional grid uses CPG, which works based on fossil fuels and throws hazardous gases into the atmosphere. Thus, the traditional grid now has become an inefficient, expensive system, which is dangerous for the environment and to health.
According to Feisst et al. [34], 25% of global greenhouse gases is pollution caused by traditional grids. Present-day technologies are not feasible with the traditional grid, which cannot integrate solar, wind energy, low-inertia sources of electricity generation and distributed generation system [33]. Meanwhile, current research proves that a smart grid is suitable for use with a renewable energy and distributed system since it contains contemporary technologies for electricity generation and supply. A smart grid can automatically identify system conflicts and fix them, thus providing reliable protection from external dangers and cyber-attacks [35]. Currently, smart grid is a wide research area [36]. Atteya et al. [37] state that renewable energy system integration and serving as a storeroom in a distributed system are a small part of smart grid features. A smart grid provides a reduction of greenhouse gas pollution, a decrease in fossil fuel consumption, as well as makes electricity generation and distribution much cheaper. Furthermore, in a smart grid system, electricity consumers are at the head of the charge since smart grid allows end-users to control electricity usage and get electricity equal to their demand [35].

The changeover of non-renewable to renewable energy sources is reinforced by the depletion of fossil fuels, its high cost, environmental safety and disruption in technology. Even though without proper government regulations, economic tendencies are going towards renewable sources and costs of renewable energy will be reduced more, while costs of fossil fuels are expected to grow. Solar and wind sources require the least cost to generate energy yearly because it is facilitated through natural resources. Furthermore, shifting from a centralized power generation system to a decentralized and localized system is recommended because these systems are highly equipped and can easily be integrated with renewable energy sources. These power generation systems are close to end users which reduces the cost of transmission lines and annual electricity losses. Finally, the traditional grid is an old “stupid” power distribution system. It can only be integrated with centralized power generation systems, runs on fossil fuels and emits greenhouse gasses which are harmful to the environment whereas, a smart grid is an “intelligent” system. It can easily be integrated with renewable energy sources and supports decentralized and localized power generation systems which help to provide clean energy at a low price to the consumers.

4. Disruptive Technology

According to Kuhnn [38], if new technology completely changes existing technological standards, mechanisms or models, it is called a “disruptive technology”. The industry of telecommunication describes the influence of disruptive technologies by emphasizing all obstacles and chances, which the electric utility industry is facing now. The telecommunications industry had high entry barriers in the 1970s because at that time the business was capital-intensive and government regulations were higher [11]. The development of mobile technologies strongly affected income sources of telecom companies. As a result, rules and regulations changed for the whole industry in order to maintain competition between firms.
Thus, the telecommunication industry of the 1970s was different from today’s one. Large US telecom companies, such as Verizon and AT&T, changed their business models and developed marketing methods in order to keep leading position in services of the wireless telephone. In the same vein, in the 1990s, Internet technology development enabled people to communicate more easily [39]. For example, due to the modem, customers could access the internet by computer or telephone. This development encouraged telecom companies to interconnect the system of household communication and provide more and better telecom services [39].

According to Qiu [40], disruption relates to new knowledge, processes, products or services. Furthermore, disruptions could relate to new rules and regulations. For instance, recent disruption occurred in the US immigration policy where new rules and regulations are imposed on newly applied visa candidates. When social relationships are transformed, it could be disruptive as well [41].

Neither existing market nor disruption of existing technological standards disrupts emerging technologies. It is caused by the transformation of the existing capitalism model, social relations, and business structures, which are more significant disruptions. According to Gonzalez [42], a Keurig K-Cup single-serve coffee machine is an example of a disruptive technology. In the 1990s, a single-serve plastic coffee pod, which is called a K-Cup, was invented by John Sylvan. Initially, the K-Cup was for office use. However, Hamblin [43] mentions that the new product started to conquer the market after Keurig Green Mountain purchased it and advertised it for home usage. The company sold 9.8 billion individual coffee pods in 2014, which would circle the equator 10.5 times, if placed end-to-end. The coffee pod and single serve coffee machine disrupted the coffee market. Therefore, disruptive technologies influence other industries and social norms. Eventually, disruptive technologies make severe changes in society, physical environment, institutional rules and in organizational structures.

4.1. The Disruptive Innovation Model
4.1.1. Implication of Disruptive Innovation Model in Energy Sector

4.1.2. Low-End/New Market & Return-on-Investment

4.1.3. From Low-End and New Market to Mass-Market Based on a New Feature
firms, other actors, such as cooperatives, households, and farmers, have been showing more interest in renewable energy primarily because other actors are satisfied with the ROI level. Moreover, renewable energy generation is more beneficial from an environmental perspective since it has zero level of CO$_2$ out-flow. Consequently, decentralized generation expanded in Germany swiftly. The growth rate of renewable energy generation in Germany during 1990-2015 is presented in Figure 7 [45].

It took 15 years for renewable energy technologies to have full market entrance. The enhancements in quality and security are required to achieve the market demands. Figure 7 shows that farmers and households are the primary investors of Germany’s renewable energy sector. In 2012, utilities provided only 12% supply of 73 gigawatts (GW) of renewable energy, and 46% of the electricity was provided by households and farmers [45]. Government rules and regulations have a massive impact on the electricity market. Although utilities can invest in renewable energy, they do not hurry to do it. The traditional power plants’ market share and revenues will be challenged if utilities decide to invest in renewable energy technologies. However, currently, electric companies are more in favor of maintaining their market share and income level by using their power plants. It is visible in Figure 7 that growing shares of renewable energy reduced revenues from gas-fired power plants, and overall electricity price shrunk due to renewable energy [45].

According to Christensen, some strategies are applicable for integrating disruptive innovations. One method is the business unit splitting, which applies to establishing a startup focusing on disruptive technologies, for instance, renewable energy generation. The core of business unit splitting is that the whole company should be involved in the disruptive innovation, and not only its separate units. If a new company focuses on innovation, its business model, strategy, vision as well as a culture will cover all its business units. In 2016 the German companies “RWE” and “Eon” followed a business unit splitting scheme and created a new business unit focusing only on renewable energy generation.
4.2. Disruptive Forces: Lessons Demonstrated by Other Industries

The concept of "disruptive forces" is used to explore the limitations of current business models and innovative products, which transform the market. To demonstrate the importance of reestablishing the business models of the firms along with the advancement of technology, four vivid illustrations such as; Kodak, Tesla, iPhone, and Nokia have been quoted. These four firms are associated with three different industries; photography, automobiles, and mobile respectively. These firms prove that only depending on the advancement of technology is not sufficient for survival in the market or gaining more profit but along with it, establishing a new business model is key for commercializing your products or services in the market against your competitors.

Kodak: Eastman Kodak many years ago was a leading company in the photo film industry. The year 1888 was revolutionary for camera and film industry because "Eastman" company, which would become known as "Kodak" in the future, introduced its first camera. In 1900, Brownie, the first pocket camera was introduced, which had transformational success. It was cheap and easy to use. These products allowed Kodak to get huge profits and invest it in R&D. In 1935 Kodak created a color film camera, which could make high-quality color videos and photos. Later Kodak was involved in the development of X-ray cameras, color printers and space pictures in 1962. During the 20th century, Kodak was an incredibly successful company. However, the company started declining when digital technologies entered into the photo business. The reason behind the failure of Kodak was the misused opportunity opened by disruptive technologies [47].

The main disruption in the camera industry is concerned when cameras were merged with mobile phones. When mobile phones started to include features such as taking photos and sharing them, people began to post pictures on social media. The quality of electronic pictures eventually defeated the quality of printed pictures. Kodak invented the first digital camera. Furthermore, when the internet started to expand, and users got the opportunity to share images, news, and other information, Kodak made a strategic move in 2001 and purchased photo sharing website, which was called "Ofoto". At that time, Facebook and other social networks did not exist. Thus, "Ofoto" was an excellent chance for Kodak to revise its core business and move into the digital sphere. Nevertheless, here Kodak made its most significant mistake and refused to change the business model even though they focused on digital media [48]. Instead, Kodak used "Ofoto" as another way to print pictures. The company used the webpage to get more customers for photo printing. For several decades the company was a market leader in the film industry, but when digital technologies came into the arena, Kodak tried to use them as a way for growing its sales instead of changing its business model. The company asked the wrong marketing question, which was "How we can sell more products?" rather than the question which should have been asked which was "In what business we are in now?" If Kodak had rea-
lized that the old camera and printed picture technology would not be their core business in the future, then the company would have survived. On the other hand, Kodak’s main Japanese competitors Fuji Films, Canon and Sony were actively trying to upgrade their business model by making new products such as optic tapes, videotapes, digital cameras, printers and office automation equipment[49]. Thus, inventing or innovating a disruptive technology is not enough for success. The most important is a business model innovation which can commercialize the products or services to compete with similar companies. Therefore, Cuthbertson et al.[47] stated that Kodak had been a valuable lesson to companies that they should understand that disruptive technologies require a new business model innovation for their new products or services to be commercialized with new ways which can keep the old, as well as draw new customers.

Tesla: It was just ten years throughout which Tesla Motors has moved from zero to the top innovative company in the world. The company produces electric vehicles and engines. The headquarter of Tesla is located in California, Silicon Valley, which creates a more innovative atmosphere in the company[50]. Tesla is famous for its magnificently designed electric cars and brand. The company is targeting wealthy customers by offering them luxury cars with high quality, comfort and modern technical features[51]. Due to the target market, Tesla is getting high profit. However, the strategy has a negative side as well because there is a small percentage of wealthy customers. Thus, general sales have limits[52].

Disruptive technology drives towards new development[53]. The concept of the new electric affordable car is one of the results of the disruptive innovation[50]. Tesla integrates innovative ideas and makes them real by developing new methods of the electric car and engine production[54]. Furthermore, Tesla is investing more in research and development to emerge with better electric vehicles. Many technologies, such as 18650 ternary lithium-ion batteries, as well as dual engine drive with all-wheel, are used only by Tesla Motors. Tesla Model “S” won US high speed Road Safety Authority and European Euro NCAP prizes for safe cars. The unique business model is the core of Tesla’s success, which includes great customer experience, easy understandable instructional guide and security preferences[50]. Further success factors are mentioned below:

 Strong positioning in the market: Tesla has a clear vision regarding its customer. Based on customer segment, Tesla develops its business model. Tesla’s first preference is to produce expensive, beautiful and fast sports cars for rich and famous people who care about the clean environment. Second preference is to manufacture cars which are less expensive but comparatively equally in cost with Mercedes-Benz and BMW electric cars. The last choice is to produce low priced electric cars for families and vehicles which could be used as public transport[55].
More focus on capital investments: Huge investments are required for innovating the business model. Tesla uses retailers to promote its additional services, such as long-term leasing, outsourcing, and capital funds. Tesla purchased substantial capital through US Department of Energy's Advanced Technology Vehicles Manufacturing projects [50].

Assets Management: Tesla uses outsourcing companies for car production, and the company itself gives more concentration to value-adding, mainly for marketing and distribution. The company Matsushita Electric is producing electric batteries for Tesla and Tesla is focusing on the development of battery technology [50].

A new industry of electric vehicles will be based on business model innovation. The sector of electric vehicles creates a new business model through relationships between its sectors, as well as with government. This relationship includes government support for new infrastructure. Companies should have the main role in creating advanced electric vehicles and distributing them using a new business model. Thus, the new business model is required for disruptive electric vehicle technology which can help them to commercialize electric cars as well as to gain the support of the respective governments for further research. However, when Tesla started to develop a low-priced Model 3, the demand for large-scale manufacturing was a necessity that Tesla did not have and could not easily cope with. Still, until now the transformation from a specialized, small-scale manufacturer to large-scale mass production of electric cars is not seen as a success. The business model of Tesla is still not proven to be successful for the new Model 3. If they fail, the entire survival of Tesla might be challenged.

iPhone: iPhone is an excellent example of business model innovation for disruptive technology. Although smartphones were existing until iPhone's debut, it disrupted the market and left the giant firms, such as Nokia and Blackberry almost out of business. iPhone captured the same target market as incumbents, but the smartphone succeeded because of its quality and unique features. Until 2007, people accessed the internet mainly via laptops and PCs (personal computers). With iPhone's introduction, the internet became accessible from smartphones as well. Later Apple introduced the "App Store" on iPhone which created a new business model where app developers can meet with customers through the App Store. Thus, easier internet access and a new business model are the underlying factors of Apple's success [44].

Nokia: For almost a decade Nokia was setting the game rules in the mobile industry. However, in 2007 Nokia was challenged by Apple which weakened Nokia's positions. After the entrance of the iPhone in the market, Nokia tried to maintain its position but soon got attacked by Google and Samsung. Nokia started to fall rapidly. The company attempted to return through partnership, and was later acquisition by Microsoft, but not any significant developments occurred. Similar to numerous companies, Nokia was not sufficiently flexible and failed to innovate its business model [56]. Nokia could not understand the new market trends and deliver new value to their customers like Apple, Google...
4.3. Smart Grid as a Disruptive Technology

The smart grid is one of the future's most powerful technologies, and it has the full potential to be disruptive to energy providing firms, as it can change the entire process and structure of the energy market [21]. Richter [58] stated that the term "disruptive technology" in the energy industry is mostly associated with solar PV and electricity storage because these technologies have had a massive impact on centralized power generation. Disruptive technologies, such as solar PV and electricity storage, support the concept of decentralized and localized power generation systems which give open access to households to generate power for their home usage. As per Cardenas et al. [59], the association of the smart grid with information and communication technologies is very influential, because the use of ICT in the smartgrid plays an essential role in transmitting and distributing energy. According to Zhou et al. [60], smart grid is an emerging technology which is transforming the whole energy industry. It can easily be integrated with different energy objects; such as; electric vehicles, natural gas, energy saving devices, and renewable energy sources. Yigit et al. [61] stated that information and communication technologies have made it possible for homes, buildings, and communities to make them smart and integrate and connect with each other through the help of advanced metering, sensing, and digitalized communication systems. Furthermore, Zhou et al. [62] pointed out that developing market strategies for the targeted market, and understanding the demand of customers and essential data technology can support and help the energy service providers. Niesten et al. [63] and Welsch et al. [64] stated that several scholars have claimed that there is no technical and functional existence of a smartgrid yet but they claim that this disruptive technology is going to make its emergence soon. According to Colak et al. [65], a disruptive technology has transformed the electrical industry and made it possible to integrate communication and information technologies into traditional electric grids and permit two-way flow of
Electricity and information between consumers and generators. Siano explains that modern technology such as smart meters, communication networks, and data management systems made it possible for consumers and service providers to transmit and receive information regarding usage and demand for energy. Thus, these technologies are the requirements if any energy providing firms are planning to offer smart grid services to their consumers.

Electric utilities used to have two ways of increasing revenue. The first way is to expand the electricity sales or in other words, to increase consumption volumes. The second method is to charge higher prices for per unit of sales. For decades, investors got revenues due to these methods. However, for the future, electric utilities need to change their business models for getting higher revenues and for satisfying the requirements of investors. Prices for electricity are a function of consumption volumes. Electricity companies need to charge higher rates for remaining volumes if sales of electricity decrease, which could be caused by the more efficient use of power, programs of demand management, distributed generation, and other changes. More charges will help to cover the capital cost or service cost. When the prices of electricity are growing, users are starting to reduce electricity usage through programs of demand management and innovative technologies. This situation is described as a "death spiral" by the media. Grace brought the example of the Western Australian South West Interconnected System when the high prices of solar PV resulted in the reduction of consumption because most customers could not afford that high price. However, nowadays industry analysts and researchers have less concerns about consumers, who are going off-grid and causing a "death spiral" for electric companies. There are high expectations that the majority of consumers will keep their network connection despite electricity storage. The reason is that consumers understand that batteries have technical limitations and the distribution network has its benefits, such as the trade of surplus energy between local regions, and the generation of solar energy should be high in the peak of demand. Instead of making investment limitations for electric utilities, solar PV utilization should be considered. The enormous amount of energy could be accumulated due to the usage of solar PV systems, which will require significant investments in smart grids and grid-scale batteries. Although electric companies will have lower incomes from traditional generation methods, extra earnings from smart grids and solar technologies will compensate their loses. Therefore, Tayal stated that due to easily accessible and cheap capital, as well as customer monopolies, electric firms have avoided disruptive challenges for a long time. Electric utilities should consider the effects which disruptive threats have had in other industries such as policy changing, technological innovation, and the preferences of customers as well. These threats should be considered while making plans for business growth and business strategies and companies should be willing to change their business models along with accepting new technologies. Moreover, Faucheux et al. stated, that it is necessary for the energy providing firms to develop new or redesign their business model.
5. Business Model and Smart Grid

A smart grid is an electric energy distribution technology which enables utilities and end-users to get full usage of data and aims to utilize electricity more efficiently and flexibly to adapt to variation in production and consumption [7]. A smart grid is equipped with a rich apparatus, such as a network of communication, smart meters for users, and automated data gathering devices [74]. These integrated technologies of a smart grid allow electric utilities to provide quality services to end-users [66]. However, only technologies are not sufficient to make
Electric companies are required to transform their business models because a smart grid changes the traditional value network for electricity [7]. Smart grid technology and a new business model enabling commercialization of a smart grid system in a localized and decentralized system are the two principal components to start the process of renewable energy economy evolution, which includes the switching from fossil fuels to an economy based on renewable energy sources [71].

A dozen theories describe the business model in various ways. However, most of them connect the business model with creation and capture of value. For example, a business model is a tool which shows how a company will create and deliver value to its customers and how a company can get profits [14]. Chesbrough et al. [75] stated that business models describe the running structure of the businesses. Baden-Fuller et al. [76] explained that through business models, companies and markets could be compared and analyzed to determine effective ways of doing business. Johnson [77] pointed out that for managers, the business model is a tool to examine their businesses and develop them further. However, Magretta [72] suggests two questions that companies should ask themselves when making their business models: “What value are we going to deliver?” and “How can we get profit from delivering the value?” Business models should clearly show the value creation and delivery [73].

This paper focuses on business models from value creation and value capture viewpoints. Nine building blocks of business models are described by Österwalder et al. [78] and Table 1 contains information about how companies are creating and capturing the value through these building blocks.

### Table 1. Business Model and its nine building blocks

<table>
<thead>
<tr>
<th>Building Block</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value Proposition</td>
<td>What value can the new smart grid system create for energy producers and consumers? The focus is on a combination of products and services, through which companies create and deliver value to clients and get profits.</td>
</tr>
<tr>
<td>Customer Segment</td>
<td>Targeted customer whom the value would be an offer by the company.</td>
</tr>
<tr>
<td>Distribution Channel</td>
<td>Ways of the approach used by the company to reach to the customer.</td>
</tr>
<tr>
<td>Customer Relationship</td>
<td>The company establishes and maintains a relationship with its specific customer.</td>
</tr>
<tr>
<td>Key Activities</td>
<td>Combination of different activities in offering and delivering value.</td>
</tr>
<tr>
<td>Key Resources</td>
<td>Assets and technologies required to offer and deliver value.</td>
</tr>
<tr>
<td>Key Partners</td>
<td>Suppliers and partners who are involved as support in offering and delivering value.</td>
</tr>
<tr>
<td>Cost Structure</td>
<td>The cost involved to execute the business model.</td>
</tr>
<tr>
<td>Revenue Model</td>
<td>Shows how production costs and profits related to each other.</td>
</tr>
</tbody>
</table>
5.1. Modern Trends in Electricity Market

Currently, consumers want to control electricity usage more than before. Consumers are paying more money for electricity due to modern gadgets and higher prices for electricity. According to Mardookhy et al. recent research on electricity usage and end-users attitude shows that most consumers are dissatisfied with the current electricity system. For example, 82% of survey respondents consider that electricity prices are too high and new mechanisms should be integrated to measure electricity usage more effectively. More control over electricity consumption could be gained through smart grids, which have visual displays for showing live data about usage of electricity. However, the smart grids’ features show that usage data could decrease the profits of electric companies. Thus, if companies want to integrate a smart grid system, they need to change their business model and the value they are offering. Mainly, the companies need to offer electricity efficiency services in more flexible ways instead of only providing electricity. In other words, electric companies will offer energy services and not electricity in itself. However, the energy industry needs a higher level of maturity for integrating the new business model. With the help of smart grid systems, they can adjust leverage and delivery according to a variation in demand with different prices, which is difficult in today’s “dumb” system.

The next trend in the electricity industry is customers’ changing attitude towards electric vehicle usage. In order to charge the battery of electric vehicles, more electricity will be used, which will create additional pressure on grids. The pressure will be increased when battery charging is happening during the power usage pinnacle. Thus, electric companies could deliver new value to consumers through constructing sufficient stations for recharging, which can take more pressure. However, electric vehicle usage is actively concerned with government policies and regulations, because electric companies will start to deliver new value when the government gives support to electric vehicle market through new policies.

Another trend in customer behavior is their expectations of high quality electric power and better delivery without power interruptions. Smart grids are equipped with several units connected to each other. This feature could provide better and uninterrupted electricity. The smart grids’ advanced mechanism can show electrical system problems immediately, which allows companies to fix technical issues by switching between diverse power delivery sources. Because of the vertical integration level of electric companies, they can focus on supply quality as a value to deliver to customers. When new government policies were introduced in the European electricity market, generation, transmission, and supply became separate stages. Outside of Europe, mainly electric companies with vertical integration exist, which assumes that a single company is controlling all stages of electricity generation and delivery. Many markets have companies which are specialized only in electricity delivery. These companies
are called electricity retailers. Smart grid systems will not be valuable for electricity retailers since the generation of electric power is not a focus of these companies.

A new area of usage of the smart grid system is the electric road system which is being developed that enables small cars as well as large vehicles, buses, and trucks to charge while driving on solar roads, with wires in the ground and in the air. Regardless of the chosen technology, there will be localized energy production that needs to be integrated with local dynamic consumption and the rest not used can be integrated into the grid system. To enable these innovations, smart grid systems are needed.

A smart grid has the capability to affect the relationships between consumers. Traditionally, electricity usage information was managed only by large companies in a centralized distribution grid system. As a smart grid provides electricity usage data to consumers, they can have more significant control over electricity. Furthermore, consumers can choose their electricity service providers, which give the opportunity to create trade relationships with electric companies. Meanwhile, electrical firms can benefit from consumers' increasing authority, because the firms can allow consumers to control the electricity system ("demand response") [80]. This permission includes the opportunity for consumers to shift electricity load based on pinnacle electricity usage time and the time with the lowest level of electricity usage. Faruqui et al. [88] state that investments in a smart grid will be productive only in cases of mutual benefit for both electric firms and consumers, when through the smart grid, firms are giving and receiving electricity usage data and allowing consumers to control loads in response. Thus, demand response and transparent data are significant components of the new value created by electric firms. Nonetheless, many consumers are not willing to control loads, and electric companies should try to solve this issue by offering new services to customers in order to enhance customers' participation [89]. For instance, companies could gain demand response by offering advice on how to use electricity efficiently [90], real-time feedback [91], equipment for measuring and controlling electricity [92] as well as pricing signals and micro-generators [88]. Research shows that these offerings can give positive results [80] and consumers attitude depends on their education, income level, thinking and specific climate in different regions. Thus, new value creation is based on demand response, which relates to the level of consumers' involvement [93].

The new Millennium has created an arena for new technologies, which has created new customer needs. Customers have changed their attitude and the way they perceive value. The smart grid system is an opportunity for electric companies to fit the new customer requirements [21]. Presently, customers have more awareness about environmental issues, and they follow new government regulations, for instance, feed-in tariffs, aimed to decrease the usage of fossil fuels [94]. Consequently, customers are more worried about environmental cleanliness [95].
As per Smil [96], societies have been taking into consideration issues relating to changes in climate, sustainable energy demand, as well as the development of the sustainable economy, which is built on renewable energy sources. Nowadays, the concept of global warming is a widespread topic of discussion. Lehtovaara et al. [97] stated that during the 20th century, over 1°C global temperature rise was registered. Furthermore, more temperature rise is expected throughout the 21st century because the concentration of carbon dioxide (CO\(_2\)) could increase up to 450 parts per million in the atmosphere [98]. According to forecasts, in 2050 humanity will consume 50% more energy than today, mainly caused by increasing gross domestic production (GDP) and population growth [99]. In 2050, CO\(_2\) emissions will increase up to 130% in the case of maintaining current levels of energy consumption and global warming [97]. As a result of increased emissions, global temperature will rise more than 6°C, which will severely damage the environment and society.

Fortunately, the problem of global warming has an optimal solution, which can decrease current change rates. The answer is concerned with the usage of renewable energy sources, including wind, hydro and solar energy, biomass and geothermal [98]. By using renewable energy through integrating smart grid system, electric vehicles and a new system of energy storage, climate issues can be solved [100].

Markets of wind energy are boosted by growing demand for energy and climate change issues. The decentralized and localized power generation systems can fulfill the growing demand for electricity which can be integrated with wind and solar energy [101] and biofueled combined heat and power production [102]. A biomass energy system should be integrated into those areas which are more abundant in natural resources [102]. Smart grid integration is a new and unexplored way to adapt and manage renewable energy sources which provide clean energy [10]. Although, integration of renewable energy sources will distribute the profitability of electric companies with ICT companies, investing in renewable energy will be a wise decision for them because the public requires a "green environment" [95]. One drawback is insufficient governmental support in the renewable energy sphere [103]. Despite that, governments of many countries have introduced new regulations. Still, there are lacks in governmental support. Therefore, new government policies for the energy industry will be the next step towards smart grid integration.

5.2. Response of Electricity Market Trends

As mentioned above, nowadays consumers are demanding sustainable power as well as control over their electricity usage. In order to maintain market position and gain profit, electricity firms need to follow these rising trends by providing new services. Companies can provide full services for installing and optimizing the generation machines, and they can charge optimal prices or offer free services.
Consumers may get help from electric companies when purchasing devices or kitchen instruments, which are energy-efficient. The US electricity company Duke Energy is buying consumers' old electric equipment and appliances and offers free energy-efficient bulbs. Electric firms can make partnerships with appliance producers and offer installment services or discounts to consumers. The companies can offer an advanced system of home energy or remotely manage appliances. Prosumers, who organize home-based renewable energy generation, could get assistance from electric companies to manage their operations. For example, companies could give advice relating to the efficient use of energy and support the generation apparatus to serve for a long time. Energy consumers' information provided to the retailers by a smart grid with the help of “big data” technology is the first way to increase revenue level. Electric companies can offer electricity usage feedback for the specific time period. Consumers would allow electric firms to gain data about electricity usage and users' demography. Then firms can use gained information for new value creation or to optimize the grid. Furthermore, electric companies can develop their business models to take advantage of detailed usage information, such as usage type (lighting, cooling, heating). The new business model could include electricity charges based on usage type rather than electricity kilowatt per hour. In addition, various charging mechanisms could be implemented, such as different electricity costs based on what time of the day consumers are using electricity. Consumer data could be used in other ways as well. Firms can sell the data to providers of electric devices, software or other companies in order to help other companies to create products matching with consumer needs. For instance, firms offering energy services could purchase consumer data and use it for making better tips and notifications about effective energy usage. Companies outside the electricity sector might be interested in the data in order to enhance their understanding of the behavior of customers. Thus, electric firms can get profit by selling the data. Despite that, it is not clear what the interest level would be of other companies. Social networks, and online retailers most probably will show interest, and they can be big players in the market.

5.3. Challenges to Offer New Energy Services

Still, the question of whether to provide the grid services themselves or to give the responsibility to other players is bothering electric companies. Even if electricity companies assign third-party firms to offer grid services, they can still get profits. Thus, smart grid builds a new market, which requires a new business model. The new market contains electric companies, ICT firms and electricity consumers. Inserting new participants in the electricity delivery chain creates new value. This approach is beneficial for electricity firms as well since they can access resources of ICT firms. Electric companies have already established a network of partner suppliers and consumers. It is
possible for electric firms to generate extra revenue from consumers and service firms by giving them rights to access the data. However, the most significant issue is the integration of more consumers and service providers, because the new delivery chain will be profitable only if there are huge customers and service providing firms [109]. Changes in cost structure are unavoidable during smart grid integration. As new participants enter the market, the infrastructure will evolve, and huge capital investments by electric firms will be necessary. Nonetheless, the investments will save companies from additional expenditures in the future. The main destinations of investments will be facilities of communication, smart meters, controllers, grid equipment, software, and removal of the existing grid [92]. Due to fluctuations in fossil fuel prices, high repairing costs, and high taxes, the existing grid becomes inefficient and expensive [110]. After smart grid installation, electricity firms will face the need to maintain the grid, train personnel to deal with the new technology and spend time on the data transferring process, which requires more capital investments. If electric companies use ICT firms for providing services, grid maintenance will be cheaper. ICT firms could use remote controls over the grid, which saves electric companies from spending money on staff, who would need to physically go and visit smart grid places. Therefore, instead of physically going and fixing problems, electric companies can save money and allow ICT firms to detect and fix system errors from a distance by using cloud computing technology [92]. The same approach applies to other operations, for example, meter reading. A smart grid has to automate data collection technology, which gathers the data and sends it to electricity providers. Thus, there will be no need to keep employees for reading meters. Moreover, automated meter reading eliminates the risk of customer’s stealing electricity [88]. Load-shift technology is another source of cost-cutting. If consumers are able to use load-shift technology, it can give 20%–50% investment compensation after installing smart meters. No new investment will be needed to build a transmission system since in a smart grid, distributed energy is generated close to the usage place [111]. Thus, the integration of a smart grid system will change the way electric firms create and deliver value. Still, there are uncertainties concerning the financial benefits smart grids can provide, which cause unwillingness to adopt the new system [112]. Features which a smart grid provides, such as power control by end-users, and effective usage of distributed resources of renewable energy, will reduce profits of electric firms [113]. However, at the same time, the smart grid will bring new opportunities and needs, which the firms can use to deliver new value to the consumers and gain more revenue by changing their business models.

5.4. Commercialization of Smart Grid’s Services through Business Model
5.4.1. Services to Integrate Renewable Energy
Table 2. Customer side renewable energy generation [63].

| Value proposition | Utilities sponsor the construction of home-based solar systems. Later, consumers generate electricity and get energy certificates, which can be used for refunding the investments. |

Customer segment

Utilities are doing consumer discrimination for dividing active and passive consumers through the management of consumers’ interface with transparent data.

Key resources

Integration of renewable energy sources equipment (wind power system and photovoltaic solar systems) are the essential technologies for electricity generation.

Key activates

Distribution of localized energy production to localized energy consumption on demand. Surplus goes to the grid system. Utilities for managing resources elaborate new techniques. Integration is the key component of activities between the production and the consumption side.

Key partners

The central partners are the companies which produce renewable energy (wind and solar) and those building energy systems. Energy distribution actors need to be integrated along electric roads, and integrated solutions need to be developed with many actors.

Revenue model

Revenues for utilities contain loan interests, as well as investments added to property value. Banks are getting revenue via using feed-in-tariff plan. There is a possible direction that energy distributors and smart grid system owners will change their value chain position to energy production in order to control the entire system. Thus, the revenue model will transform to integrated system providers. However, there is a risk of monopoly.

Table 3. Values through integrating of renewable energy sources with a smart grid for different actors [63].

<table>
<thead>
<tr>
<th>Services Provided by Smart Grid</th>
<th>Values for Consumers</th>
<th>Values for System Operators</th>
<th>Values for Service Providers/Aggregators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services for Integrating Renewable Energy</td>
<td>Electricity usage can be reduced</td>
<td>Benefits associated with finance</td>
<td>Good control over Power usage and bill</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Benefits associated with the environment</td>
<td>Consumers involvement will increase in the electricity system</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reduction of CO$_2$</td>
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<td>Network and supply reliability will be improved</td>
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<td>Network stability and security will be improved</td>
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<td>Operations associated with grid will be improved</td>
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<td>Peak demand can be reduced</td>
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<td>Additional income in the form of interest when solar systems are connected on loans</td>
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<td>Extra benefits through feed-in-tariff</td>
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<td>Profit in providing balancing services</td>
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<td>Income through charging batteries for electric vehicle as well as generating electricity at a low price using wind power and solar systems</td>
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<td>Smart way of batteries charges for electric vehicle and renewable energy will improve the financial sources to their own generated sustainable energy.</td>
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Demand response section contains the description of all sorts of dynamic pricing, such as real-time pricing, time-of-use pricing, and critical-peak pricing. As a result of dynamic pricing, peak loads decline, and the grid operates efficiently during the peak times [115].

Gordijn and Akkermans [116] discuss a service concerning with technologies of distributor generators which are used to stabilize the system. The technologies include combined-heated power which generates and supplies the heat. The providers of this service at profits provide equipment to consumers. Distributor generators (DG) are possible to add to the distribution system without reinforcements of the network. When overall DG electricity price is growing, management service providers make profits [116]. Electric vehicle batteries can serve as electricity storage, and later send the power to the grid [117]. According to Richardson [118], almost 30% to 75% growth of energy capacity is possible if the electric vehicle will store the power and send it to the grid which is
5.4.2. Electric Vehicle Services

As per the guidance of literature, two types of services have been explored in this section. These services are named vehicle to grid (V2G) and grid to vehicle (G2V) services. The batteries of EVs can store electric power, which later energy actors can sell to operators of the system. This process relates to V2G services. Meanwhile, G2V services include the process when energy actors purchase electricity for EV battery charging. Both services are provided by the EV aggregator, which is the new player in the electricity market. V2G and G2V services can be seen as a platform, which is built by EV aggregators. Furthermore, Giorlando and Fulli describe this platform as a business model which combines more than two interdependent groups of customers and products or services that can be offered to the groups. Niesten and Alkemade mentioned the players that are involved in the platform of service providing and consuming V2G and G2V. These electric vehicle aggregators are electric vehicle owners, the electricity market, system operators and battery switch stations. The electricity demand and supply overlap via EV aggregator, which provides G2V and V2G services for creating and capturing value. EV aggregator uses two mechanisms: firstly, electric vehicle batteries can be charged during the off-peak hours at a lower price than it can be discharged by selling the electricity at the battery stations during peak hours. Secondly, it uses EV batteries as electricity storage and offers the storing services to system operators. Table 4 shows a quick look at the values that are provided through electric vehicle services in the domain of smart grid system for different actors.
Table 4. Values through electric vehicle services for different actors

<table>
<thead>
<tr>
<th>Services Provided by Smart Grid</th>
<th>Values for Consumers</th>
<th>Values for System Operators</th>
<th>Values for Service Providers / Aggregators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Vehicle Services</td>
<td>Consumer participation will increase in the electricity system</td>
<td>System cost will be lower</td>
<td>Income from vehicle to grid services</td>
</tr>
<tr>
<td>Prices will be lower for energy and battery</td>
<td>Clean environment</td>
<td>Access will be easy which can help to improve the regulation services</td>
<td>Providing energy at lower cost from the grid to vehicle</td>
</tr>
<tr>
<td>Additional services</td>
<td>Reduction of CO$_2$</td>
<td>Stability and reliability of the grid will be increased</td>
<td>Peak demand can be controlled</td>
</tr>
<tr>
<td></td>
<td>Operations associated with supply and demand can be improved</td>
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</table>

Thus, it is essential to have a good knowledge about when EVs are arriving during the day, and owners of EVs can get benefit from charging batteries at specific times throughout the day. The case of an EV aggregator, which provides G2V service for EV battery charging, is proposed by Goebel. Although, in this case per annum profit is low for EV owners but there are several methods for getting higher revenues from the G2V business model. Firstly, the EV fleet needs to have a bigger size. Secondly, the batteries of EVs should be charged in specific time intervals, such as between 9 a.m. and noon and between 1 p.m. and 5 p.m. During these time periods, most of the EV owners are parking their cars near to their workplace. The involvement of renewable energy is significant in this case because it stabilizes the power supply and controls charging methods which are profitable financially. A V2G case is proposed by Loisel et al. The case includes EV fleets which sell electric power to the market. The authors found out that currently, V2G services are not profitable enough since many EV owners are not willing to get the service. The business model should be ameliorated for stimulating EV users. For instance, numerous approaches could be integrated in order to make V2G services more profitable, such as: offering additional services to electric car owners and remunerating them for using renewable energy. The second mechanism is proposed by Kempton and Tomiuke, who analyzed the case of V2G in order to find how companies can create and capture value through offering EV batteries’ electricity to the operator of the system. Managers of distributed electricity generation, network providers of mobile phones, retailers of electricity, as well as EV producers and fleet operators, can all be in the role of EV aggregators. Kempton and Tomiuke determined that the spinning reserves and regulation are the main sources of profits in V2G model. Furthermore, regulation is more beneficial than spinning reserves. Richardson mentioned that service providers are getting $100-300 profit yearly from a single EV. It is a matter of question whether service providers can engage EV aggregators or EV owners to the V2G model by this profit level. In order to involve owners of EVs aggregators need to offer packaged services, including discounts for battery charge, as well as purchasing and maintaining the battery with preferential rates. According to a contract, the owners of EVs
are required to charge their EV batteries from the grid at certain hours of the day. Due to lower transaction costs and economies of scale, the EV aggregators can afford preferential rates [126]. The bigger EV aggregation is, the higher capacity for additional services which can be offered by EV aggregator [126]. Some of the EV fleets are providing free space of battery (G2V). This service is called downward reserves for frequency control which are proposed by Jargstorf et al. [127]. Further Jargstorf and Wickert [127] argued that G2V service revenues are reaching from 5 to 16 euros monthly for a single EV. Nevertheless, installation, communication control costs are excluded from mentioned monthly revenues. EV fleet's accelerated battery degradation contains financial risks and Hill et al. [128] suggested that the profitability of V2G model is dependent on the duration of battery service. If the life cycle of the EV battery is short, V2G has low profitability. According to Niesten and Alkemade [63], Better Place is an appropriate EV aggregator case, which has been studied by some scholars. Better Place is a large international organization, which develops electric batteries, smart devices for battery charging, offers numerous services and software for EVs and operates in numerous countries, such as Denmark, Japan, Netherlands, and Israel. Better Place uses renewable energy sources, which are purchased from the market and makes partnerships with electric car producers, as well as with operators of the grid. Through partnerships, the company connects battery charging places with the grid and serves as a mediator between car producers and system operators. Consequently, EV owners are getting e-mobility services from Better Place through leasing batteries from the company and using switch stations and places for battery charging. Unfortunately, Better Place went bankrupt in May 2013, even though the company managed sizeable capital investments and had numerous partners. The company failed because firstly, the huge time required for the company to enter the market [116], and secondly, the company could not meet the demand for continuous investments [129]. Better Place, as an aggregator, invested in charging infrastructure at the time when EVs were in their initial stage of market entrance. Better Place used a business model requiring huge capital investments. Meanwhile, there are business models with a lower capital requirement [130], which could be implemented in the inceptive dispersal of EVs. Initially, EV owners are charging the batteries at their home according to their agreement with electricity providers. However, when EV sales grow, charging stations should be built mainly on streets and system operators will take the role of station owners [84].

5.4.3. Demand Response Services

Demand response (DR) service is another smart grid service in which electricity consumers regulate the load according to the requirement of the system operator or electric utility. When electricity usage reaches to the maximum in rush hours, operators will ask consumers to reduce the usage level in order to maintain the safety of the system and deliver the proper amount of electricity [84]. The US
Department of Energy relates demand response with the process of adjusting the electricity usage by the consumers in case of higher prices or serious system errors [67]. Demand response is divided into two types, such as price-based and incentive-based response. When consumers alter the electricity usage according to retail prices, it is called price-based response. It has numerous subtypes, such as real-time pricing (RTP), time-of-use pricing (TOU), and critical-peak pricing (CPP). In case of real-time pricing, consumers in advance are apprised about spot market-based tariffs, and they can adjust the usage appropriately [131].

The day is split into two intervals in TOU approach which includes electricity charges collected through on and off-peak tariffs [120]. If the price of electricity rises rapidly and the grid cannot meet peak demand, then the critical-peak method is used [132].

Incentive-based response method offers electricity regulation which is not connected with retailing prices [67]. In this model, electric utilities pay consumers and in response get permission to manage electricity load distantly [66]. Utilities can regulate electricity for the appliance. Nonetheless, consumers can choose to partly modulate the load and thus, interact with the utilities [133]. Thus, a new player is entering the market due to demand response service, and it is called demand response (DR) aggregator. According to Dave et al. [134], DR aggregator is an entity which controls a load of electricity in order to regulate the grid system and have lower peak demand. Aggregator provides electricity to the market, retailers, or actors who stabilize the power and maintain electricity on a safe level. While some stabilizing actors demand only 0.1 MW power for getting it from various sources (for example demand response), mainly actors need at least 1 MW electricity offer [135]. In any case, quite higher load levels should be produced by demand response service providers, particularly in urban areas. For having a lower load, up-front and on-going capacity payments are becoming widespread [67]. DR aggregators strive to have lower costs and higher profits; these payment methods are appealing to them. If electricity retailers need to purchase services of active demand, consumption and flexibility can be offered to them by the aggregators [92]. Therefore, aggregators are getting profits by providing services of demand response to retailers, stabilizing actors, and the market. Meanwhile, due to regulating their usage level and to being involved in the demand response services, electricity consumers are getting paid by the aggregators.

Niesten and Alkemade [63], claim that unfortunately, the proper business model of demand response is not provided by the existing literature. However, articles discuss how the providers of demand response services are creating and capturing value which is summarized in Table 5.

Over 500 consumers from four European countries who participated in the survey mentioned that they are pleased to follow smart grid signals and to get an opportunity to regulate their electricity usage [136]. Therefore, the end-users can reduce their consumption level and pay less for electricity. In December 2011, 69 Japanese households joined an inquiry of demand response service, which had a
6. Discussion
The 21st century is establishing a new era of energy sources by attempting to switch energy production from fossil fuels to renewable sources. This changeover is reinforced by several aspects, such as fossil fuel delivery restrictions, costs, environmental safety (especially changes in climate and temperature) and evolution in technology [25]. Timmons et al. [24] pointed out that costs of renewable energy will be reduced more, while costs of fossil fuels are expected to grow. Furthermore, Bhatti and Danilovic [1] stated that in decentralized and localized systems, electricity is distributed to specific geographic areas. Therefore, if electricity is generated in the same place where consumers live, the distribution and transmission costs will be reduced. Meanwhile, in a centralized system of power generation, there is a long distance between consumers and generation places which makes the distribution costly. Moreover, decentralized and localized systems can be integrated with renewable energy sources which provide clean energy whereas centralized systems produce electricity with the use of fossil fuels and emit greenhouse gases which are harmful to the environment. Similarly, Feisst et al. [34] repeated that traditional grids emit 25% of global greenhouse gases. Digitalized technologies are not viable with the traditional grid, as it cannot be integrated with solar, wind energy, low-inertia sources of electricity generation and distributed generation system [33]. Therefore, Banerjee et al. [35] claimed that smart grid is suitable for renewable energy and distribution system since it contains contemporary technologies for electricity generation and supply. Smartgrid can automatically identify system conflicts and fix them, by providing reliable protection from external dangers and cyber-attacks. Thus, economic tendencies are shifting towards renewable sources, even without proper government regulations. Shomali and Pinkse [21] stated that the smart grid is the future energy technology, and it has full potential to disrupt the energy providing firms, as it can change the entire process and structure of the energy market. Furthermore, Richter [58] claimed that the term “disruptive technology” in the energy industry is mostly associated with solar photovoltaic, wind turbines and energy storage technologies. These technologies have an immense impact on centralized power generation systems whereas, on the other hand, the same technologies support decentralized and localized power generation systems which give open access to households to generate power for their home usage. Zhou et al. [60] stated that smart grid is an emerging technology which is transforming the whole energy industry. It can easily be integrated with different energy objects; such as; electric vehicles, natural gas, energy saving devices, and renewable energy sources. However, Niesten and Alkemade [63] and Welsch et al. [64] argued that several scholars have claimed that no technical or functional smart grid exists yet but claimed that the smartgrid would make its emergence soon. Therefore, Tayal [68] stated that electric firms should not avoid disruptive challenges for a long time. Electric utilities should consider the effects of disruptive threats in other industries such as policy changes, technological innovation,
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DOI: 10.4236/ajibm.2018.89134

American Journal of Industrial and Business Management

and the preferences of customers as well. Energy providing firms should be willing to change their business models along with accepting new technologies. Moreover, Faucheux and Nicolaï [70] stated, that it is necessary for the energy providing firms to develop a new or redesigned business model. Thus, they can create and capture value on a larger scale by providing smart grid services to customers whereas Johnson and Suskewicz [71] stated that for the complete change of the energy industry, it is crucial to develop a new business model concurrently with the rapid shift in technology. Osterwalder [13] stated that business models are the instruments for firms to identify their technical challenges and clarify the capabilities needed to be achieved. Chesbrough [138] stated that business model innovation is a process of trials rather than planning. Companies try to change their business models based on experience and mistakes. It is about trying not predicting. Sosna et al. [17] claimed that business model innovation is the development of ways to create, deliver and capture value. Mardookhy et al. [79], stated that recent surveys show that 82% of respondents are dissatisfied with their present electricity system as they reported that electricity prices are too high and new mechanisms should be integrated to measure electricity usage. Geelen et al. [80] stated that by adopting smart grid technology energy providing firms offer more value to the customers regarding more control over electricity consumption. However, Marino et al. [81] argued that the features of smart grid will show the usage of data to the consumers which could decrease the profits of electric companies. Thus, if companies want to integrate a smart grid system, they need to change their business model as well as the values that they are creating for consumers. Schiavo et al. [84] stated that electric companies could deliver new value to consumers through constructing sufficient stations for electric vehicle recharging. Zio and Aven [86] stated that energy firms add value by providing better and uninterrupted power supply. Furthermore, Clastres [10] pointed out that smart grids’ advanced mechanism can show electrical system problems immediately, which allows companies to fix technical issues through switching between diverse power delivery sources. Boait et al. [89] claimed that demand response and transparent data are significant components of the new value created by electric firms. Similarly, Fox-Penner [105] stated that companies would change their value delivery by adopting smart grid. Smart grid allows retaining data from grid components and distributed energy sources. Piccoli and Pigni [107] stated that with the help of big data energy providing firms can understand the requirements of the customers which enables them to deliver better values according to the demand. Subsequently, Adam and Wintersteller [113] stated that smart grid would open up new opportunities and needs by which firms can utilize and deliver new value to their consumers, and in return, they can capture value. Energy providing firms can sell data to the energy retailers which they can use to build energy equipment for the consumers according to their need. Geelen et al. [80] stated that value could be captured by establishing a partnership with appliance producers. These producers can sell energy efficient kitchen or home-based in-
7. Conclusions

Conflicts of Interest
References
Electric Roads: Energy Supplied by Local Renewable Energy Sources and Microgrid Distribution System

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Summary

The electric road system is an emerging concept in this modern era. The advancement of technology has made it possible to give a real shape of this concept (electric road system). However, the energy which is provided to the electric roads is still been produced by non-renewable energy sources which is completely unhealthy and harmful for the society. Furthermore, the traditional grid is not suited to integrate with decentralized/localized energy generation and distribution systems. It is an ineffectual and environmentally extravagant system. Therefore, the preliminary contribution of this research is to introduce a decentralized/localized energy generation system based on renewable energy sources and energy distribution to electric roads through the emerging technology of microgrid and smart grid systems which have capability to easily integrate with renewable energy sources. Thus, producing electricity with renewable energy sources are environmentally friendly, less expensive and available without having any charges. However, each source of energy has some environmental impacts as well as cost differences. A brief description of environmental and cost impact of renewable energy sources (wind, solar) is also presented.

1 Research Questions / Purpose of the Study

The aim of this study is to explore the decentralized/localized energy generation system with renewable energy sources such as; solar and wind and energy distribution system to electrified roads with microgrid/smart grid and their economic and environmental impacts in order to lower carbon-dioxide emission at a low cost.

2 Methodology

To explore the environmental and economic impact of energy production through renewable energy sources and distribution through smart decentralized way (microgrid) to electrified roads, a literature study has been performed through the largest databases, such as; ABI/Inform Global, ACM digital library, IEEE, Emeralds journal and ScienceDirect. In order to get the complete picture, different keywords have been used to search the literature on electric roads such as; environmental and cost impacts, renewable energy sources, smart grid and decentralized distribution systems.

3 Results

Transportation system plays a crucial role in satisfying the needs of everyday life. However, transportation has its negative effects on people’s health as well as environmental effects due to emissions from fossil-fuels
(coal, oil and natural gas) in the form of sulphur oxides, nitrogen and carbon dioxide. Not only fossil fuels are depleting in the world, but it is expensive to install the huge power plants needed to produce and distribute electricity to electrified roads.

According to Schulte et al. [1] in the EU 24.4% of greenhouse gases as well as 33% of overall energy usage is contributed to transportation. In Sweden almost half of the gas emissions are caused by the transport sector, especially road transport which causes 93% of overall CO₂ emissions. For comparison, in Europe 24.4% of overall CO₂ is emitted by transport sector in which road transport causes 72.6% of emissions. In the USA transport sector is responsible for 26% of emissions [2]. Especially lorries are responsible for one fourth part of gas emissions. The reducing of gas emissions and switching to renewable energy sources have become essential parts of European laws and regulations, such as the Paris agreement. Teske et al. [3] stated that an important step in building a sustainable society is to make more electric cars since they are not emitting hazardous gases to the atmosphere. Electric vehicles or EVs has become a widespread research object. Since trucks emit more gases, making electric trucks could be a panacea for reducing emissions in the transportation sector.

In Sweden road transport has the biggest part in overall emissions. Nevertheless, when it comes to the electricity market Sweden shows positive results because in 2015 47% of overall electricity was generated from hydropower, second place was nuclear power 37% and wind power 10.5%. Consequently, gas pollution on roads can be reduced through building electric roads and the amount of electricity that is provided to electrified roads should be produced through renewable energy sources and more EVs [2].

**Power Generation / Supply to Electric Roads**

Electric roads will not be a solution to reduce greenhouse gases if the power is generated through the centralized power generation system as this system requires coal boilers and fossil fuels which emits gases. The centralized power generation system is completely outdated, insecure and inefficient, as it cannot be efficiently integrated with renewable energy sources and smart energy equipment. Furthermore, the cost is very high to generate and distribute electricity to the electrified roads as it requires heavy power generation plants and huge transmission lines. Whereas, decentralized/localized power generation system is the advanced and updated system as renewable energy sources and advanced technological energy equipment can easily be integrated. Moreover, decentralized/localized power generation systems can be located close to the energy consumption side which saves the transmission and supply cost. Although, the initial cost of the system is high but operational cost is low as it uses renewable energy sources to produce electricity.

In this modern world, where technology is evolving and bringing revolution in different sectors, similarly the advancement of technology has proved that the distribution of electricity with traditional grid is entirely an old and obsolete system, as it is basically a one-way channel system where power distribution system cannot receive immediate information if the electricity is terminated at the consumption side. The grid is incompetent to bear maximum load if it exceeds its projected demand. Moreover, it is not suited to integrate with decentralized/localized and renewable power generation sources. Therefore, traditional grid does not have sufficient capacity to fulfill the increasing demand for electricity [4]. On the otherside, smart grid and microgrid can be fully equipped with innovative technologies and be able to fulfill the future demand for electricity. Smart grid is a system, combination of innovative sensors, two-way communication system, intelligent electricity supply equipment and completely computerized system. Smart grid and microgrid systems can quickly adapt revolutionary enhancements in economics, reliability, efficiency, and sustainability of different electricity services. The beauty of microgrid and smart grid is that, networked intelligent sensors can be integrated with long-distance transmission lines which can be profited in increasing efficiency, improving operations and synchronizing alternative and even small power sources. By enabling the core functionality of plug-in electric vehicles, renewable sources, micro-grids and of other technologies would make it possible for smart grid to penetrate and integrate with these technologies. Finally, microgrid and smart grid can fulfill the future demand for electricity and the need for power for electric vehicles and electrified roads. Moreover, it is well capable of keeping environmental concerns[4].
Environmental Impacts of Renewable Energy Sources

Here, only two technologies, wind and solar, have been focused.

Wind Power

According to Macintosh et al. [5] producing energy with the wind is one of the lowest environmental impacts of all energy sources. Wind turbines can be installed on agricultural land and it occupies less land area than any of the other sources and technologies used to produce energy and still it is compatible with crops and grazing. It provides clean energy without emitting any gas or pollution during its operation. Klugmann-Radziemska [6] stated that modern turbines are designed to significantly reduce the noise and rotate slowly enough so that they are no hazard to birds. Furthermore, Leventhall [7] mentioned that infrasound and low frequency sound which are emitted by artificial sources (traffic, air conditioning) and by natural sources (wind and rivers) are everywhere in the environment. The modern design of wind turbine blades (upwind instead of downwind) have significantly contributed in reducing the level of infrasound. Health authorities and scientific research have proved that the low level of infrasound which are emitted by wind turbines have no health risks.

It is possible that during the sunset shadow flicker can be created by the wind turbines near residences. However, it can easily be avoided by turning off the turbines for the few minutes of the day when sun is at the angle that causes shadow or place the wind turbines at the suitable place [8]. According to Sovacool [9] a comparative study has been conducted in the United States on avian mortality in which it has been assessed the number of birds killed per kilowatt hour when power is generated through different sources, such as; wind electricity, fossil fuel and nuclear power systems. The study estimates that there is a higher chance of birds striking to wind blades or wind turbine towers but there is also a high mortality rate of birds with electricity produced with fossil fuels as it impacts on the climate change which destroys the habitats that birds depend on.

Solar Power (PV)

As compared to different electricity generating sources and technologies, photovoltaic is been proven a fundamentally safest technology with lower environmental risks. A photovoltaic module produces more electricity over its estimated life than the electricity uses to produce a single unit. A photovoltaic unit is noiseless and pollution-free operational system. Almost over two tonnes of CO$_2$ are prevented with a 100W PV module. However, the substances which are used in photovoltaic cells can be released at the installation site and in the air [6]. The photovoltaic devices are manufactured with the combination of different chemicals and materials. The amount of different types of chemicals varies according to the types of cell being manufactured. The types and the amount of chemicals varies based on the different kinds of cells being manufactured. Furthermore, a research has been done on the six photovoltaic manufacturing companies’ “Toxics Release Inventory System” database in the US, it has been found out that the amount of chemicals released to the air is almost negligible which cannot even be reported by the PV manufacturing companies. However, the two chemicals, air stack emission and fugitive air emission have been reported which are released to the air by the photovoltaic services. The air stack emission is used for etching and cleaning reported by all the six photovoltaic companies [10].

The environment is been impacted by the space occupied for the solar PV services. The habitat loss and land degradation issues could be raised if the solar services are provided on the larger scale and the important location is been chosen. These issues can be solved if the solar systems are placed at the lower quality locations such as; transmission corridors or mining land [11].

Cost Analysis

In these days, when fossil fuels are depleting, and the demand of energy is rising day by day, the cost has become a big issue to choose a right source of energy and technology to produce electricity. The figure 1 and figure 2 represents the past and expected price tendencies of wind and solar energy. The curves in the figure 1 and 2 shows that the prices are declining slower than in the past. Moreover, the price differences between solar and wind energies will shrink according to the figures. Thus, the cost of renewable energy can be predicted whereas the prices of fossil fuels are more unpredictable. According to the report of US energy department, each year 5% to 7% of cost on PV systems declined from 1998 to 2011. Furthermore, the prices on PV systems keep declining from 11% to 14% during the period of 2010 to 2011 and it is expected to decline more in the future as well [12].
Timmons et al. [13] stated that even though the cost of producing energy with renewable energy sources are decreasing but it is too early to say that compare to the price of fossil fuels the price of renewable energy will be lower in the future market. The main cost issues of generating energy with renewable energy resources are the net energy obtained by the renewable energy sources and the discontinuity of the capital intensity. However, the cost of producing energy with wind and solar is lower per capita as once the energy production system is installed then little operating cost is required to produce energy. Therefore Bhatti et al. [14] pointed that to build a renewable energy plant which produces equal amount of energy as a fossil fuel plant requires higher capital investments but operation and distribution of energy is much cheaper than fossil fuels.

Electrifying roads with energy supplied by renewable energy sources is a safe and efficient way for creating emission-free transport system. Therefore, to fully use the potential of renewable energy sources such as solar and wind power, new systems should be developed that enable renewable energy sources to be integrated into the grid systems which is hardly done in today’s old technology used by centralized grid systems.

Acknowledgments

The authors express their gratitude for all the support given by VTI, the Swedish National Road and Transport Research Institute, Sweden.

References


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Paper – IV
MULTIDIMENSIONAL READINESS INDEX FOR ELECTRIFICATION OF TRANSPORTATION SYSTEM IN CHINA, NORWAY, AND SWEDEN

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Abstract

The main objective of this paper is to develop a readiness index model that can serve as an analytical tool for exploring the achievements of electrification of transportation systems. We have applied this readiness index model to evaluate the readiness positioning of China, Norway, and Sweden towards transport electrification. We have chosen these three countries as they represent diversity among countries that are in the process of adopting electrified transport system solutions. Our developed readiness index model has four key dimensions, technological readiness, political readiness, societal readiness, and economic readiness. The embeddedness of all four dimensions in one model provides a multi-perspective way of analyzing and evaluating the readiness levels of countries moving towards transforming the transportation system. Therefore, we named the model a “multidimensional readiness index.”

Our main conclusions are that the political processes and political decisiveness involved are the most important factors followed by the societal needs and economic ability, with the current technology available as the fourth. Without the participation of dedicated and determined political decision-makers being involved, the other three factors are challenging to obtain. Political decision-makers need to facilitate the use of economic means to support the transformation in the society and affected industries to balance the initial economic disadvantages of the electrically powered systems until they pass the cost disadvantage turning point. The development of the relevant technology is no longer a great barrier as it was in the beginning of this transformation, about 20 years ago. The technology for electrically powered transportation systems and devices is widely available now, although it is continuously evolving and being improved. Associated industries cannot be expected to initiate, finance, take the risk, and take the lead in this global societal transformation without clear and strong political support.

Based on our multidimensional readiness index analysis, China is being positioned as the leading country in the world in the electrification of its transportation systems. This is mainly so because of the strong technology advancements, control of the entire value chain of research, development (R&D) and manufacturing of EVs, strong government decisiveness and execution power in developing and implementing favorable electric vehicle (EV) policies. The willingness of China’s public sector to take the lead and their citizen’s support to adopt clean technology are additional factors facilitating this advancement. Norway has rapidly become one of the newcomers in electrification with large numbers of registered electric vehicles, despite lacking manufacturing industries of electric vehicles. Sweden is a rapidly developing country in the electrification of transport, with three vehicle manufacturers introducing EVs in 2021. The government has been committed to
building demonstration sites for electric roads systems for more than ten years. Sweden is also working on establishing battery manufacturing facilities dedicated to the needs of electrified transportation equipment and systems.

Keywords: Electric transport, technology readiness, political readiness, societal readiness, economic readiness.

1. Introduction

The concept of electrification of all forms of transportation systems has been rapidly evolving worldwide. Technological innovation in the transportation sector has made it possible to give this concept a real shape (Bhatti et al., 2019). Many contenders had derided Toyota when they launched the first hybrid vehicle (Prius) in 1997 (Stephen, 2016). In 2003, Elon Musk started Tesla from ground zero because of the groundbreaking design and development work he was putting into the powertrain units for his vehicles. It took five years, but Tesla made phenomenally fast progress for the completely new territory. Tesla was not a prior manufacturer that had to diversify to survive but an entrepreneurial startup that did not follow traditional methods of the automotive manufacturer and came into being to fulfill an intuitively perceived need. Tesla has become the role model of modern electric vehicle development and also the developer of high-performance storage and recharging systems for electrified conveyance. Tesla develops and commercializes integrated system solutions, electric cars, charging infrastructure and batteries for their vehicles and energy storage. Tesla demonstrates a total system solution approach.

Some of the significant issues like the growing environmental warnings, increased pollution problem, and struggle for global market share forced the transformation of traditional internal combustion engine (ICE) manufacturers towards electrification of the entire automotive and transportation industry. Also, the old successful and prestigious European automakers such as Mercedes, BMW, Audi, and Volvo were finally forced to go electric due to political decisive pressure, new regulations, and new expectations from the lawmakers, markets, and customers. Now in 2021, also the most prestigious brands such as Bentley, Porsche, Rolls-Royce, Jaguar and super brands as Ferrari, and others are adopting electrical solutions with the increasing global awareness of the necessity for all nations to reduce their carbon footprint, nobody can afford to resist moving towards electrification of transport. One of the challenges is not ‘if’, but rather how fast the old automotive industries can make successful transformation. The main question will be if the dominant positions in the coming EVs will be taken by old established brands or by newcomers.

Some countries such as China, Norway and Sweden have already taken the initiative to an innovative approach to redesign their governmental policies that supports the diffusion of the developed electrified transport systems (electric vehicles and charging infrastructure seen as an entire system). Some countries are still at the early stages of development and are moving towards electrified transportation systems at a slow-paced whereas others are being rapidly left behind as they are still waiting and wanting to evaluate the success rate of the adoption of all forms of electrified conveyance. The other challenge is which government will ‘grasp the nettle’ and steer its nation to a position where its citizens accept all necessary initial expenditure and introduce firmly resolved policymaking to ensure that all dimensions of the electrification of transport systems proceed in an expedient manner. Thus, electrification of transport is becoming a political tool for global competition as well as battling the environmental consequences of fossil energy.

In this modern era, the technology used in electric vehicles is widely commercially available and possible to obtain on the Asian, European, and US markets as a commodity. The main understanding is to know which countries are the buyers and which are the manufacturers, i.e., value creators and wealth distributors, and which countries have the capacity to develop the entire value chain in each country that brings value to the country, industry, and wealth to the people.
Electrification of transport is a complex system associated with energy sourcing and distribution sub-systems all the way to electricity consumption (Bhatti & Danilovic, 2018a, 2018b). The whole transport electrification system is interrelated and interdependent on technology, industrial politics, economic conditions, political and societal domains, and the global competition for controlling market shares. To understand the content and consequences of electrification and handle this transformation, it is necessary to observe, analyze and evaluate the interconnectivity of readiness levels of all four domains (technology, political, societal, and economy) of the electrification of the transportation system. Thus, we aim to explore and understand how these factors influence the readiness of each country to go the electrical direction of the transportation system. Also, we hope that our multidimensional readiness index model can serve and support policy makers in different countries to speed up the electrification process for the benefit of the environment and citizens of the world.

2. Purpose

This paper aims to develop a readiness index model embedded with four dimensions, i.e., technology, political, societal, and economic. The idea of technology readiness is adopted from NASA, while the other three dimensions are empirically derived from our research on electrification of transportation system. Together these four dimensions form the readiness index model that we have used to i) analyze the development progress, ii) evaluate the readiness maturity level, and iii) determine the transitioning position of China, Norway, and Sweden in the electrification of transport. This paper also aims to that the ‘multidimensional readiness index model’ can assist decision-makers in identifying the essential and practical dimensions that can support the process of transforming the transportation system towards electrification.

3. Methodology

We have selected China, Norway, and Sweden as empirical grounds to explore their approaches to the electrification of transport, analyze the different conditions and contextual aspects of importance for electrification or transport to identify major critical dimensions, and to design the proposed multidimensional readiness index model. China has been chosen as it is today the dominant and leading country in the electrification of transport equipment and systems. Norway as one of the most electrified transport countries globally, and Sweden as one country with ambitions to become one of the world-leading countries in the electrification of transport. The selected countries are characterized by their ambitions to diligently pursue the electrification of transport and our explicit understanding of their development direction, although they might choose different paths. Figure 1 represents the procedure of research followed in this paper to obtain results that show the readiness of China, Norway, and Sweden in the area of transport electrification.

Our research on electrification of transport systems has been conducted from a system perspective and the research approach is based on a collection of secondary material from databases, journals, and publications. We have collected and analyzed the data of each country based on their technology, political, societal, and economic capability, decisions, and actions towards the electrification of transport. Technology is analyzed based on the vehicle ‘EVs’ and ‘EVs batteries’ manufacturing capabilities and charging infrastructure solutions. Political is interpreted based on government interest and demonstrated actions in the transport electrification, government support to provide subsidies and rebates to EVs buyers and EVs manufacturers and investment in charging infrastructure solutions. Societal is analyzed based on the sales and market share of EVs and the willingness of citizens to adopt EVs. Economic is analyzed based on the economic conditions for diffusion of EVs, purchasing and charging cost, the operational cost of EVs and government subsidiary to support the diffusion of EVs.
The main focus of this research is on passenger vehicles, although there are many vehicles such as motorcycles, two and three-wheelers, trucks, and buses. The development of heavy-duty vehicles, trucks, and buses has recently become commercially available worldwide. Two-wheelers are very common in Asia and emerging countries but not in developed countries. The attention in the electrification of transport from media and decision-makers has been directed to passenger vehicles. For the reasons of development phases of passenger vehicles and the great attention as the leading automotive industry, our focus has been chosen to be passenger vehicles. We have reasons to believe that the readiness model we have developed based on our research of passenger vehicles also can be used for other electrified vehicles. Also, trucks and buses as those aspects included in the readiness analysis and the model are valid for all other electric vehicles, although the commercial context differs.

To examine each country’s technology readiness capabilities, we have used NASA’s original model estimating the technological readiness while developing rockets to the moon program as the technological challenges were the most prevailing at that time. The decision to go to the moon was political and it was embedded in the US politics, supported by the public side and economy was not considered as restriction. The remaining challenges were technology related.

Thus, the moon project served as inspiration, but in the case of electrification of transport, the other three dimensions political, societal, and economic emerged from our previous research on the electrification of transport. In our studies of electrification of transport in China and in Sweden, we have noticed that while technology is getting high attention the other dimensions have high impact on the outcome and speed of the electrification (Danilovic & Liu, 2021; Danilovic et al., 2020; Liu & Danilovic, 2021). In the case of electrification of transport these dimensions cannot be taken for granted, rather they must be explored, understood, and put into practice to support ongoing transformation of transport electrification.

**Selected Countries**
China, Norway, and Sweden

**Data Collected**
Statista, Reports based on transport electrification, scientific papers

**Analysis**
Analysis has been done on the development capabilities and transformation processes in four areas, technology, political, societal and economic of each country.

**Technology**
Technology is analyzed based on manufacturing capabilities, such as EVs and batteries for EVs, Charging infrastructure solutions.

**Political**
Political part is analyzed based on government interest in transport electrification, support in order to provide subsidies, rebates and investment in charging infrastructure.

**Societal**
Societal is analyzed based on the sales and market share of EVs, acceptance of transformation by citizens, willingness to invest in and buy EVs.

**Economic**
Economic is analyzed based on the purchasing cost and operation cost of electric vehicles.

**Results**
Finally, results have been obtained by evaluating each dimension based on their readiness scoring scales. Each country’s score of all four dimensions has been added and then taken out the percentage. These mathematical results have been depicted in a graph that can be used to evaluate each country’s positioning against the 100% readiness scale in the development of electrification of the transportation system.
Our research has developed a ‘multidimensional readiness index model’ that enables us to explore and understand any transport mode, including flight and shipping. But for this research, we have applied the model to China, Norway, and Sweden to evaluate the development progress of these countries in their electrification of transportation systems. We have also developed and classified the political and economic readiness levels based on empirical observations. For societal readiness levels, we have been inspired by the European societal readiness levels (Büscher & Spurling, 2019) but adopted them based on our need that focuses on the adoption of electric vehicles by society. The pattern of each readiness scale that looks like a thermometer has been adopted from the “KTH Innovation Readiness Level.” Each readiness dimension is divided on a scale between 1 and 9. Each of the 1-9 levels shows a certain level of readiness; the 9th level shows the highest readiness scoring, whereas the 1st level shows the lowest readiness scoring of the countries in the electrification of the transportation system.

Finally, results have been obtained by evaluating each dimension based on their readiness scoring scales. The score of all dimensions (technology, political, societal, and economic) of each country has been summed up (Σ) and taken out the percentage (%) by dividing the total score as shown in table 5 in section 6. These mathematical results have been used to plot a graph, as shown in figure 11 in section 6, which shows the positioning of each country in the development of electrification of the transportation system.

The proposed four-dimensional readiness index scales are tentative and should be further developed, elaborated, and thoroughly tested. As the diffusion of transport electrification continues, new technologies will be launched, and new experiences will be developed, thus creating reasons for reevaluation of the scales of political, societal, and economic readiness to achieve high maturity levels.
4. Multidimensional Readiness Index Model

The multidimensional readiness index model is basically sourced from the technology readiness level (TRL) introduced by the National Aeronautics and Space Administration (NASA) in the early 1970s. The multidimensional readiness approach consists of four dimensions, technology readiness (TRL), political readiness (PRL), societal readiness (SRL), and economic readiness levels (ERL). These four dimensions form a web and, therefore, create a whole system where no one can be left out to gather a broader understanding of the electrification of the transportation system (Danilovic et al., 2020), as shown in Figure 2.

We have adopted an innovation perspective to examine the TRL and explore other key components to understand and incorporate into a system approach. Generally, the term ‘innovation’ refers to the introduction of new or recombined ideas or methods, however in the context of this analysis, ‘innovation’ is also about using technology to succeed with the commercialization, value creation, and diffusion in the society via a suitable business model. The technological element is merely one of the essential dimensions of the business concept. The technology requires a proper and relevant context to be embedded and integrated for its commercialization. Economic, societal, and political acceptance are the main elements needed for a potential technological solution to become a successful innovation accepted by a majority of the market. When it comes to some of the most successful innovations in our society, such as fast trains, airplanes, electric vehicles, and smartphones, we can see that they are all rooted in the political, economic, social, and socio-cultural contexts of their respective eras.

The diffusion and deployment of technologies are based on social acceptance; without socially being accepted, technology for technologies’ sake will face endless public resistance. It will be difficult to achieve commercial success for technology and attract investment and partners if political, institutional, and regulatory players do not support it. Therefore, the acceptance of developed
Technologies need to be observed and examined in the context of a complex web of interactions that includes technical, political, societal, and economic elements.

The technology readiness levels can be used to evaluate the readiness of technology. The political readiness levels express the dedication and willingness of the government to adopt and promote the technology in the country. The societal readiness levels show the technology’s adoption rate, and the technology has been supported by society. The economic readiness levels demonstrate the affordability of the technology for the buyers to consume the product. Thus, all the readiness levels are interdependent and interrelated to each other. However, the role of the political readiness levels is the most significant in holding all the other three readiness levels in one net to support the transformation.

4.1 Technology Readiness Levels (TRL)

Technology readiness level (TRL) is an approach for conducting a logical analysis, assessment, and decision-making process when selecting an appropriate technological solution based on maturity of technologies. TRL has become a standard approach to measuring a particular technology’s maturity. Fundamentally, TRL determines if technologies are ready for adoption by potential consumers (Hirshorn & Jefferies, 2016). Level 1 is considered the lowest, and level 9 is the highest measuring criterion on the TRL scale. Figure 3 demonstrates all nine levels of TRL.

![Figure 3: Technology Readiness Levels (Hirshorn & Jefferies, 2016)](image)

Table 1 illustrates those 9 TRL levels in more detail.

<table>
<thead>
<tr>
<th>TRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Technology is ready to be deployed on a larger scale.</td>
</tr>
</tbody>
</table>

Table 1: Description of Technology Readiness Levels
Table 1 illustrates the nine steps of evaluating the maturity levels of technology that begin with an idea and transform to the fully functional technology that reaches the level where it can be deployed on a larger scale. The levels from 1 to 9 can assist the decision-makers in observing and analyzing the development progress and transitioning of technology into a desired form. It can be noted that the established TRL is focusing on technologies and not on system level where different technologies can be combined or recombined.

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>The evaluation of the evidence proves that technology works and is ready for deployment.</td>
</tr>
<tr>
<td>7</td>
<td>The fully functional technology is tested in the planned operational system and gathered evidence of its success.</td>
</tr>
<tr>
<td>6</td>
<td>The technology is tested in a simulation environment that replicates the natural world and provides almost accurate results. A fully functional representational model is considered a TRL – 6.</td>
</tr>
<tr>
<td>5</td>
<td>Technology at TRL 5 is a continuation of technology at TRL 4. However, TRL 5 is considered a breadboard technology and must undergo more thorough testing than technology at TRL 4.</td>
</tr>
<tr>
<td>4</td>
<td>The initial findings are collected, and multiple parameters are tested.</td>
</tr>
<tr>
<td>3</td>
<td>When active research and design starts on a particular technology.</td>
</tr>
<tr>
<td>2</td>
<td>When basic concepts have been investigated, and practical applications may be developed based on those results. However, TRL – 2 could be risky as there is no empirical evidence that the technology exists.</td>
</tr>
<tr>
<td>1</td>
<td>The beginning phase of any technology when the conceptual study is translated and reported for future research and development.</td>
</tr>
</tbody>
</table>

We have experienced that technology has been one of the most critical driving forces of societal and industrial transformation. The advancement of technology has introduced various technological solutions for decarbonizing the environment, such as renewable energy, transport electrification, hydrogen-based transport, etc. However, large-scale R&D, implementing new technical solutions, and diffusion of new technologies are almost impossible without political decisiveness and determination to utilize technology to transform and develop society. This is especially valid for the electrification of transport as transport is one of the most harmful environmentally impacting industrial sectors globally. At the same time, it is directly associated with the coal and oil industry, which are an economic engine and a significant employer of many countries and will be the loser when transport is electrified. Some are suggesting that this ongoing electrification of the European automotive industry might lead to about 500,000 people losing their contemporary jobs. Political readiness is seen when the politicians recognize the problems and challenges and provide immediate support in framing new regulations, laws, and policies to support economic, industrial, and consumers for achieving the capabilities of purchasing expensive but desirable technologies that are costly in the beginning. Figure 4 explains the nine levels of PRL.

4.2 Political Readiness Levels (PRL)
Table 2 illustrates those 9 PRL levels in more detail.

<table>
<thead>
<tr>
<th>PRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The government includes the idea in its national plan and monitors the development and implementation from the top level.</td>
</tr>
<tr>
<td>8</td>
<td>The government sees the impact of the new innovative product/project from a holistic system perspective and integrates other dimensions (economic, societal, and environmental) in their policy rebuilding and deals with it as one system.</td>
</tr>
<tr>
<td>7</td>
<td>The government provides the fund to the relevant stakeholders to begin the work.</td>
</tr>
<tr>
<td>6</td>
<td>The government approves the funds for converting the idea into a physical reality.</td>
</tr>
<tr>
<td>5</td>
<td>The coherence and commitment among the local/regional, provincial governments and institutions on each level in developing the budget planning and planning to monitor the idea to be implemented.</td>
</tr>
<tr>
<td>4</td>
<td>The government makes new policies or reshapes their old approaches to transform the idea into reality. For instance, imposing taxes to eliminate the old product that is not environmentally friendly reduces or eliminates taxes on the new product that the government wants to promote, which is good for society and the environment.</td>
</tr>
<tr>
<td>3</td>
<td>The new innovative idea and benefits are announced in the parliament, where the government and opposition parties mutually approve it.</td>
</tr>
<tr>
<td>2</td>
<td>The idea is discussed in the cabinet meeting where local, regional, and state governments show their willingness to move forward and develop the action plan.</td>
</tr>
<tr>
<td>1</td>
<td>The head of the state publicly expresses his/her interest in moving towards new innovative ideas/new inventions or adopting new technology.</td>
</tr>
</tbody>
</table>
4.3 Societal Readiness Levels (SRL)

Societal readiness level is a scale for analyzing and evaluating the readiness level of societal acceptance; for example, a product or a technology to be integrated into society needs to be accepted and desired by its citizens. Suppose we continuously design technologies, infrastructure, and policies in which people are not incorporated and do not see the benefits for them and their lives. In that case, there will be a risk in moving forward towards electrified solutions because it could be a failure (Cardullo & Kitchin, 2019). SRL 1 is the lowest, and the SRL 9 is the highest level of readiness indicating that society has already started adopting new technology or product. Figure 5 demonstrates all nine levels of SRL.

Table 3 illustrates those 9 SRL levels in more detail.

<table>
<thead>
<tr>
<th>SRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The product diffused in society, and many citizens buy the product.</td>
</tr>
<tr>
<td>8</td>
<td>Business development and product commercialization are done, and the product’s initial sales begin.</td>
</tr>
<tr>
<td>7</td>
<td>The citizens and the relevant stakeholders test the first product and confirm the benefits.</td>
</tr>
<tr>
<td>6</td>
<td>Establishing a business relationship by demonstrating the solutions with the customers and the relevant stakeholders.</td>
</tr>
<tr>
<td>5</td>
<td>Customers and stakeholders’ views confirms the success rate of the proposed solutions in the specific area.</td>
</tr>
</tbody>
</table>
Table 3 illustrates the nine levels of evaluation of incorporating society in the transformation of an innovative product (electric vehicles) and the citizens’ adoption and diffusion of EVs.

### 4.4 Economic Readiness Levels (ERL)

Economic readiness level is a dimension for analyzing and evaluating the readiness levels of cost affordability of a technology or a product by the industry that impacts them and by the large number of citizens expected to adopt electric vehicles. Economic readiness plays an important role in diffusing innovative products (electric vehicles) in society. The consumer’s approach is to pay for something less expensive or better than they already have.

The word “economic” is a vast subject divided into microeconomics and macroeconomics. Microeconomics is a bottom-up approach that deals with individuals, business decisions and concentrates on supply – demand and forces that determine the price levels. Macroeconomics is a top-down approach that deals with decisions made by governments and countries. It focuses on the economy, where the government determines the investments in R&D, prices, imposes and reduces the taxes, and provides rebates and subsidies to balance the development and manufacturing cost for early technologies with the price level of the products in the market (Potters & Logan, 2021). After all, the business operators and citizens must afford to buy the new technology and products coming on the market.

The transformation of the transportation system is a national and international matter that involves facing national and international challenges such as global warming, pollution, and depletion of fossil fuels in the world. Being responsible nations, it is countries’ governments’ responsibility to deal with these challenges and support the transformation of the transportation system towards electrification. Therefore, we have used the macroeconomic concept to build the economic readiness levels where the government controls the prices to bring stability and affordability to the market. The government has the mandate to manage and set the minimum or maximum prices for specific products, including gasoline, electricity, and vehicles (Kenton & Potters, 2021).

To develop the economic readiness levels, we have focused on balancing cost of three main factors (manufacturing cost of EVs, energy supply for the transport infrastructure, and operational cost), where governments can support by providing subsidies, rebates, imposing /reducing taxes on the EVs to push the EVs in the market for societal diffusion to achieve certain benefits, for instance, decarbonizing the environment and less relying on fossil fuels. The government can support until the economic readiness reaches the highest level where the price balances for consumers and producers, which means that the consumers can afford the product, and the producers can still capture the value. Figure 6 demonstrates all nine levels of ERL.

<table>
<thead>
<tr>
<th></th>
<th>The proposed solution is tested by collecting views of the customers and relevant stakeholders through the pilot projects.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Suitable solutions that fit the best for the problems and the awareness are provided to citizens and relevant stakeholders.</td>
</tr>
<tr>
<td>2</td>
<td>To specify the need or problem of society, some market research is performed mainly based on secondary data.</td>
</tr>
<tr>
<td>1</td>
<td>In the initial stage, problems are identified, such as environmental problems, different customer needs or factors associated with human health, etc.</td>
</tr>
</tbody>
</table>
Table 4 illustrates those 9 ERL levels in more detail.

**Table 4: Description of Economic Readiness Levels**

<table>
<thead>
<tr>
<th>ERL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The EVs’ purchasing and operational costs become equal to or less than gasoline-based vehicles.</td>
</tr>
<tr>
<td>8</td>
<td>The government provides affordable/free charging facilities at public charging stations or affordable/free charging piles at public parking or support installing charging piles at home. This act will reduce the operational cost of EVs for citizens.</td>
</tr>
<tr>
<td>7</td>
<td>The government reduces/eliminates the registration and insurance fees on EVs, which will further support citizens in the cost reduction on purchasing EVs compared to gasoline-based vehicles.</td>
</tr>
<tr>
<td>6</td>
<td>The government provides extra support to encourage citizens to buy EVs by offering subsidies and rebates.</td>
</tr>
<tr>
<td>5</td>
<td>The government reduces/eliminate taxes on EV purchase for citizens to control the initial cost of EVs.</td>
</tr>
<tr>
<td>4</td>
<td>The government also supports renewable energy providers by eliminating/reducing taxes for those who provide energy to the EV infrastructure.</td>
</tr>
<tr>
<td>3</td>
<td>The government provides extra support to encourage automotive manufacturers to produce electric vehicles by offering subsidies and rebates.</td>
</tr>
<tr>
<td>2</td>
<td>The government reduces/eliminates taxes for companies producing electric vehicles and charging equipment.</td>
</tr>
<tr>
<td>1</td>
<td>The government revises their tax duties on import/export of EVs, EVs batteries, charging equipment, and equipment supporting renewable energy (solar panels, wind turbines, etc.)</td>
</tr>
</tbody>
</table>
Table 4 illustrates the nine levels of government involvement to make economic readiness ready for each stakeholder participating in the transformation of the transportation system. The technology, political and societal readiness levels are more of general readiness levels that can be used for any technology, political and societal context, but the economic readiness levels depend on the development requirement of the product and the context where the product will be used.

Economic readiness is itself a complex dimension that is interrelated and interdependent on various factors such as government policies related to import/export, manufacturing companies’ capabilities (they have complete value chain capability or need to import the parts for manufacturing the product), and the market behavior. Not all the products require the same or specific infrastructure to operate. For instance, the airline and shipping industry follows international laws, customer segments vary from country to country, and the airplanes manufacturers are limited, so the economic policies are designed by considering these factors, which do not apply to the automotive industry. Therefore, the economic readiness levels are explicitly developed for electrification of transportation systems because economic readiness depends on the import/export policies of the government, requires specific infrastructure and support of energy companies to operate electric vehicles.

5. Analysis of the selected countries

5.1. China

5.1.1. Technology Readiness Level in China

The electrification of transport started in China already 15-20 years ago. China is presently taking the lead in developing electric vehicles, electric motors, batteries of all kinds, charging infrastructure and also the most important component of the EVs, the software based control and monitoring systems (Danilovic & Liu, 2021; Liu & Danilovic, 2021). Different manufacturers introduced more than 200 brands of electric vehicles in China in 2020. Even though not all of those brands houses have manufacturing capabilities, they have outsourced a few large-scale electric vehicle manufacturers to design and use specific technology based on their required criteria (Danilovic & Liu, 2021). In 2021 several Chinese EV manufacturers announced to export EVs to Europe, focusing on the Scandinavian market. The top 10 brands of EVs sold in China in April 2021, among 9 of them are Chinese brands except for Tesla, which is also manufactured in China, as stated in figure 7.

Figure 7: Top 10 selling brands and their sales of EVs in China in April 2021 (Kane, 2021b)
China has established the entire value chain and system from components to the fully integrated system for developing and manufacturing EVs. China is also taking the lead in developing the vehicle battery charging infrastructure as well as one of the largest battery manufacturing capabilities in the world, beside South Korea. The China Electric Vehicle Charging Infrastructure Promotion Alliance (EVCIPA) estimated that by the end of June 2021, China had almost 1.947 million EV charging piles available for public use, which represented an increase of 47.3% in one year. The installation of public chargers has risen rapidly in China and reached 923,381 by the end of June 2021. There were around 374,000 fast chargers, 550,000 slow chargers, and 426 DC-AC integrated charging piles. According to EVCIPA estimation, almost 30,400 public EV battery chargers were installed each month from July 2020 to June 2021. Five major cities of China hold the most EV chargers as of June 2021. These cities are Guangdong (10,514), Jiangsu (5,981), Zhejiang (5,355), Shanghai (5,337), and Beijing (5,190) (Nika, 2021).

However, another implemented charging infrastructure solution has been developed for operating EVs as complementary charging solution, which is battery swapping technology. The Chinese government has put battery-swapping and hydrogen technology on the national strategic agenda. Hydrogen has been mulled as an alternative fuel for ICE powered vehicles as an alternative to hydrocarbon-based fuels, thus representing a further means of reducing the carbon footprint. Electric vehicle manufacturers’ key leaders (NIO, Geely, BJEV, and Changan New Energy) have adopted battery swapping technology. By the end of June 2020, there were 452 battery-swapping stations in China. The growth of battery swapping stations continued and reached over 716 battery-swapping stations by the end of June 2021. Estimations indicate that there will be 25,000 swapping stations in 2025 for passenger vehicles (Danilovic & Liu, 2021) and more than 400 swapping stations for heavy trucks in few years’ time (Liu & Danilovic, 2021). The electrification of Chinese mega cities is complex and complicated to manage through cable charging solutions only. Thus, swapping systems are introduced as complementary systems. Thus, China is positioned at level 9 in the technology readiness level of the multidimensional readiness index.

5.1.2. Political Readiness Level in China

In 2009, the central government of China started subsidizing EV sales for public and government fleets, and in 2013, it began supporting private EV owners. The subsidies were between $5400 to $9000 per vehicle in 2013, dependent on the vehicle’s electric range. At the end of 2020, the government introduced a new EV subsidy policy for 2021. According to the new policy, 20% of the subsidy was reduced on pure electric vehicles. Vehicles with a driving range between 300 to 400 km dropped from $2500 to $2000 per vehicle, and vehicles with a driving range of 400 km or more decreased from $3500 to $2800 per vehicle. In addition, for hybrid vehicles, the subsidies dropped from $1320 to $1050 per vehicle. The unexpected drop of 20% subsidy on EVs sharply decreased the sales of EV’s in the industry. The government extended the EV subsidy support for two years until the end of 2022 to get the market back on track. The sales of EVs rebounded when the government approved the extension (Barrett, 2021).

The Chinese government decided in May 2020 to include battery swapping technology as a national strategic development technology which handles a new infrastructure policy that focuses on the whole life cycle value of the battery. By the end of 2020, the battery swapping technology was highly supported in the most significant Chinese national policy that drives industrial development in China, ”The new energy vehicle development plan 2021 – 2035” (Danilovic & Liu, 2021). Battery swapping has become attractive to drivers since it decreases upfront costs and reduces re-charging time. In 2020, NIO introduced a new business model based on unbundling vehicle purchases, battery renting, and swapping subscriptions. The four major Chinese electric vehicle manufacturing companies that provide battery swapping services are NIO, Geely, BJEV, and Changan New Energy. Standardizing battery-swapping services has been a priority for the Chinese government. In April 2020, the Chinese government extended the subsidies for the EV manufacturing companies, with the condition that
companies will only be eligible for grants if the prices of EVs are below about $46000. However, this policy does not apply to battery swapping models. The policy indicates that most premium electric vehicle manufacturers will have to decrease the EV prices to meet the requirements for the subsidy scheme, and the policy also shows the clear intention of the government to boost the battery swapping business in China. The Chinese Finance Ministry has announced to cut down 30% subsidies on new electric vehicles (NEV) in 2022 and eliminate the subsidies from 31st December 2022 (Randall, 2022). China will become the first country to eliminate all sorts of subsidies on NEVs by the end of this year, which might affect the sales of NEVs. However, the overall interest of the Chinese government in the diffusion and adoption of sustainable electrified transportation is very high. Therefore, China is placed at level 9 in the political readiness level of the multidimensional readiness index.

5.1.3. Societal Readiness Level in China

Chinese society has been introduced to the concept of electrification for more than 20 years. In 2019, battery electric vehicles (BEVs) sales reached almost one million, three times more than plug-in hybrid electric vehicles (PHEVs). The sale of electric vehicles continuously increased in 2020 and reached above one million. In July 2021, 271,000 electric vehicles were sold in China, which nearly broke another monthly record. Compared to July 2020, 164.4% of electric vehicle sales increased in just one year, indicating that the electric vehicle sector is booming, with numerous brands and models selling in large numbers. The overall market share of EVs, including 12% BEVs and 3% PHEVs have increased and reached 15% in the mid of 2021 (Kane, 2021a). In the six largest Chinese cities, electric and hybrid vehicles now account for approximately a fifth of new car sales on average. Consumers in China’s industrialized cities on the east coast have adopted electric vehicles more rapidly than their inland counterparts. The electric vehicle penetration rate in major cities is 8% higher than in other cities of China. Like Shanghai 31%, Beijing 16%, Guangzhou 13%, Shenzhen 25%, Hangzhou 21%, and Tianjin 12% (Bloomberg, 2021). Already ten years ago, the 12 million inhabitant’s city of Shenzhen introduced electric vehicles on large-scale buses for the initial electrification of the public transport domain. Now, Shenzhen has 22,000 EV taxis, 18,000 EV buses, and 86,000 EV logistic transport vehicles. Now ordinary people see that the next step is full electrification of private vehicles. Chinese society is fully committed to moving expeditiously towards sustainable transport based on a fully electrified and fossil-fuel-free transportation system. Therefore, China is positioned at level 9 in the societal readiness level of the multidimensional readiness index.

5.1.4. Economic Readiness Level in China

The economic readiness analysis is based on the electric vehicle cost, the operational cost of the vehicle, subsidiaries’ support to make the price and cost affordable for citizens, businesses, and the outcome in terms of value creation to the country and people. A survey was conducted in June 2019 by 'Rakuten Insight' on the "Acceptable price level for purchasing an electric car compared to a conventional car in China." Almost 26% of the Chinese consumers are only willing to pay the same price for an electric car as a conventional car, whereas 18.8% of the consumers agree to pay up to 10% and 22.4% of the consumers are ready to pay 11 to 30% higher than conventional cars (Wong, 2021). In total, 45% of the consumers are willing to pay a higher price for electric vehicles than traditional cars. In contrast, only 8% of the consumers are not willing to pay a higher price for electric vehicles than conventional cars. It means more people favor electrified transport in China besides the cost of the electric vehicle. One explanation behind this is that electric vehicles bring health improvements to citizens, especially in highly dense cities, which are values for citizens they are ready to pay.

The price of electric vehicles is continuously dropping in China. Consumers achieve cost competitiveness on electric vehicles many years earlier than expected, primarily due to the vehicles’ fuel savings. In 2022–2026, electric cars provide a compelling new vehicle purchase proposition based on an analysis of first owners’ 5-year vehicle ownership expenses. Electric vehicles’ fuel and maintenance savings greatly surpass home chargers and other expenditures for the first buyers in
2025. The BEV ranges of 250–500 km and PHEV ranges of 40–100 km is compared to the conventional cars in these two categories. In 2020, the initial prices of electric vehicles were $5,000 to $17,000 more than similar gasoline vehicles. By reducing the cost of components and subsystems, and the assembling of EV and EV batteries, the projected prices of a short-range BEV in 2026 and a long-range BEV in 2030 will be equal to their similar types of gasoline vehicles. The charging cost of electric vehicles depends on the prices of electricity provided by the grid. Since China wants to encourage the use of electric vehicles, the charging prices have been set at low levels. There are time-of-use fees for EV charging in several provinces and cities in China. State Grid’s charging stations also use time-of-use pricing. State Grid Beijing costs RMB 1.0044/kWh (approximately $0.16) during peak hours, RMB 0.6950/kWh (approximately $0.11) during shoulder hours, and RMB 0.3946/kWh (approximately $0.062) during off-peak hours, plus a service fee RMB 0.8/kWh (approximately $0.13) (Boya & Jing, 2018). However, the cost of electric vehicles is still not competitive compared with gasoline vehicles, and it is mostly the subsidies and rebates that encourage people to buy electric vehicles. Estimations are made that the EVs will be price neutral to ICE technology in 3-5 years. Therefore, China is placed at level 8 in the economic readiness level of the multidimensional readiness index.

5.2. Norway

5.2.1. Technology Readiness Level in Norway

Norway does not produce electric vehicles but primarily imports them from other countries. The top ten selling brands of electric vehicles in Norway in September 2021 are imported from the Czech Republic (Skoda), Germany (Volkswagen and Audi), Japan (Nissan and Toyota), South Korea (Hyundai), and the USA (Ford and Tesla) as shown in figure 8.

Figure 8: Top 10 selling brands and their sales of EVs in Norway in September 2021 (Kane, 2021c)

In May 2021, NIO China, a BEV manufacturing company, started its operation in Norway to provide a full-fledged ecosystem incorporating cars, services, and charging infrastructure. NIO Norway has introduced its first smart electric vehicle model NIO ES8 SUV, but it was available on 3rd September 2021 at Honefoss Airport for a test drive. NIO provides a total system solution offering electric vehicles supported by charging infrastructure, battery swapping system and cable charging solutions. NIO plans
to establish 20 battery swapping stations in Norway in 2022, and one is already operational outside Oslo. Sweden will follow in 2022 with 10 swapping stations followed by Denmark.

Norway has a lower population density than many other European nations and a relatively high percentage of private house ownership. It is simple to install private home-based electric vehicle chargers, and many electric vehicle owners utilize them as their primary source of power. The Norwegian Electric Vehicle Association surveyed in 2017 that electric vehicle owners living in apartments and houses were asked how often and where they charged their vehicles. The results indicate that electric vehicle owners rely very little on public charging and rely much more on charging EVs at home or work (Lorentzen et al., 2017). However, the lack of public chargers is a challenge for travelers and tourists.

Norway is a long country with a low population, and the driving range between cities is long. A well-organized public charging infrastructure is required for long-distance travel. For this purpose, in 2017, the Norwegian government started funding for the construction to build at least two multi-standard fast-charging cable charging based stations on every 50 km along all of Norway’s major highways.

One factor that will affect the technology readiness in Norway is the massive pressure on the nation’s electrical grid due to the substantial number of electric vehicles conventionally charged at the same time, i.e., with charging stations or outlets. In that case, the power grid can experience massive spikes of stress during peak hours. However, the stress on the power grid can be flattened out by charging the vehicles outside the peak hours and ensuring that every charging stations has a solar panel array and battery storage to help reduce the peak loads drawn from the grid. The charging infrastructure is, to a large extent, private, and the lack of public charging piles is a barrier to the diffusion of BEVs. Besides having a well-organized home-based charging system, Norway is far behind in technology readiness, as Norway has to import each component used for electrification from other countries. Therefore, Norway is positioned at level 5 in technology readiness levels of the multidimensional readiness index.

5.2.2. Political Readiness Level in Norway

Norway introduced policies to encourage the use of electric vehicles by temporarily eliminating the electric vehicles import tax in the early 1990s. The Norwegian government has also launched various incentives (access to driving on the bus lanes, limited parking fees and no road tolls) for electric vehicles to eradicate vehicles and on-road taxes that reduce the upfront and lifetime cost of electric vehicles. The government's goal is to have all new vehicles sold from 2025 to be either electric or hydrogen driven. The incentives for electric and hydrogen-fueled vehicles can be considered to be the Norwegian government's strategy to promote electrification to Norwegian society.

In Norway, the existing electric vehicle policy incentives stabilized and successfully established the electric vehicle market, and in return, a profitable second-hand EV market emerged in Norway. The electric vehicle market is well established in the main cities of Norway, like Bergen and Oslo, whereas the electric vehicle market in rural areas is rapidly growing. One of the most prominent incentives applied in Norway is the 'vehicle tax system,' which allows the electric vehicle to become price competitive with ICE vehicles. The 'tax system' is based on the vehicle's weight, carbon dioxide and nitrogen oxide emissions, and value-added taxes. These combined taxes make EVs affordable to buy or import with very few added costs compared to ICE vehicles, which in some cases cost more than double the import price (Haugneland et al., 2017). These are some of the most significant incentives policies implemented by the Norwegian government that has led Norway to the massive adoption of electric vehicles.

The Norwegian government is working towards future policies to meet the goals of the Paris Agreement to reduce the nation's greenhouse gases by 40% by 2030 compared with the levels of the
1990s. Furthermore, the country is striving towards the following three goals to meet the criteria of the Paris Agreement (Olsen, 2017):

- All new private vehicles must be purchased as zero-emission configuration or using biogas by 2025.
- Having all distribution of goods by near-zero-emission vehicles in major cities by 2030.
- Have all new heavy vans, 75% of new long-distance buses, and half of all new trucks of zero-emission status by 2030.

Norway is at the global forefront in adopting electric transport. The Norwegian government played a decisive role in promoting electric vehicles by implementing favorable incentives policies. Therefore, Norway is positioned at level 9 in the political readiness levels of the multidimensional readiness index.

5.2.3. Societal Readiness Level in Norway

Norway has become the leading country in the world to sell more electric vehicles than vehicles with diesel, petrol, or hybrid engines already in 2020. Norway made a global record by selling 54.3% of all new battery electric vehicles in 2020. In contrast, in 2019, it was 42.4%, which means the sale of battery electric vehicles increased by 11.9% in only one year. This was achieved even though Norway is an oil-producing country. Norwegian policy exempts taxes for fully electric vehicles and imposes taxes on vehicles run by fossil fuels. The goal of the Norwegian government is to become the first country in the world to stop selling new diesel or petrol cars by 2025 (Klesty, 2021). In March 2021, 8,624 electric passenger cars and 4,379 plug-in hybrid vehicles were sold. The sales of fully electric vehicles are increasing, whereas plug-in hybrid vehicle sales (PHEV) are declining. In March 2020, the sales of PHEV were 83.1%, but in March 2021, the sales of PHEV were at 28.6%, which means the sales of PHEV declined almost 54.5% in one year. However, it is still higher than the sales of vehicles run on diesel and petrol (4.7 and 4.8 percent, respectively) (Manthey, 2021). Norway is a rich country where people get paid handsome salaries. The costs involved in generating and distributing electrical energy in Norway are very high. But consumers are willing to pay a premium fee for the fast-charging service as it costs them three times less than what they pay for electricity at home. We place Norway at level 9 in the societal readiness levels in the multidimensional readiness index.

5.2.4. Economic Readiness Level in Norway

In Norway, ten years ago, nobody could even predict that there would be more electric cars than non-electric in 2021, and there are not only cars that have gone electric, but bikes, trams, trains, and buses have all become propelled by electrical means. The Norwegian government policies and the incentives for the buyers are the leading cause for the rapid transition of the transportation system from fossil-based fuels to electric in Norway. The key to accelerating EV adoption in Norway was to make them affordable. The government reduced taxes and even exempted road tolls tax to keep the operating cost for EV’s down (Reve, 2021).

The cost of buying an electric vehicle is also lower than buying a petrol-fueled car in Norway. In November 2020, the new Volkswagen Golf (petrol) price was higher than the Volkswagen Golf (Electric). To encourage the buyers to buy EVs, the Norwegian government reduced other taxes to make them affordable. The operational cost of EVs is much lower than gasoline vehicles.

Driving an electric vehicle for an operating distance of 12,300 km/year, which is moderate, can save NOK 12,000 (approximately $1355). The service cost for electric vehicles is generally lower since moving components are very much less than gasoline vehicles. In addition, the traffic insurance tax is far lower for EVs in Norway (Elbillading, 2020). Thus, Norway is positioned at level 9 in the economic readiness levels of the multidimensional readiness index.
5.3. Sweden

5.3.1. Technology Readiness Level in Sweden

Sweden is an innovative industrial country. Volvo, the Swedish automotive manufacturing company, has now become owned by the Chinese vehicle manufacturer Geely. In 2021, Volvo introduced two new EV brands, Volvo, and Polestar, which are so far manufactured in China. However, the top ten selling brands of electric vehicles in Sweden in September 2021 are imported from various countries, such as the Czech Republic (Skoda), Germany (Audi and Volkswagen), Japan (Nissan), South Korea (Kia), China (MG), and USA (Ford and Tesla) as shown in figure 9.

Figure 9: Top 10 selling brands and their sales of EVs in Sweden in September 2021 (Holland, 2021)

In Sweden, several alternative EV charging technologies are in the testing phase, such as dynamic (conductive and inductive), semi-dynamic and static charging, and further looking for battery swapping solutions. Static charging is considered a relatively mature technology that is primarily used to charge passenger vehicles. However, heavy-duty vehicles (HDVs) can utilize the current chargers used by cars. Still, it takes a longer time to charge the battery due to the battery capacity of heavy-duty vehicles. In Sweden, charging stations have gradually increased during the last three years and crossed almost 10,000 units with type 2 sockets and 610 charging stations with CCS/Combo sockets until mid-2020 (Wagner, 2020).

The electric trucks manufactured by Volvo and Scania can be charged through static chargers by using the latest CCS type 2 connectors. However, these CCS type 2 connectors are intended to charge regular EVs and not HDVs like Volvo’s FE/FL and Scania’s BEVs. Because of the lack of fast chargers designed for HDVs and the high demand for electric trucks, Volvo and Scania chose to use the existing charging solutions. The fast chargers for HDVs are available on the market and implemented in three major cities in Sweden. These fast chargers adapted for HDVs have a higher charging power and are less time-consuming than chargers for light vehicles. Installing fast chargers for HDVs near the most operated transport routes is crucial to aid electric truck diffusion. Moreover, the European Union and its members collaborate to develop and implement a common standard for Megawatt’s chargers (Hasselgren & Näsström, 2021).

Sweden is working on static and dynamic (conductive and inductive) road charging, which means that vehicles will be able to charge their batteries while in motion. Sweden has built its first
electric roads for demonstration purposes at Arlanda (1.2 miles in length), at Sandviken, in Lund city and in Visby city. Sweden is further working on wireless charging and looking to have battery swapping technology. However, these technologies are still in the demonstration and testing phase on a small scale. On the other hand, inductive charging, considered a reliable solution, is in the development process. The charging output is limited, facing the technical standardization problem. Therefore, Sweden is positioned at level 6 in the technology readiness levels of the multidimensional readiness index.

5.3.2. Political Readiness Level in Sweden

Swedish policies support the transformation of the transportation system from fossil-fueled vehicles to electric vehicles and offer several incentives to electric vehicle owners. Sweden is transitioning to electrified vehicle transport systems with a 26% EV market share and a 253% rise in EV sales in 2019. Sweden has increased incentives such as municipal incentives, tax rebates, and government grants, contributing to the rising popularity of electric vehicles. In 2007, the Swedish government introduced a program called the “green car award.” The purpose of this program was to offer a tax credit of 10,000 SEK (approximately $1166.45) for new vehicles which satisfied the specified emission standards. The impact of the green car award program was positive, and this program raised the market share of green cars (with emissions of 50 g CO$_2$/100 km or less); however, it is claimed that the majority of buyers would have purchased green vehicles regardless of the subsidies being offered (Huse & Lucinda, 2014).

The Swedish government plan is to reduce to 70% of the present level of greenhouse gas emissions from the transportation sector by 2030. To achieve this target, the government has further introduced a scheme of subsidies for low emission cars serviced before 2020 with CO$_2$ emissions of up to 60 g/km and vehicles serviced during 2020 or after with CO$_2$ emissions of up to 70 g/km, a grant of 60,000 SEK (approximately $6998.70). These subsidies are available for up to 25% of the new car’s purchase price. This scheme applies to both individuals and businesses. Similarly, the grants are available for heavy-duty vehicles, especially for public transportation agencies, municipalities, and small businesses, a grant of 20% of the EV bus purchase price is available.

Furthermore, the incentive covers 40% of the difference between the cost of an electric bus and a comparable diesel bus for private transportation businesses. The Swedish government is also focusing on the development of charging infrastructures. The number of charging units has increased from 500 to 10,000 between 2012 and 2020. The major cities in Sweden, such as Stockholm, Gothenburg, and Malmö, also provide local charging incentives for the EV owners. In Stockholm, free charging of BEVs and PHEVs is available for parking space subscribers; only non-electric vehicle owners have to pay the parking fee. The local government of Gothenburg has decided to install 500 new charging stations at the public parking areas around the city during the autumn and winter of 2020 and 2021. Malmö has more than 150 public charging stations. The chargers are of different speeds - some of them are fast chargers of up to 22 kW/h, whereas others have only up to 3.7 kW/h to charge electric vehicles. The local government of Malmö is planning to equip 20% of parking spots with EV charging stations (Asunción, 2021). However, while static charging is considered a reliable source of charging, EV drivers face technical standard problems with different sockets used at different charging stations for a plug-in to charge a vehicle. The absence of institutions and policymakers is prevailing. The role of institutions and policymakers is required to develop and implement a common standard plug connection for static charging. On the other hand, the dynamic solution (electric road technology) is still in the testing phase. Therefore, Sweden is located at level 7 in the political readiness of the multidimensional readiness index.
5.3.3. Societal Readiness Level in Sweden

Sweden is a well-educated society with substantial awareness of environmental concerns. Swedish society is rapidly adopting electric vehicles. In February 2020, the market share of electric and plug-in hybrid cars reached 24.3% in Sweden. The rapid adoption of electric vehicles has increased in Sweden since the Swedish government introduced a new subsidy scheme in January 2020.

In February 2020, around 6.4% of all Swedish new cars registered were battery electric vehicles (1,430), and approximately 18% of cars registered were plug-in hybrids (4,027). Compared with February 2019, the sale of electric cars has increased by 112% and plug-in hybrid vehicles by 59%. In January 2020, around 7.1% of all new cars registered were battery electric vehicles (1,269), and about 23.1% of cars registered were plug-in hybrids (4,113). Compared with January 2019, the sale of battery electric vehicles increased by 15% and plug-in hybrid vehicles by 160.8% (Randall, 2020). The adoption rate of plug-in hybrid vehicles is high in Sweden and is increasing faster than sales of fully battery electric vehicles. Therefore, Sweden is located at level 7 in the multidimensional readiness index in societal readiness levels.

5.3.4. Economic Readiness Level in Sweden

In 2018, Sweden introduced a new incentive scheme called "Bonus-Malus" to encourage buyers to buy electric cars, light trucks, and buses. The government announced 60,000 SEK (approximately $6998.70), a purchase incentive bonus to the buyers of fully electric vehicles, and a 25% climate bonus of the vehicle’s value. The government announced a 35% bonus on buying a climate-friendly vehicle for businesses. The incentive was a maximum of 35% difference between the new vehicle price and the similar fossil-fueled vehicle price. Six months after the car is registered, the incentive is paid straight to the owner, preventing the vehicle from being sold onward within that time frame. The bonus is decreased by 833 SEK (approximately $97.17) per gram of CO\(_2\) up to 60 g/km (AG, 2019).

To make the operating cost affordable, the Swedish government started supporting the development of increased charging infrastructure. Therefore, the government introduced the climate shift program in the Swedish language called “Klimatklivet.” This program aims to reduce CO\(_2\) emissions at a local level. For this purpose, the government announced granting up to 50% of the installation cost for a single charging point to the local housing associations. Moreover, electric vehicles are much more affordable than fossil fuel-based vehicles in Sweden. The energy cost of running an electric car is SEK 2.25 (approximately $0.26) every 10 kilometers, compared to SEK 12 (approximately $1.40) for the same distance traveled in a fossil fuel-based vehicle.

Moreover, the maintenance cost of electric vehicles is lower than fossil fuel-based vehicles due to the fewer moving components (Dahlstrand, 2020). Additionally, electric vehicles are quiet and fun to drive due to their high-performance capabilities. Even though the government provides rebates on purchasing electric vehicles, the prices are still high. Because of the present lack of charging infrastructures, buying a fully electrified vehicle is not economical. Therefore, Sweden is positioned at level 7 in the economy readiness levels of the multidimensional readiness index.
6. Discussion

The data discussed in the above disclosure is based on the factors involved in assessing the state of global readiness for the electrification of all modes of electrical transportation equipment and supporting systems. This discussion leads us to conclude that merely relying on technical analysis will not lead us towards the complete transport system towards electrification. We need other political, societal, and economic perspectives to explore, understand, and support the whole system for the successful transformation of the transport system towards electrification.

As a result, to attain a high degree of diffusion of an electrical transportation system, additional factors such as political, societal, and economic readiness also must be considered and balanced alongside the available technology. Our research has noted that the major dimension in the public discussions of electrification has been globally focused on technology. Until all the readiness factors have been globally given their due consideration, the introduction of complete and effective electrification of all modes of transport equipment and their associated systems will not proceed effectively or expeditiously. From our point of view, all those four dimensions of the states of readiness are complementary and thus equally important, and all need to be fully integrated and implemented to support the development and diffusion of electrification of transport.

To evaluate the readiness level of technology, political, societal, and economics of each country, we have used TRL, PRL, SRL, and ERL scales. Each country is positioned in the multidimensional readiness index model based on the evaluation of the readiness scales. We have taken out the percentage for further graphical representations based on the multidimensional readiness index model results. Table 5 shows the status in the percent of each countries’ readiness level (technology,
political, societal, and economic) and the position of each country (China, Norway, and Sweden) in the development of electrification of the transportation equipment and supporting systems.

Table 5: Status of the countries in the development of electrification of the transportation system

<table>
<thead>
<tr>
<th>Countries</th>
<th>Total score of each country</th>
<th>In Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>35</td>
<td>97%</td>
</tr>
<tr>
<td>Norway</td>
<td>32</td>
<td>89%</td>
</tr>
<tr>
<td>Sweden</td>
<td>27</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table 5 shows that China has scored 97% followed by Norway and Sweden 89% and 75% respectively, in the development of transport electrification. These results have been plotted in the form of graph in figure 11 below that shows the positioning of these countries in the process of transformation of the transportation system.

Figure 11: Countries positioning in the field of transport electrification

China is a leading country in the field of electromobility technology, industry, and market, according to the electric vehicle index in 2021. China is at the forefront of the transition from fossil-fueled vehicles to electric vehicles. Chinese society is rapidly moving towards BEVs. China is leading in manufacturing pure battery electric vehicles as well as in battery along with South Korea which is ranked 1st in innovation, according to Bloomberg (Jamrisko et al., 2021). Of the top 10 fully battery-
electric vehicle manufacturers, nine are Chinese companies, and the other one, Tesla, is a US brand that is also manufactured in China. By the end of June 2021, 1.947 million charging piles and 716 battery swapping stations were available for charging electric vehicles in China. One key system for electrified road transportation is batteries. Asian companies are leading the electric vehicle battery industry. They are expanding their manufacturing capacity in Europe and the USA to gain secure profitable contracts from international electromobility manufacturers. LG Chem and Samsung SDI are the largest South Korean battery manufacturing companies.

From January 2020 to August 2020, the South Korean LG Chem was the top leading company in manufacturing lithium-ion batteries worldwide. Contemporary Amperex Technology Limited (CATL) and BYD are two of the leading Chinese battery manufacturers. CATL is ranked second with a market share of over 29%. CATL is the biggest international electric vehicle battery exporter to BMW, Honda, Hyundai, Tesla, and Volkswagen. China and South Korea are leading in battery manufacturing for electric vehicles beside the Panasonic which is a Japanese battery-making company. China has a complete value chain in the electromobility industry from the initial reception of materials through its delivery to market and everything in between. The success behind China’s leading in the field of electromobility is the Chinese government’s implementation power of favorable electric transport policies and strategic positioning of EV in the process of upgrading the automotive industry, communication technology and smart-city development. The Chinese central government considers it to be a vital, national policy matter to promote the country’s development and diffusion of electric transportation. In 2019, when the Chinese government stopped providing subsidies on EV purchases, the EV manufacturing industry reported five months of decreasing sales in the second half of 2019. Once the government revived the subsidies on EVs in 2020, EV sales sharply increased and reached 1.3 million units in 2020 compared with the 1.1 million units sold in 2019. The Chinese government provides rebates, subsidies, and tax exemptions and keeps the charging rates low for electric vehicles to promote clean electric transport in China. Therefore, China is positioned at level 9 in technology, political and societal, whereas at level 8 in the economic readiness of the multidimensional readiness index. The overall score of China is 35 based on the readiness scoring scale of transport electrification and 97% readiness in the field of transport electrification systems, as shown in figure 11.

Norway does not manufacture electric vehicles or electric vehicle batteries, but it imports from other countries such as the US, South Korea, Japan, and China. NIO Norway (Chinese BEV supplier) has also started its sales in 2021 and several other Chinese brands such as XPeng, LiAuto, BYD and other are moving to Europe. Norway is a small but geographically long country, and people need to travel long distances for their daily life activities. Almost 96% of electric vehicle owners have access to a charging station in their own homes or apartment. However, long-distance travelers or tourists with their electric vehicles need public charging stations, which presently lack in number and distribution. The government has started funding to construct at least two multi-standard fast-charging stations at every 50 km along all of Norway’s major highways. Despite lacking in electromobility technology, Norwegian government policies are the game-changer positioning Norway as the global leader in EV adoption. The sales of electric vehicles are rapidly increasing over those for fossil-fueled vehicles in Norway, with a staggering 54% of new cars sold in 2020 being powered by electricity. In 2020, December was the best month, with sales reaching 66.7% of electric vehicles. The goal of the Norwegian government is to sell 100% electric cars by 2025. The cost of purchasing and operating fully electric vehicles is more affordable than fossil-fueled or hybrid vehicles. Even though Norway is an oil-producing country, the government has imposed high purchase and CO\textsubscript{2} taxes on fossil-fueled vehicles; in contrast, electric vehicles are exempted from purchase, VAT, and road tolling taxes along with free parking. The dedication of the Norwegian government in the ways that it has introduced electric transport in society is maintaining Norway’s position as a successful global leader in the world in the transformation of a clean transportation system. Therefore, Norway is positioned at level 9 in politics, societal, and economic readiness levels and 5 in technology readiness in the multidimensional
readiness index. The overall score of Norway is 32 based on the readiness scoring scale and 89% readiness in the field of transport electrification systems, as shown in figure 11.

Sweden is one of the top innovative countries in the world and the number one in EU. According to the Bloomberg innovation index 2021, Sweden is ranked 5th in the innovative countries worldwide, while in the EU Innovation Scoreboard, it is ranked as 1st. However, in the field of electromobility, Sweden still lags behind, despite manufacturing its own electric vehicles in Belgium and China. The Swedish Volvo manufactures its prestigious electric vehicle (Polestar) in China. The new Volvo XC-40 launched in 2021 is manufactured in Belgium and China. However, Sweden yet does not have its own battery manufacturing and thus Swedish EV manufacturers purchase batteries mainly from Asia, Europe, and the US. Volvo in the majority manufacturers hybrid vehicles rather than fully electric vehicles. Scania and Volvo have launched their first electric trucks in 2020/2021. In Sweden, several charging technologies are in the testing phase, such as electric roads (conductive and inductive), and the government is considering to further looking into battery swapping solutions. Static cable-based charging is considered a relatively mature technology that is primarily used to charge passenger vehicles. However, static charging faces a standard technical problem in that there is no standardized charging plug. Buying electric vehicles and operational costs are still expensive in Sweden despite government rebates and the exemption of taxes. Therefore, Sweden is positioned at level 7 in politics, societal, and economic readiness levels and 6 in technology readiness in the multidimensional readiness index. The overall score of Sweden is 27 based on the readiness scoring scale of transport electrification and 75% readiness in the field of transport electrification systems, as shown in figure 11.

7. Conclusion

The development and implementation of electrification of the transportation system depends on society’s readiness to pursue development, adoption, and diffusion of electrified transport. Technology itself is a crucial foundation for electrification and must be viewed and understood when commercialization and value creation to business, people, and benefits to the entire society are also considered. Technology cannot be diffused in society and create value without a well-developed interplay of industry, academia, politics, economic institutions, and policy systems pushing and supporting economic and policy tools and regulatory tools.

Our analysis shows that only focusing on technology will not lead us to the successful complete transformation of electrification of the transportation system. Therefore, to achieve a high level of diffusion of electric transport systems, it is important to balance the political dimension focusing on government support to develop and implement policies that promote the electrification of the transportation system. The other factors involved are the degree to which societal readiness to switch from fossil fuel to electric vehicles has been enrolled. The fourth is the economic readiness in which subsidiaries have met the transformation financial needs to compensate for any price difference. The motivation of people to preserve until the scale of the costs involved in the adaption and adaption of the new technology meets or betters the costs incurred for old fossil-based technology must be diligently fostered.

Our analysis shows that political readiness is one of the most crucial dimensions of the readiness to support the transformation to electric transport, followed by societal and economic readiness. The political readiness is demonstrated in the political willingness to reshape regulatory aspects, introduce, and change subsidiaries and use public fundings for R&D and building the charging infrastructure. Political readiness can be observed on the rhetoric level and in the action level. Our focus is on the real action level of politics and policy making.

We view the electrification of the transportation system from a complex system perspective. The electrification of transportation is not an isolated system that can be handled independently as a
single technological entity. This system is interconnected and interdependent on the other subsystems such as energy production, electricity distribution in the grid system, and storage that form the whole technical system embedded in each country's political, social, and economic context. Therefore, a system approach is required to see the electrification of the transportation system from a holistic perspective. Other subsystems need to be brought into consideration besides technology alone, i.e., politics, society, and the economy. To help achieve this understanding, we have introduced the Multidimensional Readiness Index Model based on those key dimensions.

The depth of penetration of electrified transport system in the society is still very much premature and in the early phases of diffusion, thus still mainly relies on the economic policies developed and announced by the government, including the economics of new infrastructure, identification of solutions to electrified public transportation problems, providing rebates for EVs and tax exemptions, and imposing high taxes on CO\textsubscript{2} emission vehicles. Government commitment is the key to success for the rapid transition from fossil fuels to electrified transport. The strong government and institutional execution power are the success story behind China's leading in the electrification of the transportation system in the world. Norway is the second leading country in the diffusion and adoption of electric vehicles because of its favorable government policies for transport electrification, even though Norway itself does not manufacture electric vehicles and charging equipment. Sweden is still lagging behind China and Norway, even though Sweden is one of the most prominent countries in innovation in the world and has built its own luxury hybrid electric vehicles. But due to the Swedish government not taking rapid actions, it has been held back in the electrification of the transportation system. Volvo Cars are manufacturing electric cars in China. Scania trucks and Volvo have started to market their first generation of electric trucks. Volvo has declared strategic collaboration with Daimler regarding the hydrogen technology for ICE vehicles, while Scania officially goes for battery-based heavy trucks.

Acknowledgments

This research is conducted within the Sweden-China Bridge—Collaborative Academic Platform for the Transportation Electrification Systems Project and has been funded by The Swedish Transportation Administration (Trafikverket, TRV).
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A SYSTEM APPROACH TO ELECTRIFICATION OF TRANSPORTATION – AN INTERNATIONAL COMPARISON

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Abstract

Globally, the transportation system is transforming from fossil-based to electrification system. Some countries are leading in the transformation process. Some countries are rapidly catching up to become market leaders in developing and introducing new techniques and equipment that support the transformation process in their countries. In contrast, others are still relying on their old fossil-based system or could not have enough understanding on how to deal with this complex transformation of the transportation system.

The electrification of the transportation system is not an isolated system that can be handled as a single technological entity. It is a group of multiple technologies, political, societal, and economic sub-systems—each of these sub-systems is embedded in each other, forming the whole system. Therefore, it is important to see and manage the system from a holistic perspective to transform the transportation electrification system efficiently. We have selected eight countries from three different continents – from Asia (China, India), Australia, which is a country and continent, and Europe (Germany, Norway, Slovenia, Sweden, and the UK) to explore the transformational process of transportation electrification based on each countries’ conditions. We have chosen these continents as they are diversified in adopting the transportation electrification system solutions.

Our main conclusions are that the political processes and political decisiveness are the most important, followed by the societal and economic with the technology as the fourth. The other three are difficult to obtain without dedicated and determined political decision-makers. Political decision-makers need to use economic means to support the transformation in the society and industry to balance the economic disadvantage of electric systems until they pass the cost disadvantage turning point. Technology is no more a significant barrier as it was in the beginning about 20 years ago. Now, technology is available, although it can be improved. The important part is to understand how to utilize the existing technology efficiently to transform the old fossil-based transportation system to new electrification of the transportation system. Without clear and strong political support, the industry cannot be
expected to initiate, finance, take the risk, and take the lead in this global societal transformation.

Our analysis shows that China is being positioned as the leading country in the world in the electrification of the transportation system because of the strong technology advancements, control of the entire value chain, strong government decisiveness and execution power in developing and implementing favorable electric vehicle (EV) policies, the willingness of the public sector to take the lead and citizens support to adopt clean technology. Norway has rapidly become one of the newcomers with large numbers of registered electric vehicles according to its population size within a few years, despite lacking manufacturing electric vehicles (EVs) and equipment for transportation electrification. Germany is leading in the technological sector of transportation electrification within Europe with its prestigious top-selling electric vehicle brands in Germany such as Volkswagen, Mercedes Benz, BMW, Smart, and Audi and establishing a battery Gigafactory with an annual potential production capacity of 60 GWh. However, Germany is still lagging behind from the societal perspective of not having enough sales of electric vehicles compared to gasoline-based vehicles. Sweden is a rapidly growing country in the electrification of transport, with three vehicle manufacturers introducing EVs in 2021 and developing electric roads system for more than ten years. Sweden is also working on establishing a new 50 GWh battery manufacturing plant in Gothenburg, Sweden. The UK is also catching up with its other European countries in transforming the transportation system with its strong government support. The British government has kept transportation electrification on its national agenda and considering building a Gigafactory to obtain a position as a future battery leader. However, the UK's adoption rate of electric vehicles is still slow compared to fossil-based vehicles. India, Australia, and Slovenia are far behind in the process of transportation transformation than China, Norway, Germany, Sweden, and the UK. One of the common reasons in all of these countries is the baby steps taken by their governments even though they have high ambitions. Their governments require a revolutionized and system approach to enable remarkable change in the transformation process.

**Keywords:** Electric transport, technology readiness, political readiness, societal readiness, economic readiness.
1. Introduction

The world is facing global transformation regarding energy towards renewable energy and the transportation towards electrification systems. The old fossil-based energy is replaced with renewable energy, and the old internal combustion engines are exchanged with electric technology for vehicles of all kinds and related charging infrastructure. Electrification of transportation is spreading around the globe, although with different scope and speed of transformation. Most countries are striving to switch to electric vehicles based on new energy solutions, either driven by battery-based energy storage or hydrogen-based energy storage. Hybrid solutions, combustion engines combined with battery-based electrical motors are only temporary solutions on the way to fully electric vehicles. However, different countries have taken different technology routes, and different companies have developed different products utilizing various technologies, although striving for the same target, fossil-free solutions based on zero CO$_2$ emissions.

The electrification of transportation is important for the environment and health of people but is facing many challenges. Very often, public discussions focus on technology, but several other aspects such as government policies, societal and people’s willingness to buy and use electric vehicles (EV), and economic affordability of buying and using EVs influence and guide the development and diffusion of technologies and EVs in society.

The first important aspect of successful transformation towards electrification of transportation is the readiness of technology to be used in EVs to transform from the research stage to the commercial stage (Bhatti et al., 2022). The development of automotive technology is continuously evolving and promoting various electric vehicles solutions, such as battery electric vehicles or hydrogen-based vehicles (Ioakimidis & Genikomsakis, 2018). It is necessary to charge a battery to drive an electric vehicle as well as it is necessary to refuel hydrogen-based vehicles. Therefore, a grid-connected infrastructure system is required to ensure that charging stations are available at homes, public parking stations, and offices where vehicles can be charged when they are not in use (static charging) or on the roads while driving (dynamic charging). Similarly, fast-charging stations or battery swapping stations are required for long-distance travelers to refill the battery with a faster process in a minimum time (Danilovic et al., 2021). Hydrogen-based vehicles use two types of technologies, hydrogen fuel cells and hydrogen-fueled internal combustion engines (Boretti, 2011; Ehsani et al., 2018). To drive a hydrogen-based vehicle, a successful hydrogen-based infrastructure is needed to deliver hydrogen from production plants to refueling stations (Grüger et al., 2018). However, the development design and technology for hydrogen-based vehicles are complex, uncertain, and more expensive than the electric vehicles run on batteries (Shin et al., 2019). Therefore, hydrogen is not a mature technology yet for full scale of commercial operations, and the economic feasibility of hydrogen is not in place yet now, but it is moving and could be an upcoming technology. As of now, we know that the dominant solution for electric vehicles is the battery. China is taking the lead in the development of hydrogen-based vehicles whereas Japan, South Korea and the USA are catching up faster.

The second important aspect is the political readiness (Bhatti et al., 2022). The electrification is a disruptive transformation of technology, products, industry, and the entire society. The old fossil-based energy sourcing is transformed to renewable, and fuel to vehicles
transforming from fossil-based fuels to electrification. To manage this disruptive transformation, the political aspects are essential to explore and understand. We see from the current development that some countries are early adopters of electric vehicles. Some are focusing on buying solutions such as, Norway and Sweden, and some are focusing on creating their complete value chain like China. Most of the countries are supporting this transformation with subsidiaries and imposing strict regulatory approaches. Although there are different approaches, the main challenge is to what extent political readiness is in place to support this transformation to green solutions and electric transportation system development and diffusion in society. Electric vehicles are generally considered as an alternative low-carbon transportation and attractive promising technology. Many governments have established timelines and objectives for eliminating fossil-based technology, diesel engines and, subsequently, petrol engines by 2050 (Andwari et al., 2017; Weiss et al., 2012). The “Fit for 55” is the goal of the European Union to become a key player in the electric vehicle market and reduce greenhouse gas emissions by 55% by 2030. Therefore, most European countries have constructed policies to promote the automotive sector and create high-tech employment. There are various countries (China, Norway, Sweden, Germany, UK, and the USA) with a clear policy for transportation electrification and has pledged to stop selling fossil fuel vehicles by 2030. Chinese policy is to reach a fleet of zero-emission by 2050. Therefore, China is working on a plan to stop manufacturing and selling vehicles that are entirely fueled by fossil fuels. There are various policies in emerging nations, some of which embrace the future of electric mobility. In contrast, others are uncertain about whether electric vehicles enter the market and resist the trend towards transport electrification. Even though several countries have recommended restrictions for banned gasoline or diesel vehicles, only a few countries or towns have passed legislation banning internal combustion engine vehicles. To effectively implement the bans on combustion engine vehicles, it is substantial to have proper legal enforcement (Plötz et al., 2019). Therefore, Danilovic et al. (2020) stated that without support from the political, institutional, and regulatory stakeholders, it might be impossible to develop and commercialize technology to attract investment and partners to the sector of electric transport and achieve a favorable business outcome.

The third important aspect of the transformation of electrification of the transportation system is societal readiness (Bhatti et al., 2022). The growth rate of social acceptance of electric vehicles is rapidly increasing worldwide due to the support of government policies in several leading countries, such as China, Germany, Norway, Japan, Sweden, UK, and the United States. Electric vehicles’ market share climbed from 4.2% in 2020 to over 8.3% in 2021 worldwide (Mathilde Carlier, 2022b). For example, Nuttall (2020) stated that 25% of the people in the UK were interested in driving an electric vehicle. The same survey was conducted one year later and showed that the interest has increased by 5%. World practice has proven that the sales of electric vehicles are high in those countries where the governments are actively participating in transforming the transportation system. And where the end customers are compensated for part of the excess costs, they provide transportation tax incentives, provide high-quality charging areas, free parking, and allow driving in dedicated lanes. None of this is possible without active participation from the government. In emerging countries like India and Russia, consumers are willing to consider electric vehicles as their
future purchase options. However, the vehicle's initial cost, the uncertainty of battery life cycle, the inadequate number of charging stations, and the time required to charge an EV are pulling them away from EVs.

The fourth aspect of adopting electric vehicles on a larger scale is the economic readiness (Bhatti et al., 2022). Many countries are introducing new policies or using rebates to reduce the initial cost of electric vehicles or imposing high taxes on diesel or combustion engine vehicles to increase the adoption rate of electric vehicles. For instance, the former government of the United States approved a rebate for the first 200,000 (two hundred thousand) electric vehicles to each automaker. The amount of rebate varies from $2,500 to $7,500, which depends on the size of the battery. A pilot subsidy scheme in China reduces the cost of electric vehicles by $9,500 (60,000 RMB) (Boulanger et al., 2011). However, it is necessary to reduce the cost of the battery, as a significant part of the electric vehicle's overall cost is the price of the battery (40-60% of the vehicle cost for passenger vehicles). According to the United States Advanced Battery Consortium (USABC), the battery $150/kWh's highest price corresponds to a significant market share of electric vehicles. However, the long-term target is to reduce the cost of the battery to $100/kWh.

On the other hand, according to the International Energy Agency (IEA), the battery prices should be less than $300/kWh to ensure the competitiveness of battery electric vehicles (Andwari et al., 2017). Figure 1 represents the projected cost of lithium-ion batteries up to 2030. In the analysis of this battery research, technological advancement and breakthroughs are expected that the price of a battery will become less than $500/kWh by 2020 (Hensley et al., 2009).

For a rapid entry into the market of pure battery electric vehicles, the battery price is significantly more than the targeted price of the USABC and IEA. We are at the early stage of
battery electric vehicle technology, and technology development might change the economic conditions significantly in the future. Still, with time, as the technology advances and manufacturers gain more expertise, they will probably shift to batteries that are affordable, lighter, smaller in size, and with higher energy capacity. Nevertheless, the most significant challenges to the widespread adoption of electric vehicles are the battery cost and the lifetime cost of the vehicle, as batteries are expensive and need to be exchanged from time to time. Compared with the traditional ICE option, the actual comparison is the overall ownership costs and the payback period for the electric vehicle. Many countries worldwide are introducing and adopting various policies for each dimension (technology, political, societal, and economic) of the electric vehicle sector. However, clear guidelines are required that reduce the electric vehicle’s initial cost and government support for the rapid transformation of the whole transportation system that enables the transportation sector to adopt the changes with the electrification on a broader scale.

2. Purpose of the Study

This paper aims to explore the conditions and prerequisites of the selected countries regarding the readiness for electrification of transportation, focusing on technological, political, societal, and economic readiness to handle the transformation of society and development, and diffusion of total system solutions.

Our ambition with this paper is through the extensive international comparison, to draw the attention of policymakers towards the challenges and opportunities in their countries for transportation electrification and further draw their attention towards the importance of economical, societal and political readiness that are necessary to understand and consider if countries strive to achieve a high level of electrification.

3. Research Methodology

We have selected eight countries for our research; two from Asia (China and India), Australia and five countries from Europe (Germany, Norway, Sweden, Slovenia, and UK) as empirical grounds to explore their approaches to the electrification of transport, analyze the different conditions and contextual aspects of importance for electrification or transport to identify major critical dimensions, and to apply the proposed multidimensional readiness index model that is presented in Bhatti et al. (2022).

Our research on electrification of transport systems has been conducted from a system perspective and the research approach is based on a collection of secondary material from databases, journals, and publications. We have collected and analyzed the data of each country based on their technology, political, societal, and economic capability, decisions, and actions towards the electrification of transport. Technology is analyzed based on the vehicle ‘EVs’ and ‘EVs batteries’ manufacturing capabilities and charging infrastructure solutions. Political is interpreted based on government interest and demonstrated actions in the
transport electrification, government support to provide subsidies and rebates to EVs buyers and EVs manufacturers and investment in charging infrastructure solutions. Societal is analyzed based on the sales and market share of EVs and the willingness of citizens to adopt EVs. Economic is analyzed based on the economic conditions for diffusion of EVs, purchasing and charging cost, the operational cost of EVs and government subsidiary to support the diffusion of EVs.

The main focus of this research is on passenger vehicles, although there are many vehicles such as motorcycles, two and three-wheelers, trucks, and buses. The focus on passenger vehicles is based on the assumption that passenger vehicles are one common ground among most countries. In contrast, two and three-wheelers are more common in a specific part of the world and cannot be used for global international comparison. The development of heavy-duty vehicles, trucks, and buses has recently become commercially available worldwide. Two-wheelers are very common in Asia and emerging countries but not in developed countries. The attention in the electrification of transport from media and decision-makers has been directed to passenger vehicles. For the reasons of development phases of passenger vehicles and the great attention as the leading automotive industry, our focus has been chosen to be passenger vehicles.

We have reasons to trust that the readiness model we have developed based on our research on passenger vehicles can also be used for heavy-duty vehicles such as trucks and buses. The model is valid for analyzing the readiness aspects in all four dimensions (technology, political, societal, and economic) of all modes of electric transportation, although the commercial context differs.

To examine each country’s technology readiness capabilities, we have used NASA’s original model estimating the technological readiness when developing rockets to the moon program as the technological challenges were the most prevailing at that time. The decision to go to the moon was political and it was embedded in the US politics, supported by the public side and economy was not considered as restriction. The remaining challenges were technology related.

Thus, the moon project served as inspiration, but in the case of electrification of transport, the other three dimensions, political, societal, and economic, emerged from our previous research on the electrification of transport. In our studies of electrification of transport in China and in Sweden, we have noticed that while technology is getting high attention the other dimensions have high impact on the outcome and speed of the electrification (Danilovic & Liu, 2021; Danilovic et al., 2020; Liu & Danilovic, 2021). In the case of electrification of transportation these dimensions cannot be taken for granted, rather they must be explored, understood, and put into practice to support ongoing transformation of transportation electrification.

Our research has developed a ‘multidimensional readiness index model’ that enables us to explore and understand any transportation mode, including flight and shipping. But for this research, we have developed this model based on the analysis of the development progress of Australia, China, India, Germany, Norway, Slovenia, Sweden, and UK in their electrification
of transportation systems. We have also developed and classified the political and economic readiness levels based on empirical observations. For societal readiness levels, we have been inspired by the European societal readiness levels (Büscher & Spurling, 2019) but adopted them based on our need that focuses on the adoption of electric vehicles by society. Each readiness dimension is divided on a scale between 1 and 9. Each one of the 1-9 levels shows a certain level of readiness; the 9th level shows the highest readiness scoring, whereas the 1st level shows the lowest readiness scoring of the countries in the electrification of the transportation system.

Finally, results have been obtained by evaluating each dimension based on their readiness scoring scales. The score of all dimensions (technology, political, societal, and economic) of each country has been summed up (Σ) and taken out the percentage (%) by dividing the total score as shown in table 1 in section 6. These mathematical results have been used to plot a graph, as shown in figure 6 in section 6, which shows the positioning of readiness of each country in the development of electrification of the transportation system.

The proposed four-dimensional readiness index scales are tentative and should be further developed, elaborated, and thoroughly tested. As the diffusion of transport electrification continues, new technologies will be launched, and new experiences will be developed, thus creating reasons for reevaluation of the scales of political, societal, and economic readiness to achieve high maturity levels.
4. Multidimensional Readiness Index Model

The multidimensional readiness index model is basically sourced from the technology readiness level (TRL) introduced by the National Aeronautics and Space Administration (NASA) in the early 1970s. The multidimensional readiness approach consists of four dimensions, technology readiness (TRL), political readiness (PRL), societal readiness (SRL), and economic readiness levels (ERL). These four dimensions form a web and, therefore, create a whole system where no one can be left out to gather a broader understanding of the electrification of the transportation system (Danilovic et al., 2020), as shown in figure 2 (Bhatti et al., 2022).

![Figure 2: The Multidimensional Readiness Index Model (Bhatti et al., 2022)](image)

We have adopted an innovation perspective to examine the TRL and explore other key components to understand and to incorporate into a system approach. Generally, the term ‘innovation’ refers to the introduction of new or recombined ideas or methods, however in the context of this analysis, ‘innovation’ is also about using technology to succeed with the commercialization, value creation, and diffusion in the society via a suitable business model. The technological element is merely one of the essential dimensions of the business concept. The technology requires a proper and relevant context to be embedded and integrated for its commercialization. The economic, societal, and political acceptance are the main elements needed for a potential technological solution to become a successful innovation accepted by a majority of the market. When it comes to some of the most successful innovations in our society, such as fast trains, airplanes, electric vehicles, and smartphones, we can see that they are all rooted in the political, economic, social, and socio-cultural contexts of their respective eras.
The diffusion and deployment of technologies are based on social acceptance; without socially being accepted, technology for technologies’ sake will face endless public resistance. It will be difficult to achieve commercial success for technology and attract investment and partners if political, institutional, and regulatory players do not support it. Therefore, the acceptance of developed technologies needs to be observed and examined in the context of a complex web of interactions that includes technical, political, societal, and economic elements.

4.1 Technology Readiness Levels (TRL)

Technology readiness level (TRL) is an approach for conducting a logical analysis, assessment, and decision-making process when selecting an appropriate technological solution based on maturity of technologies. TRL has become a standard approach to measuring a particular technology’s maturity. Fundamentally, TRL determines if technologies are ready for adoption by potential consumers (Hirshorn & Jefferies, 2016). Level 1 is considered the lowest, and level 9 is the highest measuring criterion on the TRL scale. Figure 3 demonstrates all nine levels of TRL.

The table below provides a detailed description of the nine technology readiness levels.

<table>
<thead>
<tr>
<th>TRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Technology is ready to be deployed on a larger scale.</td>
</tr>
<tr>
<td>8</td>
<td>The evaluation of the evidence proves that technology works and is ready for deployment.</td>
</tr>
<tr>
<td>7</td>
<td>The fully functional technology is tested in the planned operational system and gathered evidence of its success.</td>
</tr>
</tbody>
</table>
Table 1 illustrates the nine steps of evaluating the maturity levels of technology that begin with an idea and transform to the fully functional technology that reaches the level where it can be deployed on a larger scale. The levels from 1 to 9 can assist the decision-makers in observing and analyzing the development progress and transitioning of technology into a desired form. It can be noted that the established TRL is focusing on technologies and not on system level where different technologies can be combined or recombined.

### 4.2 Political Readiness Levels (PRL)

We have experienced that technology has been one of the most critical driving forces of societal and industrial transformation. The advancement of technology has introduced various technological solutions for decarbonizing the environment, such as renewable energy, transport electrification, hydrogen-based transport, etc. However, large-scale R&D, implementing new technical solutions, and diffusion of new technologies are almost impossible without political decisiveness and determination to utilize technology to transform and develop society. This is especially valid for the electrification of transport as transport is one of the most harmful environmental impacting industrial sectors globally. At the same time, it is directly associated with the coal and oil industry, which are an economic engine and a significant employer of many countries and will be the loser when transport is electrified. Some are suggesting that this ongoing electrification of the European automotive industry might lead to about 500,000 people losing their contemporary jobs. Political readiness is seen when the politicians recognize the problems and challenges and provide immediate support in framing new regulations, laws, and policies to support economic, industrial, and consumers for achieving the capabilities of purchasing expensive but desirable technologies that are costly in the beginning. Figure 4 explains the nine levels of PRL.

<table>
<thead>
<tr>
<th>TRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>The technology is tested in a simulation environment that replicates the natural world and provides almost accurate results. A fully functional representational model is considered a TRL – 6.</td>
</tr>
<tr>
<td>5</td>
<td>Technology at TRL 5 is a continuation of technology at TRL 4. However, TRL 5 is considered a breadboard technology and must undergo more thorough testing than technology at TRL 4.</td>
</tr>
<tr>
<td>4</td>
<td>The initial findings are collected, and multiple parameters are tested.</td>
</tr>
<tr>
<td>3</td>
<td>When active research and design starts on a particular technology.</td>
</tr>
<tr>
<td>2</td>
<td>When basic concepts have been investigated, and practical applications may be developed based on those results. However, TRL – 2 could be risky as there is no empirical evidence that the technology exists.</td>
</tr>
<tr>
<td>1</td>
<td>The beginning phase of any technology when the conceptual study is translated and reported for future research and development.</td>
</tr>
</tbody>
</table>

Table 1: Illustrates those 9 TRL levels in more detail (Hirshorn & Jefferies, 2016)
The table below provides a detailed description of the nine political readiness levels.

<table>
<thead>
<tr>
<th>PRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The government includes the idea in its national plan and monitors the development and implementation from the top level.</td>
</tr>
<tr>
<td>8</td>
<td>The government sees the impact of the new innovative product/project from a holistic system perspective and integrates other dimensions (economic, societal, and environmental) in their policy rebuilding and deals with it as one system.</td>
</tr>
<tr>
<td>7</td>
<td>The government provides the fund to the relevant stakeholders to begin the work.</td>
</tr>
<tr>
<td>6</td>
<td>The government approves the funds for converting the idea into a physical reality.</td>
</tr>
<tr>
<td>5</td>
<td>The coherence and commitment among the local/regional, provincial governments and institutions on each level in developing the budget planning and planning to monitor the idea to be implemented.</td>
</tr>
<tr>
<td>4</td>
<td>The government makes new policies or reshapes their old approaches to transform the idea into reality. For instance, imposing taxes to eliminate the old product that is not environmentally friendly reduces or eliminates taxes on the new product that the government wants to promote, which is good for society and the environment.</td>
</tr>
<tr>
<td>3</td>
<td>The new innovative idea and benefits are announced in the parliament, where the government and opposition parties mutually approve it.</td>
</tr>
<tr>
<td>2</td>
<td>The idea is discussed in the cabinet meeting where local, regional, and state governments show their willingness to move forward and develop the action plan.</td>
</tr>
<tr>
<td>1</td>
<td>The head of the state publicly expresses his/her interest in moving towards new innovative ideas / new inventions or adopting new technology.</td>
</tr>
</tbody>
</table>

*Table 2: Description of political readiness levels (Bhatti et al., 2022)*
Table 2 demonstrates the nine levels to assess the government’s intention, willingness, and firm, decisive move towards adopting innovation or invention and implementing new favorable policies for the relevant stakeholders to encourage them to embrace it.

4.3 Societal Readiness Levels (SRL)

Societal readiness level is a scale for analyzing and evaluating the readiness level of societal acceptance; for example, a product or a technology to be integrated into society needs to be accepted and desired by its citizens. Suppose we continuously design technologies, infrastructure, and policies in which people are not incorporated and do not see the benefits for them and their lives. In that case, there will be a risk in moving forward towards electrified solutions because it could be a failure (Cardullo & Kitchin, 2019). The SRL 1 is the lowest, and the SRL 9 is the highest level of readiness indicating that society has already started adopting new technology or product. Figure 5 demonstrates all nine levels of SRL.

![Figure 5: Societal Readiness Levels (Büscher & Spurling, 2019)](image)

The table below provides a detailed description of the nine societal readiness levels.

<table>
<thead>
<tr>
<th>SRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The product diffused in society, and many citizens buy the product.</td>
</tr>
<tr>
<td>8</td>
<td>Business development and product commercialization are done, and the product’s initial sales begin.</td>
</tr>
<tr>
<td>7</td>
<td>The citizens and the relevant stakeholders test the first product and confirm the benefits.</td>
</tr>
<tr>
<td>6</td>
<td>Establishing a business relationship by demonstrating the solutions with the customers and the relevant stakeholders.</td>
</tr>
</tbody>
</table>
Table 3 illustrates the nine levels of evaluation of incorporating society in the transformation of an innovative product (electric vehicles) and the citizens’ adoption and diffusion of EVs.

### 4.4 Economic Readiness Levels (ERL)

Economic readiness level is a dimension for analyzing and evaluating the readiness levels of cost affordability of a technology or a product by the industry that impacts them and by the large number of citizens expected to adopt electric vehicles. Economic readiness plays an important role in diffusing innovative products (electric vehicles) in society. The consumer’s approach is to pay for something less expensive or better than they already have.

The word “economic” is a vast subject divided into microeconomics and macroeconomics. Microeconomics is a bottom-up approach that deals with individuals, business decisions and concentrates on supply – demand and forces that determine the price levels. Macroeconomics is a top-down approach that deals with decisions made by governments and countries. It focuses on the economy, where the government determines the investments in R&D, prices, imposes and reduces the taxes, and provides rebates and subsidies to balance the development and manufacturing cost for early technologies with the price level of the products in the market (Potters & Logan, 2021). After all, the business operators and citizens must afford to buy the new technology and products coming on the market.

The transformation of the transportation system is a national and international matter that involves facing national and international challenges such as global warming, pollution, and depletion of fossil fuels in the world. Being responsible nations, it is countries’ governments’ responsibility to deal with these challenges and support the transformation of the transportation system towards electrification. Therefore, we have used the macroeconomic concept to build the economic readiness levels where the government controls the prices to bring stability and affordability to the market. The government has the mandate to manage and set the minimum or maximum prices for specific products, including gasoline, electricity, and vehicles (Kenton & Potters, 2021).

To develop the economic readiness levels, we have focused on balancing cost of three main factors (manufacturing cost of EVs, energy supply for the transport infrastructure, and

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>In the initial stage, problems are identified, such as environmental problems, different customer needs or factors associated with human health, etc.</td>
</tr>
<tr>
<td>2</td>
<td>To specify the need or problem of society, some market research is performed mainly based on secondary data.</td>
</tr>
<tr>
<td>3</td>
<td>Suitable solutions that fit the best for the problems and the awareness are provided to citizens and relevant stakeholders.</td>
</tr>
<tr>
<td>4</td>
<td>The proposed solution is tested by collecting views of the customers and relevant stakeholders through the pilot projects.</td>
</tr>
<tr>
<td>5</td>
<td>Customers and stakeholders’ views confirms the success rate of the proposed solutions in the specific area.</td>
</tr>
</tbody>
</table>

Table 3: Description of societal readiness levels (Büscher & Spurling, 2019)
operational cost), where governments can support by providing subsidies, rebates, imposing /reducing taxes on the EVs to push the EVs in the market for societal diffusion to achieve certain benefits, for instance, decarbonizing the environment and less relying on fossil fuels. The government can support until the economic readiness reaches the highest level where the price balances for consumers and producers, which means that the consumers can afford the product, and the producers can still capture the value. Figure 6 demonstrates all nine levels of ERL.

The table below provides a detailed description of the nine economic readiness levels.

<table>
<thead>
<tr>
<th>ERL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The EVs’ purchasing and operational costs become equal to or less than gasoline-based vehicles.</td>
</tr>
<tr>
<td>8</td>
<td>The government provides affordable/free charging facilities at public charging stations or affordable/free charging piles at public parking or support installing charging piles at home. This act will reduce the operational cost of EVs for citizens.</td>
</tr>
<tr>
<td>7</td>
<td>The government reduces/eliminates the registration and insurance fees on EVs, which will further support citizens in the cost reduction on purchasing EVs compared to gasoline-based vehicles.</td>
</tr>
<tr>
<td>6</td>
<td>The government provides extra support to encourage citizens to buy EVs by offering subsidies and rebates.</td>
</tr>
<tr>
<td>5</td>
<td>The government reduces/eliminate taxes on EV purchase for citizens to control the initial cost of EVs.</td>
</tr>
<tr>
<td>4</td>
<td>The government also supports renewable energy providers by eliminating/reducing taxes for those who provide energy to the EV infrastructure.</td>
</tr>
</tbody>
</table>
Table 4 illustrates the nine levels of government involvement to make economic readiness ready for each stakeholder participating in the transformation of the transportation system. The technology, political and societal readiness levels are more of general readiness levels that can be used for any technology, political and societal context, but the economic readiness levels depend on the development requirement of the product and the context where the product will be used.

Economic readiness is itself a complex dimension that is interrelated and interdependent on various factors such as government policies related to import/export, manufacturing companies’ capabilities (they have complete value chain capability or need to import the parts for manufacturing the product), and the market behavior. Not all the products require same or specific infrastructure to operate. For instance, the airline and shipping industry follows international laws, customer segments vary from country to country, and the airplanes manufacturers are limited, so the economic policies are designed by considering these factors, which do not apply to the automotive industry. Therefore, the economic readiness levels are explicitly developed for electrification of transportation systems because economic readiness depends on the import/export policies of the government, requires specific infrastructure and support of energy companies to operate electric vehicles.

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>The government provides extra support to encourage automotive manufacturers to produce electric vehicles by offering subsidies and rebates.</td>
</tr>
<tr>
<td>2</td>
<td>The government reduces/eliminates taxes for companies producing electric vehicles and charging equipment.</td>
</tr>
<tr>
<td>1</td>
<td>The government revises their tax duties on import/export of EVs, EVs batteries, charging equipment, and equipment supporting renewable energy (solar panels, wind turbines, etc.).</td>
</tr>
</tbody>
</table>

Table 4: Description of economic readiness levels (Bhatti et al., 2022)

The technology readiness levels can be used to evaluate the readiness of technology. The political readiness levels express the dedication and willingness of the government to adopt and promote the technology in the country. The societal readiness levels show the technology’s adoption rate, and the technology has been supported by society. The economic readiness levels demonstrate the affordability of the technology for the buyers to consume the product. Thus, all the readiness levels are interdependent and interrelated to each other. However, the role of the political readiness levels is the most significant in holding all the other three readiness levels in one net to support the transformation.
5. Asia

Asia is the biggest continent on earth, both in size and population. As of 2018, the population of Asia was about 4.561 billion, which is approximately 60% of the world’s total population. Asia is spread over 44,579,000 square kilometers (17,212,000 square miles), which covers almost 30% of the world’s land.

Asia is rapidly growing in its population size. China and India are the most populated countries in Asia. Considering its increasing population, it comes as no surprise that Asian economies and industries are evolving. Automotive industry is one of the rapidly growing industries in Asia. China, Japan, India, and South Korea are the top four countries producing passenger vehicles in Asia. Chinese, Japanese, Indian, and South Korean automotive industries produced approximately 21.4 million, 6.6 million, 3.6 million, and 3.1 million passenger vehicles in 2021 (Statista, 2022f). As the population is increasing the demand of effective mobility is increasing too. Approximately 27.67 million passenger vehicles were sold in the Asian Pacific region in 2011. Within nine years, the sales of passenger vehicles increased and reached 32 million in 2020, of which 20.18 million were sold in China (Statista, 2022g). The top 10 selling brands in Asia are Toyota, Honda, Nissan, Suzuki, and Mazda are from Japan; SAIC and BAIC are from China; Hyundai and KIA are from South Korea; Tata is from India (Statista, 2022d).

Since the “electric vehicles” have been introduced globally, the rapid shift has been seen in the automotive industry from manufacturing fossil-based vehicles to electric vehicles in Asia. Asia is becoming a central hub of manufacturing electric vehicles and batteries due to its complete value chain control, from producing components, systems, and entire vehicle fleets to distribution and services, including hardware and application software. Among the top 10 selling brands of electric vehicles worldwide, six are Chinese brands such as Wuling HongGuang Mini EV, BYD Qin Plus PHEV, Li Xiang One EREV, BYD Han EV, BYD Song Pro/Plus PHEV, Changan Benni EV. China exported about 0.55 million passengers EVs in 2021, which increased up to 1.5 times as compared to 2020 (Mathlide Carlier, 2022). In 2021, approximately 2.96 million battery electric vehicles were sold in Asia (Statista, 2022a). China is leading in electric vehicles sales throughout the Asia Pacific region, with approximately 1.16 million electric vehicles sold in 2020 compared to approximately 1.6 thousand electric vehicles sold in India (Statista, 2022e). China is also leading in the market share of electric vehicles throughout the Asia Pacific region with approximately 6%, whereas India is far behind with 0.06% market share of electric vehicles in 2020. Asia is leading in manufacturing and exporting batteries for electric vehicles worldwide. The top five electric vehicle batteries manufacturers that provide 80% of the global automotive batteries are CATL and BYD from China, LG and Samsung from South Korea, and Panasonic from Japan (Buchholz, 2022). China and Japan have a strong position in electric vehicles manufacturing and market size, and South Korea is strong in technology. In contrast, India is far behind in electric vehicle manufacturing technology, and India imports batteries from China for its two and three-wheelers.
However, the megacities of China and India are facing substantial pollution problems, which is the highest mortality excess caused by air pollution. “East Asia and South Asia are the regions that suffer the most deaths attributable to air pollution. In 2019, air pollution exposure caused more than two million deaths in each region, with the majority of those deaths occurring in China and India (Tiseo, 2022).” Therefore, it is highly significant for Asian countries to continue striving towards environmentally friendly technologies such as electric vehicles, which will support phase-out fossil-based vehicles, dramatically reduce vehicle emissions, and improve the air and life quality of citizens across the region (Statista, 2022b).

We have selected China and India as Asian countries to evaluate their electrification of transportation readiness conditions because China has the largest and India has the second-largest population globally. China is one of the leading countries in electric vehicles worldwide. In contrast, India is far behind technically and economically even though both countries are very close in the size of population and land, but with a huge difference in adopting clean transportation. Figure 7 represents the readiness positioning of China and India in the electrification of transportation systems.

Figure 7 represents China’s position at level 9 in technology, political and societal readiness and at level 8 in economic readiness. In contrast, India lags behind and is positioned at level 4 in technology and societal readiness, level 5 in political readiness, and at level 3 in economic readiness.
5.1 China

China is the biggest country in Asia, with the largest population in the world of 1.44 billion. It is one of the leading countries in the world in adopting electric vehicles. In 2019, China had the largest electric car fleet with 47% globally, whereas, in 2009, China was the home of the world’s largest internal combustion engine (ICE) vehicle market. China is historically a landmark of success for automotive companies. China’s automotive industry has been flourishing and growing at an average of 15% each year and was acknowledged 70% growth globally during the last ten years (Teece, 2019). China overtook the U.S. as the world’s largest electric vehicle market in 2015, and became more than three times larger in 2018 compared to the U.S. (Richter, 2019).

China is a densely populated country. The most common transportation mode in China is automobiles. Figure 8 shows that 59.5% of the population prefer to use automobiles for commuting from one place to another (Cox, 2019).

![Figure 8: Different modes of transportation in China in 2019 (Cox, 2019)](image)

The east part of China is the most densely populated with various customer segments. Some customers exist in smaller cities where they freely spend money without worrying about future costs or savings. Many customers live in more extensive and expensive cities, for example, Beijing, Shanghai, and Guangzhou. They adjust to a costly lifestyle where increased housing costs change their spending preferences. Chinese youth between 20 to 30 years demand eco-friendly products and stand for most expenditures, wealth, and investments (Ho
et al., 2019). The diversity and variety of people’s preferences make China an attractive market for electric vehicles, and therefore, we have chosen China as part of our research.

Figure 9 represents the positioning of China in the transformation of the transportation electrification system in four dimensions: technology, political, societal, and economic.

Based on our research, we rate technology, political and societal readiness at level 9, but economic readiness, we place level 8 to China. Figure 8 represents the multidimensional readiness index model of China. Each level of readiness is analyzed below in the subsections.
5.1.1 Technology Readiness Level in China

The electrification of transport started in China already 15-20 years ago. China is presently taking the lead in developing electric vehicles, electric motors, batteries of all kinds, charging infrastructure and also the most important component of the EVs, the software based control and monitoring systems (Danilovic & Liu, 2021; Liu & Danilovic, 2021). Different manufacturers introduced more than 200 brands of electric vehicles in China in 2020. Even though not all of those brands houses have manufacturing capabilities, they have outsourced a few large-scale electric vehicle manufacturers to design and use specific technology based on their required criteria (Danilovic & Liu, 2021). In 2021 several Chinese EV manufacturers announced to export EVs to Europe, focusing on the Scandinavian market. Among the top 10 brands of EVs sold in China in April 2021, 9 of them are Chinese brands except for Tesla, which is also manufactured in China, as stated in figure 10.

China has established the entire value chain and system from components to the fully integrated system for developing and manufacturing EVs. China is also taking the lead in developing the vehicle battery charging infrastructure as well has one of the largest battery manufacturing capabilities in the world, beside South Korea. The China Electric Vehicle Charging Infrastructure Promotion Alliance (EVCIPA) estimated that by the end of June 2021, China had almost 1.947 million EV charging piles available for public use, which represented an increase of 47.3% in one year. The installation of public chargers has risen rapidly in China and reached 923,381 by the end of June 2021. There were around 374,000 fast chargers, 550,000 slow chargers, and 426 DC-AC integrated charging piles. According to EVCIPA estimation, almost 30,400 public EV battery chargers were installed each month from July 2020 to June 2021. Five major cities of China hold the most EV chargers as of June 2021. These cities are Guangdong (10,514), Jiangsu (5,981), Zhejiang (5,355), Shanghai (5,337), and Beijing (5,190) (Nika, 2021).
However, another implemented charging infrastructure solution has been developed for operating EVs as complementary charging solution, which is battery swapping technology as shown in figure 11.

The Chinese government has put battery-swapping and hydrogen technology on the national strategic agenda. Hydrogen has been mulled as an alternative fuel for ICE powered vehicles as alternative to hydrocarbon-based fuels, thus representing a further means of reducing the carbon footprint. Electric vehicle manufacturers’ key leaders (NIO, Geely, BJEV, and Changan New Energy) have adopted battery swapping technology. By the end of June 2020, there were 452 battery-swapping stations in China. The growth of battery swapping stations continued and reached over 716 battery-swapping stations by the end of June 2021. Estimations indicate that there will be 25,000 swapping stations in 2025 for passenger vehicles (Danilovic & Liu, 2021) and more than 400 swapping stations for heavy trucks in few years’ time (Liu & Danilovic, 2021). The electrification of Chinese megacities is complex and complicated to manage through cable charging solutions only. Thus, swapping systems are introduced as complementary system. Thus, China is positioned at level 9 in the technology readiness level of the multidimensional readiness index.

Figure 11: Patterns of Charging Electric Vehicles (Tianyu, 2020)
5.1.2 Political Readiness Level in China

In 2009, the central government of China started subsidizing EV sales for public and government fleets, and in 2013, it began supporting private EV owners. The subsidies were between $5400 to $9000 per vehicle in 2013, dependent on the vehicle’s electric range. At the end of 2020, the government introduced a new EV subsidy policy for 2021. According to the new policy, 20% of the subsidy was reduced on pure electric vehicles. Vehicles with a driving range between 300 to 400 km dropped from $2500 to $2000 per vehicle, and vehicles with a driving range of 400 km or more decreased from $3500 to $2800 per vehicle. In addition, for hybrid vehicles, the subsidies dropped from $1320 to $1050 per vehicle. The unexpected drop of 20% subsidy on EVs sharply decreased the sales of EV’s in the industry. The government extended the EV subsidy support for two years until the end of 2022 to get the market back on track. The sales of EVs rebounded when the government approved the extension (Barrett, 2021).

The Chinese government decided in May 2020 to include battery swapping technology as a national strategic development technology which handles a new infrastructure policy that focuses on the whole life cycle value of the battery. By the end of 2020, the battery swapping technology was highly supported in the most significant Chinese national policy that drives industrial development in China, “The new energy vehicle development plan 2021 – 2035” (Danilovic & Liu, 2021). Battery swapping has become attractive to drivers since it decreases upfront costs and reduces re-charging time. In 2020, NIO introduced a new business model based on unbundling vehicle purchases, battery renting, and swapping subscriptions. The four major Chinese electric vehicle manufacturing companies that provide battery swapping services are NIO, Geely, BJEV, and Changan New Energy. Standardizing battery-swapping services has been a priority for the Chinese government. In April 2020, the Chinese government extended the subsidies for the EV manufacturing companies, with the condition that companies will only be eligible for grants if the prices of EVs are below about $46000. However, this policy does not apply to battery swapping models. The policy indicates that most premium electric vehicle manufacturers will have to decrease the EV prices to meet the requirements for the subsidy scheme, and the policy also shows the clear intention of the government to boost the battery swapping business in China.

The Chinese Finance Ministry has announced to cut down 30% subsidies on new electric vehicles (NEV) in 2022 and eliminate the subsidies from 31st December 2022 (Randall, 2022). China will become the first country to eliminate all sorts of subsidies on NEVs by the end of this year, which might affect the sales of NEVs. However, the overall interest of the Chinese government in the diffusion and adoption of sustainable electrified transportation is very high. Therefore, China is placed at level 9 in the political readiness level of the multidimensional readiness index.
5.1.3 Societal Readiness Level in China

Chinese society has been introduced to the concept of electrification for more than 20 years. In 2019, battery electric vehicles (BEVs) sales reached almost one million, three times more than plug-in hybrid electric vehicles (PHEVs). The sale of electric vehicles continuously increased in 2020 and reached above one million three times more than plug-in hybrid electric vehicles (PHEVs). Figure 12 represents the gradual sale increase of electric vehicles in China each year from 2011 to 2021. The sale of electric vehicles continuously increased in 2021 and reached above three million. However, fuel cell vehicles are not popular in China yet (Wong, 2022).

In July 2021, 271,000 electric vehicles were sold in China, which nearly broke another monthly record. Compared to July 2020, 164.4% of electric vehicle sales increased in just one year, indicating that the electric vehicle sector is booming, with numerous brands and models selling in large numbers. The overall market share of EVs, including 12% BEVs and 3% PHEVs have increased and reached 15% in the mid of 2021 (Kane, 2021a). In the six largest Chinese cities, electric and hybrid vehicles now account for approximately a fifth of new car sales on average. Consumers in China’s industrialized cities on the east coast have adopted electric vehicles more rapidly than their inland counterparts. The electric vehicle penetration rate in major cities is 8% higher than in other cities of China. Like Shanghai 31%, Beijing 16%, Guangzhou 13%, Shenzhen 25%, Hangzhou 21%, and Tianjin 12% (Bloomberg, 2021). Already ten years ago, the 12 million inhabitant’s city of Shenzhen introduced electric vehicles on large-scale buses for the initial electrification of the public transport domain. Now, Shenzhen has 22,000 EV taxis, 18,000 EV buses, and 86,000 EV logistic transport vehicles. Now ordinary people see that the next step is full electrification of private vehicles. Chinese society is fully committed to moving expeditiously towards sustainable transport based on a fully electrified and fossil-fuel-free transportation system. Therefore, China is positioned at level 9 in the societal readiness level of the multidimensional readiness index.

![Figure 12: Annual sales of EVs in China from 2011 – 2021 (Wong, 2022)](image-url)
5.1.4 Economical Readiness Level in China

The economic readiness analysis is based on the electric vehicle cost, the operational cost of the vehicle, subsidiaries’ support to make the price and cost affordable for citizens, businesses, and the outcome in terms of value creation to the country and people. A survey was conducted in June 2019 by 'Rakuten Insight' on the "Acceptable price level for purchasing an electric car compared to a conventional car in China." Almost 26% of the Chinese consumers are only willing to pay the same price for an electric car as a conventional car, whereas 18.8% of the consumers agree to pay up to 10% and 22.4% of the consumers are ready to pay 11 to 30% higher than conventional cars (Wong, 2021). In total, 45% of the consumers are willing to pay a higher price for electric vehicles than traditional cars. In contrast, only 8% of the consumers are not willing to pay a higher price for electric vehicles than conventional cars. It means more people favor electrified transport in China besides the cost of the electric vehicle. One explanation behind this is that electric vehicles bring health improvements to citizens, especially in highly dense cities, which are values for citizens they are ready to pay for.

The price of electric vehicles is continuously dropping in China. Consumers achieve cost competitiveness on electric vehicles many years earlier than expected, primarily due to the vehicles’ fuel savings. In 2022–2026, electric cars provide a compelling new vehicle purchase proposition based on an analysis of first owners’ 5-year vehicle ownership expenses. Electric vehicles’ fuel and maintenance savings greatly surpass home chargers and other expenditures for the first buyers in 2025. The BEV driving ranges of 250–500 km and PHEV driving ranges of 40–100 km is compared to the conventional cars in these two categories. In 2020, the initial prices of electric vehicles were $5,000 to $17,000 more than the similar gasoline vehicles. With the projected reduced cost of components and subsystems, and the assembling of EV and EV batteries, the prices of a short-range BEV in year 2026 and a long-range BEV in year 2030 will be equal to their similar types of gasoline vehicles. The charging cost of electric vehicles depends on the prices of electricity provided by the grid. Since China wants to encourage the use of electric vehicles, the charging prices have been set at low levels. There are time-of-use fees for EV charging in several provinces and cities in China. State Grid’s charging stations also use time-of-use pricing. State Grid Beijing costs RMB 1.0044/kWh (approximately $0.16) during peak hours, RMB 0.6950/kWh (approximately $0.11) during shoulder hours, and RMB 0.3946/kWh (approximately $0.062) during off-peak hours, plus a service fee RMB 0.8 (approximately $0.13) (Boya & Jing, 2018). However, the cost of electric vehicles is still not competitive compared with gasoline vehicles, and it is mostly the subsidies and rebates that encourage people to buy electric vehicles. Estimations are made that the EVs will be price neutral to ICE technology in 3-5 years. Therefore, China is placed at level 8 in the economic readiness level of the multidimensional readiness index.
5.2 India

India is the second-largest country in Asia, with a 1.39 billion population. It is spread over 3.287 million square kilometers. The most populated cities of India are Mumbai, Delhi, Bangalore, and Kolkata. The vast majority of the population relies on motorized transport because public transportation is expensive and inefficient in decentralized and low-density areas. The most popular mode of transportation is two wheelers (personal motor bikes) and three wheelers’ rickshaws (shared transport) as shown in figure 13.

Figure 13 represents that almost 95% of Indian population travel by road using various means of transportation such as, buses, two wheelers, three wheelers and four wheelers. In 2019, India was the largest manufacturer of two-wheelers in the world. In the same year, 295 million vehicles were registered only in India (Statista, 2021c). India is one of the largest countries with two and three wheelers while the ordinary vehicles are rapidly growing in numbers. However, India is lagging behind in the electrification of the transportation system. India does not have the proper infrastructure for electric vehicles yet. Hero MotoCorp is the market leader in producing two-wheelers has taken the initiative of producing electric bikes and scooters. The high battery cost developed a remarkable difference between battery and petrol vehicles. The income of the average Indian population is not high, so they cannot afford expensive clean energy transport. Now, the Indian government will support electrifying a large percentage of two and three wheelers in India. The vehicle manufacturers have urged the
government to set more “realistic” goals. More investments in the renewable energy sector might pave the way for the domestic market, with the two-wheeler industry expected to develop at a rate of over 9% in the coming years (Statista, 2021c). The population of India is growing, urbanization is expanding, and the middle class is flourishing with the increasing demand for electric vehicles. Therefore, India is an upcoming market for electrification.

Figure 14 shows the results of our analysis depicted in a spider graph.

Based on our analysis India is positioned in technology and societal readiness at level 4, political readiness at level 5 and economic readiness at level 3 in the multidimensional readiness index of electrification of the transportation system. Each level of readiness is analyzed below in the subsections.
5.2.1 Technology Readiness Level in India

India is currently at an early stage of electrification of the transportation system, and there is no recognized electric vehicle manufacturer in the market yet. However, three to four major players have shown up in the last few years as shown in figure 15.

Figure 15: Top 4 selling brands and their sales of EVs in India in the financial year of 2021 (Sun, 2021c)

Figure 15 represents that Tata motors sold 4,214 electric vehicles in India during the financial year of 2021. Tata is an Indian automotive manufacturing company and has introduced two electric vehicles, Tata Nexon and Tata Tigor. Another most selling brand was MG ZS electric vehicle sold 1,499 electric vehicles in India. MG was originated from the UK but is now owned by SAIC, a Chinese company. The third most selling brand of EV was Hyundai Kona (South Korean) which sold 180 electric vehicles in India. The fourth brand was Mahindra e-Verito, an Indian brand that sold only 9 electric vehicles.

The most common mode of transportation in India are two and three-wheelers. The top 12 sellers of two-wheelers in India are represented in figure 16.

Figure 16: Top 12 selling brands and their sales of two-wheelers in India in 2021 (Sun, 2021f)
India’s top two-wheelers electric manufacturers are Hero Electric, Okinawa, Ampere, Ather Energy, Revolt Intelllicorp, and Bajaj. India does not manufacture batteries but imports from other countries for their two-wheelers. China, Hong Kong, and Vietnam are significant exporters of lithium-ion batteries to India. In 2019, India imported lithium-ion batteries from China, Hong Kong, and Vietnam worth $773 million, $267 million, and $114 million, respectively (Gupta, 2020).

The Indian government has taken significant initiative to expand the public electric vehicle charging stations throughout India and started focusing on the nine mega cities such as, Surat, Pune, Ahmedabad, Bengaluru, Hyderabad, Delhi, Kolkata, Mumbai, and Chennai where the most population live in over 4 million people. Almost 1,640 public electric vehicle chargers are installed in India, among those chargers about 940 chargers are only installed in those 9 mega cities. Additionally, 678 more chargers are installed during October 2021 and January 2022 in these nine cities (Ministry, 2022). However, India is still lagging behind in its charging infrastructure for electric vehicles even though in 2021, electric vehicle charging stations expanded 2.5 times in 9 mega cities. Therefore, India is stated at level 4 in the technology readiness of the multidimensional readiness index.

5.2.2 Political Readiness Level in India

The Indian government intends to accelerate the adoption of electric vehicles in India to reduce the rising challenges of pollution that come out of the transportation sector. Therefore, the Indian government has introduced various rebates and subsidies for users and manufacturers of electric vehicles. The government is also investing in building new infrastructure and installing more charging piles for its two, three, and four-wheeler electric vehicles.

To increase the production of electric vehicles, the Indian government has introduced a scheme called the “Production Linked Incentive (PLI)” and announced the US $3.5 billion for manufacturing electric two-wheelers, batteries, and their components in India (Rokadiya, 2021). To increase the sales of electric vehicles, the federal government of India introduced the first scheme in 2015 called “Faster Adoption and Manufacture of Hybrid and Electric Vehicles (FAME).” The first phase of the FAME scheme was to encourage the buyers of EVs by providing incentives to reduce the upfront cost of the EVs. The FAME scheme was continued till March 2019 in which government supported the sales of about three hundred thousand electric vehicles with a total incentive of approximately US $45 million. After the success of the first phase of FAME, the government introduced the second phase of FAME for four years, from April 2019 to March 2022, and dedicated approximately US $150 million (Saif, 2021). The second phase of FAME aims to research and develop electric vehicle technologies, further develop charging infrastructure, and create market demand for two, three, and four-wheelers of electric vehicles by providing purchase incentives. The incentives provided to the
consumers were based on the size of the battery in the vehicle. The available incentives are mentioned in Table 5 below.

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Battery size (kWh)</th>
<th>Subsidy offered ($)</th>
<th>Total subsidy ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two–wheeler EV</td>
<td>2</td>
<td>131</td>
<td>263</td>
</tr>
<tr>
<td>Three–wheeler EV</td>
<td>5</td>
<td>131</td>
<td>657</td>
</tr>
<tr>
<td>Four–wheeler EV</td>
<td>15</td>
<td>131</td>
<td>1,972</td>
</tr>
</tbody>
</table>

Table 5: Incentives available for EV buyers under FAME-II scheme (Saif, 2021)

The subsidies mentioned in Table 5 provided for three and four-wheeled electric vehicles are only available for commercial use. The Indian state governments have also introduced policies that support the diffusion of electric vehicles in their states. The state government of Delhi, Gujrat, Maharashtra, Meghalaya, West Bengal, Assam, Rajasthan, Telangana, Goa, Odisha, Karnataka, and Andhra Pradesh have exempted road tax and registration fees on electric vehicles. However, after all that, India is the second-largest populated country globally, and these efforts are still not enough to encourage even half of the population towards transport electrification. The government has to deal with transport electrification as a national level plan and provide higher importance by imposing restrictions on fossil-based transport. The government has to take further steps in building the charging infrastructure and converting the public transport system to an electrified system that would encourage private consumers to move towards transport electrification. We have stated India at level 5 in the political readiness level in the multidimensional readiness index.

5.2.3 Societal Readiness Level in India

Indian society is aware of environmental concerns. In 2019, an Indian foundation named “Shakti Sustainable Energy Foundation; Council on Energy, Environment and Water” surveyed gathering the opinion of the Indian society for the adoption of electric vehicles. Almost 67% of participants responded that the lack of adequate charging infrastructure holds them back from not buying electric vehicles. On the other question, 60% of participants responded that the limited choice of electric vehicles in the market is another barrier for the consumers to choose electric vehicle.

The demand for electric vehicles is gradually increasing in India, and the government is seeking to accelerate it. According to the data collected from the government’s Vahaan portal, about 119,000 battery-operated vehicles were registered in 2020 in India. A year later, battery-operated vehicles sales increased and reached 311,000 recorded in 2021. Almost 95% of the battery-operated vehicles registered were two and three-wheelers recorded in 2020 and 2021. Figure 17 represents the sale of battery-operated vehicles of two, three, and four-wheelers.
Figure 17 shows that almost 152 thousand electric two-wheelers and 141 thousand electric three-wheelers were sold in 2020. But the sale of electric two-wheelers and three-wheelers dropped in 2021. It reached nearly 144 thousand and 89 thousand, respectively, primarily due to the impact of the corona virus pandemic. In contrast, the sales of four-wheelers doubled and increased in 2021 and reached from almost 3 thousand to 6 thousand in just one year. However, the sale of two-wheelers was higher in India than three-wheeler and four-wheelers. After all, the rate of sales of electric two, three, and four-wheelers are very low compared to the size of the Indian population. Another challenge is encouraging Indian society to switch from fossil-based vehicles to electrified vehicles, which is a massive task for the Indian government. Therefore, we placed India at level 4 in the societal readiness in the multidimensional readiness index.

5.2.4 Economic Readiness Level in India

In 2019, from June 7 to June 30, a company called "Rakuten Insight" conducted a survey in India, in which approximately 12,433 people participated in the age group of 16 years or above. The participants were a combination of 4,884 males and 7,787 females. This survey aimed to gain people's opinions on purchasing electric vehicles across India. Almost 52.05% of respondents responded that the purchasing and charging cost is still high compared to fossil fuel vehicles besides the government subsidies, so they will not buy electric vehicles (Shangliao, 2021).

Road transportation is widespread in India. Approximately 95% of Indian people travel by different road transportation modes such as buses, two-wheelers, three-wheelers, and four-wheelers (Sun, 2021e). However, two-wheelers are commonly used in India. In 2019,
approximately 295 million two-wheelers were registered in India (Statista, 2021c). Table 6 represents the cost comparison of electric and petrol two-wheelers.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Electric Two-wheelers</th>
<th>Petrol Two-wheelers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle price</td>
<td>$1,510</td>
<td>$1,102</td>
</tr>
<tr>
<td>Lifespan</td>
<td>10 years</td>
<td>10 years</td>
</tr>
<tr>
<td>Annual maintenance + insurance</td>
<td>$39</td>
<td>$56</td>
</tr>
<tr>
<td>Amortized annual battery cost</td>
<td>$99</td>
<td>$0</td>
</tr>
</tbody>
</table>

Table 6 shows that the price of electric two-wheelers is about $408 higher than its counterparts’ price of petrol two-wheelers. However, the federal government has introduced incentives for electric two-wheelers buyers of $197 per kWh, covering up to 40% of the two-wheeler’s total cost. The annual maintenance and insurance cost of electric two-wheelers is $17 lesser than the petrol two-wheelers due to their fewer moving parts. However, the annual battery cost makes the electric two-wheelers more expensive than the petrol two-wheelers in India. The average petrol two-wheelers offer approximately 50 to 60 kilometers per liter. In contrast, an electric two-wheeler offers the same mileage as petrol two-wheelers at about 15% of one liter of fuel, making electric two-wheelers cost-effective in the long run.

However, electric two-wheelers are a good option for short distances. Electric two-wheelers require a minimum of 2 hours to charge a battery fully. People who live in apartments may find it difficult to charge their two-wheelers. Even with the option of removable batteries, it is still a hassle to remove the battery, take it upstairs to charge and then put it together again. The whole process requires a lot of time, unlike petrol vehicles which are good to go in a few minutes. Therefore, based on the above discussion India is placed at level 3 in the economic readiness of the multidimensional readiness index.
6. Australia

Australia is the smallest continent in size, and the entire country occupies this continent. It is the sixth-largest country on earth and 2.4 times bigger than India but 1.2 times smaller than China. The total population of Australia was about 25.69 million in 2020, which was much lower than China and India. The Australian population is unevenly distributed; almost 90% of its population lives in cities along the eastern and northern coast, with nearly half in Sydney and Melbourne. The distance between Sydney and Melbourne, Australia’s two largest cities, is 877 km; therefore, people have to travel longer distances from one city to another. We have selected Australia due to the low population, low density, and large land area that it covers, which is very different from China, India, and Europe. Figure 18 represents the most common mode of transportation in Australia.

![Figure 18: Modes of transportation in Australia in the year of 2016 (Australia, 2016)](image)

Figure 18 shows that in 2016, approximately 66.3% of people traveled by private cars, approximately 3.5% people traveled by buses, and approximately 1.6% of people traveled by motorbikes and bicycles, which means that 68.4% of the road transportation contributed to commuting people from one place to another within the country. Australia is lagging behind in its train infrastructure. It mainly relies on on-road transportation and especially on large trucks to transport goods across the country. On average, a heavy-duty truck travels 75 km per day in Australia. Australia has estimated that truck traffic will increase by 50% by 2030 (S. A. F. Council, 2021). Australia is heavily dependent on the import of fuel for their trucks; 83% is imported mainly from Asia. Australia has insufficient fuel reserves with only 17 days of diesel supply.
reserves, Australia’s trucking fleet will become vulnerable in case of emergency to international disruptions (B. F. Australia, 2018).

The Swedish company "Volvo Trucks" sold 2138 heavy-duty trucks in 2018 and 2239 in 2019, averaging 2189 trucks per year (Chapman, 2020). Australia is currently the second biggest market for heavy-duty trucks. Therefore, Australia is an attractive market for electric and hydrogen fleet manufacturers and a bright spot for clean energy investors and industries. Australia is the only continent covered by oceans on all sides. It has large desolated areas, and the weather mainly consists of sunshine that supports the production of a vast amount of solar, wind, and other natural forms of renewable energy.

Figure 19 represents the readiness positioning of Australia in the electrification of the transportation system.

Based on our analysis Australia is positioned in technology and economic readiness at level 3, whereas in political readiness at level 4 and societal readiness at level 5 in the multidimensional readiness index of electrification of the transportation system. Each level of readiness is analyzed below in the subsections.
6.1 Technology Readiness Level in Australia

In Australia, the transportation sector is transforming from fossil-based to electrified vehicles but at a slow pace. The technology is evolving, and Australia’s demand for zero-emission vehicles is slowly increasing. The top 10 selling brands of electric vehicles in the first quarter of the year 2021 are Tesla (USA), Mercedes-Benz and Porsche (Germany), Hyundai and Kia (South Korea), Volvo Cars (Sweden), and Nissan (Japan) as shown in figure 20.

Figure 20: Top 10 selling brands and their sales of EVs in Australia from January - March 2022 (Misoyannis, 2022)

Figure 20 represents that the top 10 selling brands of electric vehicles in Australia are imported from Asia (Japan and South Korea), Europe (Germany, Sweden), and the USA. Australia has become the fastest-growing sector in the electric bicycle market. Over the last three years, the electric bicycle models have tripled in Australia. Now, more than 50 brands are currently providing a variety of electric bicycle models (Kennedy, 2019). The sales of electric bicycles have rapidly increased by 310% over the last six months in Australia (Keoghan, 2020; Reid, 2020). The rapid increase in the sale of electric bicycles probably comes from passengers searching for alternative means of transport during COVID-19 and the growing demand of the drivers delivering food at home because of the lockdown of the cafés and restaurants (Keoghan, 2020). The local councils of the Australian government, such as Brisbane, Melbourne, and Sydney, are installing pop-up bike tracks for the bike riders to encourage the use of bikes (NSW, 2020).

In Australia, there are several electric scooters suppliers such as Fonzarelli, Bzooma, and Vmoto. Fonzarelli sold 800, and Vmoto sold 380 electric scooters in the first half of 2019. Fleet operators for delivery services are also moving towards electric scooters. There are 1,000 Kyburz electric three-wheelers used by Australian Post, with an additional 1,000 on order for delivery in early 2021 (Hinchliffe, 2019).

Australia is a country with a lacking infrastructure when it comes to transport outside the cities. Since it has an underdeveloped railroad connection, it mainly relies on large trucks...
called road trains for transport goods across the desolate areas of the continent (Government, 2020). In 2021 Volvo Trucks released their first heavy-duty battery-electric trucks with a total range of 300 km on the giant battery pack of 540 kWh (Volvo, 2021). The buses play an important role in commuting from one place to another. For Australian transport operators, electric buses provide a substantial potential to reduce noise pollution, greenhouse gases, and operating costs. Now in Australia, almost 100,473 buses are operating in public and private sectors that account for 5% of all public transportation travels (Statistics, 2021). Each year around 1,300 new heavy buses are registered in Australia. These new buses are usually replaced on a one-for-one basis when the older ones approach the end of their service life. The average service life of these new buses is up to 25 years, and the buses rely on diesel engines that emit higher emissions (Scania, 2019). Now, electric bus technology is on the market in Australia and is increasing with the number of suppliers such as Volgren, Gemilang, BYD, Precision Buses, Carbridge, and Yuong. Several experiments, both governmental and private, are ongoing to determine the viability of electric buses.

Charging Infrastructure in Australia

The charging infrastructure is continuously developing in Australia. Figure 21 represents the charging stations distributed in various states of Australia.

Since July 2019, fast-charging stations have increased by 42%, and standard charging stations have increased by 16%. At over 150 locations across Australia, more than 350 fast-charging stations of 50 kW and more are available and over 1200 locations. Almost 2000
standard charging stations of less than 50 kW are now available for the public, as shown in figure 21. Charging is still a big issue in Australia. Australians who do not have access to off-street parking chargers charge their vehicles at home, sometimes difficult or impossible. As a result, public charging infrastructure is an issue of convenience, but it is necessary to continue adopting electric vehicles. Therefore, significant highways, metropolitan areas, and tourist attractions need public charging facilities. However, according to the E. V. Council (2020) report, a survey has been conducted. Most respondents (52%) were not satisfied with the charging facilities that hold them from buying an electric vehicle. Therefore, based on the above discussion, Australia is stated at level 3 in the technology readiness of the multidimensional readiness index.

6.2 Political Readiness Level in Australia

In recent years, many Australian local governments have shown interest in establishing policies that encourage the use of electric vehicles. The primary purpose of these policies is to facilitate engaging the community, transitioning local governmental transport to electric, and support the further development of public charging infrastructure.

The Queensland, Australian Capital Territory (ACT), and New South Wales (NSW) government have made progress in developing electric vehicle policies in the last year. The local government of NSW has committed to increasing funding in developing the infrastructure for charging stations, electrifying Sydney’s bus fleet, and co-funding for fleet transitions to electric vehicles. The government of Queensland is continuously growing and implementing the strategy for electric vehicles and further investing in public charging infrastructure along the main highways. The ACT government is trying to electrify its bus fleet system. The Northern Territory, Southern and Western Australia, and Victorian governments are all designing policies that can promote the use of electric vehicles (E. V. Council, 2020).

To promote electrification of transportation, it is significant that governments at all levels continue to implement measures that lower consumers barriers and indicates market viability to international electric vehicle manufacturers. According to the E. V. Council (2020) report, the local governments of Australia have made some progress in implementing policies for the electrification of the transportation system. Still, the federal government of Australia develops no significant policy. Therefore, in adopting policies to promote electric vehicles, Australia is still far behind the developed nations such as China, Norway, Sweden, UK and etc. as shown in the figure 22.
The electric vehicle council Australia conducted a recent survey on electric vehicles, which reports that the lack of federal government policies on electric vehicles holding the suppliers to deliver the electric vehicles to the shores. The electric vehicle manufacturers need to see the government’s policy support to justify introducing electric vehicles into specific markets. The markets with clear government policies promote the use of electric vehicles and enforce the reduction of emissions from the transportation sector. Some of the policies that can be included are the average emissions rules for the OEM fleet and fuel economy standards that help in reducing emissions. The Australian market is not ready for electric vehicles as none of these policies are in place yet. Therefore, Australia is positioned at level 4 in the political readiness of the multidimensional readiness index.

6.3 Societal Readiness Level in Australia

The adoption of electric vehicles in Australia is increasing each year. The electric vehicles sale tripled from 2,216 to 6,718 during 2018 – 2019 in Australia, and a 7.8% drop in combustion engine vehicle sales between 2018 and 2019 (E. V. Council, 2020), as shown in figure 23.
Australia itself is a continent and a big country, and the penetration of electric vehicles in Australia differs across different states and territories. The highest number of adoptions of electric vehicles is in Victorian and New South Wales (NSW) states. Between 2011 and 2019, the total sales excluding Tesla were 2,540 in Victorian and 2,532 in NSW states. Figure 24 shows the number of electric vehicles sold during 2019 according to different states and territories of Australia.

![Figure 24: EVs sold in 2019 in different states and territories of Australia (E. V. Council, 2020)](image)

The Victorian and NSW are the most populated states of Australia. In 2019, the sale of electric vehicles was almost equal in NSW 832 and in Victoria 815, as shown in figure 24. However, if we calculate the percentage of the vehicles sold in Australia, in 2019 in Australian Capital Territory, 83 electric vehicles were purchased on every 10,000 vehicles sold, which competes for all other states in Australia.

The fully electric and hybrid vehicles sale is continuously growing throughout the world. In 2019, approximately 2.26 million fully electric and hybrid vehicles were sold globally, increasing 9% sales compared to 2018, equivalent to 2.5% of all new vehicles sold worldwide. In developed nations, electric vehicle sales represented around 2.5 to 5% of new car sales, with the significant exception of Norway with 56% sale of new electrical vehicles (Irle, 2020).

In Australia, the sales of overall new vehicles dropped 20% during the global pandemic of Covid-19, but the sales of electric vehicles were impressively resilient. In the first half of 2020, there were 3,226 electric vehicles sold. However, Australia still lags behind at 0.6% in its market share of fully electric and hybrid vehicles than other developed countries, but the continuous introduction of offering new electric vehicle models creates the opportunity for further development (Dowling, 2021). Therefore, Australia is stated at level 5 in the societal readiness of the multidimensional readiness index.
6.4 Economic Readiness Level in Australia

The economic readiness level is intertwined with the political readiness level. The electric vehicle council report identifies the barriers to economic readiness in Australia. The key barriers are the high purchasing cost of electric vehicles and the high installation cost of home charging, as shown in figure 25.

Figure 25 shows the survey result conducted by Australia’s electric vehicle council in 2020. According to the survey E. V. Council (2020) report, 68% of respondents demanded the support of the government required in providing subsidies to reduce the cost of owning an electric vehicle. Approximately 66% of respondents highlighted that the cost of installing home chargers is still very high, and 43% of respondents demanded to provide discounts on vehicle registration, stamp duty, and toll roads.

In Australia, both government and industry provide the funds for the public fast-charging infrastructure. So far, government support has usually been allocated toward the capital expenses of establishing this infrastructure. However, most of the respondents demand a quick response from the government to implement favorable policies that can support the diffusion of electric vehicle technology in the other part of Australia. Therefore, Australia is positioned at level 3 in the economic readiness level of the multidimensional readiness index.
Europe

Europe is the third most populated continent after Asia and Africa, with 747 million people. It is the second smallest continent in the world after Australia and is spread over 9.9 million square kilometers (3.8 million square miles), almost 7% of the world’s land.

Historically, Europe has been a landmark in manufacturing the world’s top luxury vehicles, such as Rolls-Royce, Bentley, Mercedes, Range Rover, and Alpina. Those brands were established in the early days of the automotive industry. The European automotive industry has been a global leader and performed a significant role in the growth and prosperity of the European’s economy, environment, and society.

Since the disruptive technology “electric vehicles” have been introduced globally, the automobile manufacturing industry in Europe is facing strong headwinds. European automakers have resisted electrification and argued they would not go the electric way. New players are entering the market, and the industry is facing massive disruptive megatrends. Now all manufacturers in Europe accept this transformation and have made plans for the electrification of their fleets. However, the success of the electrified automotive industry depends on the policies introduced by governments in favor of electric vehicles and price affordability for buyers that support the diffusion and adoption of electric vehicles by society.

The European society is well-educated and is aware of the environmental consequences of using fossil fuel. Therefore, Europe is gearing up with a significant shift from gasoline-based transportation to electric transportation. The European gasoline-based automobile market shrunk by 22% during the covid pandemic in 2020. However, the registration of new electric vehicles increased and reached 1.4 million, indicating 10% of the market share (Outlook, 2021). Most of the battery electric vehicles sold in Europe are imported from Asia (China, Japan, and South Korea) and the US. It raises a big question for the European automotive industry’s contemporary position and future state: where they will stand in the future.

We have selected countries in Europe based on their historical achievements, ambitions, and goals to shift towards fully electric transport to explore and analyze the readiness levels in the electrification of the transportation system from all four perspectives: technology, political, societal, and economy. These countries are Germany, Norway, Slovenia, Sweden, and the UK. We have chosen Slovenia as a small country in the south of Europe to compare with the larger and more developed countries to explore differences between a variation of countries across Europe. Germany is renowned for manufacturing luxury automobiles, such as BMW, Mercedes, Porsche, Daimler, Müllenbach, and Audi. Norway is one of the leading countries in Europe with a high adoption rate of, especially fully electric vehicles. Slovenia is among the countries with high government ambitions to ban vehicle registration on petrol and diesel from 2030. Sweden is the fastest growing country in adopting electric vehicles; with new electric vehicle incentives, Sweden overtakes Norway in plug-in electric vehicles sales. The United Kingdom (UK) is among well-known countries manufacturing prestigious luxury vehicles, such as Rolls-Royce, Bentley, and Land Rover. Those old UK brands such as Rover, MG, and Jaguar have been turned to other international ownership.
Figure 26 represents the readiness positioning of Germany, Norway, Sweden, Slovenia, and the United Kingdom for the electrification of the transportation system.

Based on our analysis of technology readiness, Germany is stated at level 7, Sweden and UK at level 6, Norway at level 5, and Slovenia at level 3. In political readiness, Norway at level 9, Germany and UK at level 8, Sweden at level 7, and Slovenia at level 4. In societal readiness, Norway at level 9, Sweden at level 8, Germany and UK at level 6, and Slovenia at level 3. In economy readiness, Norway at level 9, Germany at level 8, Sweden and UK at level 7, and Slovenia at level 2. Each level of readiness for each country is analyzed below in the subsections.
7.1 Germany

Germany is a country situated in Central Europe. It is the sixth-largest country in Europe with a total land area of 357,114 sq km. Germany has the second biggest population in Europe, with 83.24 million people in 2020 after Russia. Germany is a well-recognized country for its excellence in the automotive industry. It is the home of producing the most innovative and luxury automobiles. In 2018, almost 426 billion euros (approximately $442 billion) were generated by the automobile industry in Germany (Koptyug, 2020). The most populated regions are North Rhine-Westphalia in the west of Germany with 18 million, followed by Bavaria with 13 million and Baden- Württemberg with 11 million people in the south. The distance between these two most populated regions from West (North Rhine-Westphalia) to South (Bavaria) is around 530 kilometers by car. The most common mode of transportation is passenger cars, as shown in figure 27.

![Figure 27: Most common mode of transportation in Germany in 2017 (Statista, 2020b)](image)

Germany has a total road network of around 643,969 kilometers. The road transportation is very common in Germany. Figure 27 shows that 84.2% of people traveled by cars and 5.6% of people traveled by buses and coaches within the country, which means that 89.8% of the road transportation contributed to commuting people from one place to another. Germany has a high ambition to transform its transportation system to electrified and ban gasoline-based vehicles by 2030 fully. Therefore, Germany is an attractive market for the electrification of the transportation system.
Figure 28 shows the readiness positioning of Germany in the electrification of the transportation system.

Based on our analysis Germany is positioned in technology readiness at level 7, political and economy readiness at level 8, whereas in societal readiness at level 6 in the multidimensional readiness index of electrification of the transportation system.
7.1.1 Technology Readiness Level in Germany

Germany manufactures five (5) among the top ten (10) selling brands of electric vehicles. The leading German electric vehicle selling brands are Volkswagen, Mercedes-Benz, BMW, Smart, and Audi. The other five brands are imported from France (Renault), South Korea (Hyundai and Kia), the US (Tesla), and Japan (Mitsubishi), as shown in figure 29.

The role of batteries is substantial technically and economically in the production of electric vehicles. Battery cells act as a heart for an electric vehicle. Germany imports batteries from Asia (China and South Korea) to produce luxury electric vehicles like BMW, Mercedes-Benz, and Audi. China is the leading supplier to supply lithium-ion batteries to Germany. In 2019, Germany imported 106 million lithium-ion batteries from China, which were worth almost US$ 1.5 billion (Xinhua, 2020). Germany is also working to establish its strength to produce batteries for electric vehicles domestically, but this process is still in its initial phase.

The charging infrastructure is essential for the transition from gasoline-based vehicles to electric vehicles. In Germany, 39,291 public charging stations were available for charging electric vehicles in 2019. Among them, 34,203 were the slow chargers with up to 22 kilowatts (<= 22 kW), and 5,088 were the fast chargers above 22 kilowatts (> 22 kW). In 2020, the number of charging stations increased, and the total number of public charging stations became 44,669, of which 37,213 were slow, and 7,456 were the fast-charging stations (Wagner, 2021a). Almost 25% of the charging stations can be found at the parking lots, 13.5% at the public streets, 6.7% at the hotels, and 0.2% of the charging stations are at the airports (Koptyug, 2021b).
Munich has the highest number of charging stations even though it is the third-largest city of Germany after Berlin and Hamburg with nearly 1.5 million people. As of 2021, Munich has 1,694 public charging stations available for charging electric vehicles. Hamburg has the second-highest number of charging stations, and it is the second biggest city in Germany after Berlin, with about 1.9 million people. As of 2021, Hamburg has 1,310 charging stations available for public use. Berlin has the third-highest number of charging stations even though it is Germany’s first biggest and capital city with the highest population of little more than 3 million people. In 2019, almost 974 charging stations were available in Berlin, which increased 70%, and as of 2021, around 1,694 charging stations are available for public use. The other newcomers are Stuttgart which has 616 charging stations, followed by Regensburg, with 467 charging stations available for public use (Koptyug, 2021a). However, Germany is still lagging behind in the charging infrastructure. Cologne is the fourth biggest city in Germany with 1.1 million people, but only 278 charging stations are available. Frankfurt is the fifth biggest city in Germany with 752,000 people and has only 14 charging stations available for public use to charge electric vehicles.

Germany has introduced its first electric road of about 10 km long in the south of Frankfurt. The electric road charging solution faces standardization issues, and the road charging technologies are still in their early testing phases. Therefore, Germany is positioned at level 7 in the technology readiness of the multidimensional readiness index.
7.1.2 Political Readiness Level in Germany

The German government is aiming to increase the adoption of electric vehicles in Germany. The Federal Government of Germany has placed “transport electrification” on the National Development plan. In May 2016, the German government-funded almost one billion euros (approximately USD one and half billion) to have at least one million electric vehicles in the market by 2020. In 2019, the German government extended its target to have 10 million electric vehicles and 1 million charging stations on German roads by 2030. In order to obtain this ambitious target, the government announced to fund an additional 130 billion euros (approximately $135 billion) in June 2020 to develop charging infrastructure and continued several electric vehicles incentives and added some new ones.

In 2015, the Federal Government of Germany first time introduced the "Electric Mobility Act." The primary purpose of this act was to promote electric mobility in Germany. The benefits announced for the electric vehicle owners were to enjoy free parking, reserved parking spots, and use the bus lane. In 2020, the government introduced an 'environmental bonus' called 'Umweltbonus' in the German language. The main focus of this bonus is to provide subsidies on purchasing electric vehicles. The grant will be offered €9,000 (approximately $9,346) on the fully electric and €6,750 (approximately $7,009) on plug-in hybrid vehicles for the cars priced up to €40,000 (approximately $41,538). Similarly, the owners of fully electric vehicles can get €7,500 (approximately $7,888), and plug-in hybrid cars can get €5,625 (approximately $5,841) for vehicles priced up to €65,000 (approximately $67,499). The Federal Government announced to provide grants on leasing and used cars and further offered a 16% tax reduction on the purchase of electric vehicles between 1st July - 30th December 2020 and now stands at 19%. Some of Germany's local and state governments also offer some additional incentives of up to €1,500 (approximately $1,557) on the purchase of electric vehicles. These incentives are added to the Federal Government incentives to promote the rapid adoption of electric vehicles in Germany.

The Federal Government of Germany is also giving equal importance to the development of charging infrastructure in order to obtain the target of having 1 million charging stations within the country by 2030. In April 2021, the government announced €300 million (approximately $311 million) incentives for small and medium-sized enterprises (SMEs) to install public chargers. This program aims to install public chargers at the hotels, catering industry, small municipal utilities, and local authorities. The subsidy covers up to 80% of the total costs for purchase and installation. The condition of the grant is to use renewable energy for powering the charging stations. The distribution of the grants is mentioned in table 7.

<table>
<thead>
<tr>
<th>Grants</th>
<th>Charging conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to €4,000 (approx. $4153)</td>
<td>Per AC/DC charger of 3.7 to 22 kW</td>
</tr>
<tr>
<td>Up to €16,000 (approx. $16,613)</td>
<td>Per DC fast chargers of 22 to 50 kW</td>
</tr>
<tr>
<td>Up to €10,000 (approx. $10,383)</td>
<td>For low voltage</td>
</tr>
<tr>
<td>Up to €100,000 (approx. $103,832)</td>
<td>For medium voltage grid connection</td>
</tr>
</tbody>
</table>

Table 7: Distribution of grants provided to SMEs in Germany for installation of public chargers
Germany’s state and local governments also offer additional incentives to promote the adoption of electric vehicles in their local and regional areas. Nordrhein-Westfalen is a western state that offers 60% grants of the total cost of installing and purchasing electric vehicle chargers to private consumers. Munich offers 40% of the total net charges on the purchase and installation of electric vehicle chargers. Hannover offers €500 (approximately $519) incentives for purchasing and installing smart chargers, and Limburg offers €300 (approximately $311) incentives per charging point. Employers are exempted from the taxes offering free charging facilities to electric vehicles or bicycles until 2030.

To meet the growing demand for domestically manufactured electric vehicles, the European Commission has decided to produce batteries in Europe. At the end of 2019, the European Commission acknowledged that battery cell production is an "important project of common European interest" (IPCEI). The IPCEI aims to focus on the entire battery manufacturing value chain from acquiring, processing raw materials, designing battery cells, and recycling used batteries. Germany also aims to become the center of European battery production. The federal government is funding around $506.7 million (approximately € 436.8 million) for the project (Manthey, 2021a). In 2020, the German and French governments collaborated “German-French battery consortium” to initiate a pilot plant and establish a factory in Germany and France. The political readiness and willingness of the German government are high to adopt a current trend of transport electrification. Therefore, the political readiness of Germany is positioned at level 8 in the multidimensional readiness index.
7.1.3 Societal Readiness Level in Germany

The German society is well aware of the environmental concerns. A German company called "prolytics market research GmbH" surveyed in 2020, asking the reasons for buying an electric car in Germany. Almost 37.6% of respondents acknowledged that eco-balance and environmental friendliness were the significant factors of purchasing electric vehicles, and 14.5% of respondents stated that the main reason for buying an electric car is its low operating cost. It means around 52% of the respondents are willing to buy an electric vehicle because of the environmental concerns and operating cost, which shows the high interest of the German society towards transport electrification.

The sale of electric vehicles is continuously increasing in Germany. The newly registered battery electric vehicles were 194,163 in 2020, which raised 6.65% of the German market share in electric vehicles compared to 1.75% (63,280) in 2019. For the first time in Germany, the newly registered plug-in hybrid cars were 200,470 in 2020, which increased the market share by 6.9% compared to 1.2% (45,350) in 2019 (Wagner, 2021b). It shows that the sales of plug-in hybrid vehicles are higher than the battery electric vehicles in Germany during 2019 and 2020.

Germany is the largest automotive market in Europe. Figure 30 shows that in September 2021, the sale of battery electric vehicles was 33,655 (17.1% market share). On the other hand, the combined sale of plug-in and plug-less hybrid vehicles was 60,159, showing a market share of 30.5%, which is 13.4% higher than the market share of battery electric vehicles. However, the battery-electric vehicles alone took 17.1% of the market for the first time, overtaking diesel’s share (15.9%).

Figure 30: Registration of passenger vehicles in Germany in September 2021 (Holland, 2021)
Figure 30 shows that the highest sales of automobiles in Germany are petrol vehicles. The sales of petrol vehicles were 70,713, which was 35.9% of the market shares in September 2021. Approximately 71.3% of passenger automobiles sold in Germany were not electric in September 2021. Even though the sales of fully electric vehicles have increased in the past couple of years in Germany, the rate of adoption of electric vehicles is slow. Therefore, Germany is positioned at level 6 in the societal readiness level of the multidimensional readiness index.

7.1.4 Economic Readiness Level in Germany

Electric vehicles could not make a place for many years in its niche market because the cars were expensive, having a short range and only targeted a small customer segment: people who were very focused on sustainability or upper-class customers. But for the last few years, electric vehicles are no longer an interest for only specific customers. Now, electric vehicles have not only become a reality, but it has become one of the primary sources to save the world from greenhouse gases. The German company Volkswagen has introduced its first electric car, “Volkswagen ID.3,” with an attractive entry price of under €30,000 (approximately $31,149) for the basic version for all sorts of customers (Volkswagen, 2019).

However, electric vehicles are often more expensive than their diesel or petrol counterparts, with most models in Germany presently costing at least €30,000 (approximately $31,149). One example is the electric car of “Hyundai IONIQ Elektro Trend.” The purchasing cost is €33,300 (approximately $34,264), and its counterpart, “Hyundai i30 1.4 T-GDI Trend DCT,” runs on petrol cost €24,550 (approximately $25,490) (Mobility, 2020). Thus, there is a price gap between electric and diesel or petrol-based vehicles. The German government is aware of the price differences; therefore, to overcome the price gap and increase the sales of electric cars, the government offers €9,000 (approximately $9,344) for customers who buy new electric vehicles by 2025. At the same time, to reduce the sales of diesel or petrol vehicles, the government has imposed an additional €0.07 (approximately $0.073) to €0.08 (approximately $0.083) CO₂ tax, which drivers have to pay at the diesel or petrol pumps since January 2021.

The operational cost of an electric vehicle depends on charging and maintenance costs. Charging an electric car saves a lot of money compared to refilling a petrol vehicle. The charging price of 1 kWh (kilowatt-hour) is around 30 cents whereas a liter of petrol costs approximately 1.50 euros (approximately $1.56) (Mobility, 2020). The basic version of Volkswagen ID.3 with 45-kWh battery cost 4 euros (approximately $4.15) to drive 100 kilometers whereas a petrol vehicle consumes 7 liters per 100 kilometers which costs almost 10 euros (approximately $10.38). It means that several hundred euros a year in energy cost can be saved by driving an electric car, which depends on the driving mode and mileage. Additionally, electric vehicles are exempted from vehicle tax till 2030. A pure battery electric vehicle's maintenance cost is almost equal or rather less than the combustion engine vehicle because of fewer parts and no worries of changing oil every six months (depends on the driving range, usually after 3,000 miles) (Miebach & Nicola, 2020).
However, charging cost of an electric vehicle is not the same in Germany. As, the cost depends on the companies providing charging facility. The E.ON charging stations is the most expensive, charges 52 cents per kWh. The second expensive charging stations are Hamburg Energie, charges 44 cents per kWh whereas on the other hand Stadtwerke Leipzig or Rhein Energie provide free charging facility (Koptyug, 2022). The standardization is a challenge for German government to provide a stable charging cost for the electric vehicle consumers. Therefore, Germany is positioned at level 8 in the economic readiness of the electrification of the transportation system in the multidimensional readiness index.
7.2 Norway

Norway is a country situated in northwestern Europe. It is the sixth-largest country in Europe, with a total land area of 323,802 sq km but a small population size of 5.4 million in 2021. Norway is renowned for producing oil and natural gas. The Norwegian economy primarily relies on exporting oil and gas. Norway is a small but significant player covering approximately 2% of the global crude oil demand. In contrast, Norway is the third biggest exporter after Russia and Qatar of natural gas globally and covers around 3% of the world’s market demand and supplies between 20 to 25 percent of the European gas demand (Petroleum, 2022). However, to contribute to climate change, the Norwegian government has to phase out producing oil in the coming decades. In Norway, the sales of battery-driven electric vehicles are continuously increasing due to the subsidies and rebates provided by the government. In 2021 almost 50% of all new vehicles sold in Norway were electric vehicles. The most populated region of Norway was Oslo and Viken, with over 1.9 million people in 2020. The most common mode of transportation in Norway is passenger cars, as shown in figure 31.

In Norway, road transportation is widespread. Figure 31 shows that in 2021, about 88% of people traveled by cars, and 5.7% of people traveled by buses and coaches throughout Norway. It means that 93.7% of road transportation contributes to commuting people from one place to another. The Norwegian government has the ambition to decarbonize the road transportation system and entirely shift away from fossil-based to electric transportation. Therefore, the Norwegian government has decided to ban the sales of new diesel and petrol cars by 2025. With 5.4 million people, Norway has the highest proportion of electric vehicles globally. In 2021, electric vehicles accounted for approximately two-thirds of all new vehicle sales in Norway. In 2021, total new vehicle sales in Norway increased by 25% to a record 176,276 vehicles, with 65 percent of them being electric, whereas in 2020, the market share...
was around 54 percent (Klesty, 2022). A significant oil producer, Norway has supported the transition to decarbonize the transportation sector by exempting BEVs from taxes imposed on ICE. Figure 32 represents the readiness progress of the electric transportation system in all four dimensions (technology, political, societal, and economic).

According to our analysis, Norway is positioned in technology readiness at level 5, whereas political, societal, and economic readiness are at level 9 in the multidimensional readiness index model. Each of the dimension is discussed below in the subsections.
7.2.1 Technology Readiness Level in Norway

Norway does not produce electric vehicles but primarily imports them from other countries. The top ten selling brands of electric vehicles in Norway in September 2021 are imported from the Czech Republic (Skoda), Germany (Volkswagen and Audi), Japan (Nissan and Toyota), South Korea (Hyundai), and the USA (Ford and Tesla) as shown in figure 33.

In May 2021, NIO China, a BEV manufacturing company, started its operation in Norway to provide a full-fledged ecosystem incorporating cars, services, and charging infrastructure. NIO Norway has introduced its first smart electric vehicle model NIO ES8 SUV, but it was available on 3rd September 2021 at Honefoss Airport for a test drive. NIO is providing a total system solution offering electric vehicles supported by charging infrastructure, battery swapping system and cable charging solutions. NIO plans to establish 20 battery swapping stations in Norway in 2022, and one is already operational outside Oslo. Sweden will follow in 2022 with 10 swapping stations followed by Denmark.

Norway has a lower population density than many other European nations and a relatively high percentage of private house ownership. It is simple to install private home-based electric vehicle chargers, and many electric vehicle owners utilize them as their primary source of power. The Norwegian Electric Vehicle Association surveyed in 2017 that electric vehicle owners living in apartments and houses were asked how often and where they charged their vehicles. The results indicate that electric vehicle owners rely very little on public charging and rely much more on charging EVs at home or work (Lorentzen et al., 2017). However, the lack of public chargers is a challenge for travelers and tourists.

Norway is a long country with a low population, and the driving range between cities is long. A well-organized public charging infrastructure is required for long-distance travel. For
this purpose, in 2017, the Norwegian government started funding for the construction to build at least two multi-standard fast-charging cable charging based stations on every 50 km along all of Norway's major roads.

One factor that will affect the technology readiness in Norway is the massive load on the nation’s electrical grid due to the substantial number of electric vehicles conventionally charged at the same time, i.e., at charging stations or outlets. In that case, the power grid can experience massive spikes of stress during peak hours. However, the stress on the power grid can be flattened out by charging the vehicles outside the peak hours and ensuring that every charging stations has a solar panel array and battery storage to help reduce the peak loads drawn from the grid. The charging infrastructure is, to a large extend, private, and the lack of public charging piles is a barrier to the diffusion of BEVs. Besides having a well-organized home-based charging system, Norway is far behind in technology readiness, as Norway has to import each component used for electrification from other countries. Therefore, Norway is positioned at level 5 in technology readiness levels of the multidimensional readiness index.

7.2.2 Political Readiness Level in Norway

Norway introduced policies to encourage the use of electric vehicles by temporarily eliminating the electric vehicles import tax in the early 1990s. The Norwegian government has also launched various incentives (access to driving on the bus lanes, limited parking fees and no road tolls) for electric vehicles to eradicate vehicles and on-road taxes that reduce the upfront and lifetime cost of electric vehicles. The government’s goal is to have all new vehicles sold from 2025 to be either electric or hydrogen driven. The incentives for electric and hydrogen-fueled vehicles can be considered to be the Norwegian government's strategy to promote electrification to Norwegian society.

In Norway, the existing electric vehicle policy incentives stabilized and successfully established the electric vehicle market, and in return, a profitable second-hand EV market emerged in Norway. The electric vehicle market is well established in the main cities of Norway, like Bergen and Oslo, whereas the electric vehicle market in rural areas is rapidly growing. One of the most prominent incentives applied in Norway is the 'vehicle tax system,' which allows the electric vehicle to become price competitive with ICE vehicles. The 'tax system' is based on the vehicle's weight, carbon dioxide and nitrogen oxide emissions, and value-added taxes. These combined taxes make EVs affordable to buy or import with very few added costs compared to ICE vehicles, which in some cases cost more than double the import price (Haugneland et al., 2017). These are some of the most significant incentives policies implemented by the Norwegian government that has led Norway to the massive adoption of electric vehicles.

The Norwegian government is working towards future policies to meet the goals of the Paris Agreement to reduce the nation's greenhouse gases by 40% by 2030 compared with the levels of the 1990s. Furthermore, the country is striving towards the following three goals to meet the criteria of the Paris Agreement (Olsen, 2017):
- All new private vehicles must be purchased as zero-emission configuration or using biogas by 2025.
- Having all distribution of goods by near-zero-emission vehicles in major cities by 2030.
- Have all new heavy vans, 75% of new long-distance buses, and half of all new trucks of zero-emission status by 2030.

Norway is at the global forefront in adopting electric transport. The Norwegian government played a decisive role in promoting electric vehicles by implementing favorable incentives policies. Therefore, Norway is positioned at level 9 in the political readiness levels of the multidimensional readiness index.

7.2.3 Societal Readiness Level in Norway

Norway has become the leading country in the world to sell more electric vehicles than vehicles with diesel, petrol, or hybrid engines already in 2020. Norway made a global record by selling 54.3% of all new vehicles sold were battery electric vehicles in 2020. In contrast, in 2019, it was 42.4%, which means the sale of battery electric vehicles increased by 11.9% in only one year. This was achieved even though Norway is an oil-producing country. Norwegian policy exempts taxes for fully electric vehicles and imposes taxes on vehicles run by fossil fuels. The goal of the Norwegian government is to become the first country in the world to stop selling new diesel or petrol cars by 2025 (Klesty, 2021).

In March 2021, 8,624 electric passenger cars and 4,379 plug-in hybrid vehicles were sold. The sales of fully electric vehicles are increasing, whereas plug-in hybrid vehicle sales (PHEV) are declining. In March 2020, the sales of PHEV were 83.1%, but in March 2021, the sales of PHEV were at 28.6%, which means the sale of PHEV declined almost 54.5% in one year. However, it is still higher than the sales of vehicles run on diesel and petrol (4.7 and 4.8 percent, respectively) (Manthey, 2021b). Norway is a rich country where people get paid handsome salaries. The costs involved in generating and distributing electric energy in Norway are very high. But consumers are willing to pay a premium fee for the fast-charging service as it costs them three times less than what they pay for electricity at home. We place Norway at level 9 in the societal readiness levels in the multidimensional readiness index.
7.2.4 Economic Readiness Level in Norway

In Norway, ten years ago, it would have been difficult even to predict that there would be more electric cars than non-electric sold in 2021, and there are not only cars that have gone electric, but bikes, trams, trains, and buses have all become propelled by electrical means. The Norwegian government policies and the incentives for the buyers are the leading cause for the rapid transition of the transportation system from fossil-base fuels to electric in Norway. The key to accelerating EV adoption in Norway was to make them affordable. The government reduced taxes and even exempted road tolls tax to keep the operating cost for EV’s down (Reve, 2021).

The cost of buying an electric vehicle is also lower than buying a petrol-fueled car in Norway. In November 2020, the new Volkswagen Golf (petrol) price was higher than the Volkswagen Golf (Electric). The operational cost of EVs is also much lower than gasoline vehicles because of fewer moving parts.

Driving an electric vehicle for an operating distance of 12,300 km/year, which is moderate, can save NOK 12,000 (approximately $1355). The service cost for electric vehicles is generally lower since moving components are very much less than gasoline vehicles. In addition, the traffic insurance tax is far lower for EVs in Norway (Elbillading, 2020). Thus, Norway is positioned at level 9 in the economic readiness levels of the multidimensional readiness index.
7.3 Sweden

Sweden is situated in northern Europe bordering Denmark, Finland, and Norway. It is the fifth-largest country in Europe, with a total land area of 450,295 sq km. The population of Sweden is double the size of the Norwegian population of approximately 10.35 million in 2020. According to the "Bloomberg Innovation Index 2021", Sweden ranks fifth among the most innovative countries globally and ranks first on European Innovation Scoreboard.

Sweden is an industrial country with some of its most innovative brands, such as IKEA, H&M, and Volvo. IKEA is a self-assembly furniture retailer. In 2021, the brand was worth about 18 billion US dollars (Statista, 2021b). H&M is renowned as a fashion clothing company in Sweden. As of July 2021, the company has a revenue of about 14 billion US dollars (Statista, 2022i). There are two Volvo companies in Sweden, Volvo AB, and Volvo Cars AB. Volvo AB is a global leader in manufacturing trucks, buses, marine, and industrial engines. As of April 2022, the turnover of Volvo AB is reaching approximately 35 billion US dollars. Volvo Cars used to be a part of Volvo AB, but in 1999 the Chinese automaker Geely has owned Volvo Cars. In 2020, approximately 53,000 Volvo cars were sold in Sweden; as of April 2022, the turnover of Volvo Cars is reaching around 27 billion US dollars (Statista, 2022c).

The most populated cities of Sweden are Stockholm, Göteborg, and Malmö, with a population of approximately one million, six hundred thousand, and three hundred and fifty thousand in 2021, respectively (O'Neill, 2022). The distance between Stockholm to Göteborg is approximately 470 kilometers, and between Göteborg to Malmö is around 272 kilometers. Road transportation is common in Sweden, as shown in figure 34.

Figure 34: Most common mode of transportation in Sweden in 2019 (Wagner, 2021a)
Figure 34 represents that in 2019, approximately 60% of people traveled by car, moped and motorcycle whereas 8% people traveled by bike which means approximately 68% of the road transportation contributed to commute people from one place to another. In recent years, public transportation utilization has risen steadily, with a share of 26% in 2019. Sweden is among the countries with great aspirations to transform from a fossil fuel-powered transportation system to an electric one. Swedish Prime Minister Stefan Löfven has announced to ban the sales of all new vehicles with petrol or diesel engines after 2030 (Hampel, 2019). In December 2021, Sweden’s plug-in electric car share reached approximately 60.7%, up from 49.4% the previous year. Fully battery-powered vehicles gained around 36.4% market share, higher than the combined market share of diesel and petrol vehicles of 32.3% (Holland, 2022a).

Figure 35 represents the transformational progress and readiness positioning of Sweden in the electrification of the transportation system in all four dimensions (technology, political, societal, and economic).

![Multi-dimensional readiness index model of Sweden (Bhatti et al., 2022)](image)

Our analysis shows Sweden is positioned at level 6 in technology readiness, level 7 in political and economic readiness, and 8 in societal readiness in the multidimensional readiness index model. Each of the dimensions is discussed below in the subsections.
7.3.1 Technology Readiness Level in Sweden

Sweden is an innovative industrial country. Volvo Cars, the Swedish automotive manufacturing company, has now become owned by the Chinese vehicle manufacturer Geely. In 2021, Volvo introduced two new EV brands, Volvo, and Polestar, which are so far manufactured in China. However, the top ten selling brands of electric vehicles in Sweden in September 2021 are imported from various countries, such as the Czech Republic (Skoda), Germany (Audi and Volkswagen), Japan (Nissan), South Korea (Kia), China (MG), and USA (Ford and Tesla) as shown in figure 36.

In Sweden, several alternative EV charging technologies are in the testing phase, such as dynamic (conductive and inductive), semi-dynamic and static charging. Static charging is considered a relatively mature technology that is primarily used to charge passenger vehicles. However, heavy-duty vehicles (HDVs) can utilize the current chargers used by cars to some extent. Still, it takes a longer time to charge the battery due to the battery capacity of heavy-duty vehicles. In Sweden, charging stations have gradually increased during the last three years and crossed almost 10,000 units with type 2 sockets and 610 charging stations with CCS/Combo sockets until mid-2020 (Wagner, 2020).

The electric trucks manufactured by AB Volvo and Scania can be charged through static chargers by using the latest CCS type 2 connectors. However, these CCS type 2 connectors are intended to charge regular EVs and not HDVs like Volvo’s FE/FL and Scania’s BEVs. Because of the lack of fast chargers designed for HDVs and the high demand for electric trucks, Volvo and Scania chose to use the existing charging solutions. The fast chargers for HDVs are available on the market and implemented in three major cities in Sweden. These fast chargers adapted
for HDVs have a higher charging power and are less time-consuming than chargers for light vehicles. Installing fast chargers for HDVs near the most operated transport routes is crucial to aid electric truck diffusion. Moreover, the European Union and its members collaborate to develop and implement a common standard for Megawatt’s chargers (Hasselgren & Näström, 2021).

Sweden is testing and evaluating static and dynamic (conductive and inductive) road charging, which means that vehicles will be able to run on electricity and charge their batteries while in motion. Sweden has built its first electric roads for demonstration purposes at Arlanda (1.2 miles in length), at Sandviken, in Lund city and in Visby city. Sweden is further working on wireless charging and looking to have battery swapping technology. However, these technologies are still in the demonstration and testing phase on a small scale. On the other hand, inductive charging, considered a reliable solution, is in the development process. The charging output is limited, facing the technical standardization problem. Therefore, Sweden is positioned at level 6 in the technology readiness levels of the multidimensional readiness index.

7.3.2 Political Readiness Level in Sweden

Swedish policies support the transformation of the transportation system from fossil-fueled vehicles to electric vehicles and offer several incentives to electric vehicle owners. Sweden is transitioning to electrified vehicle transport systems with a 26% EV market share and a 253% rise in EV sales in 2019. Sweden has increased incentives such as municipal incentives, tax rebates, and government grants, contributing to the rising popularity of electric vehicles. In 2007, the Swedish government introduced a program called the "green car award." The purpose of this program was to offer a tax credit of 10,000 SEK (approximately $1166.45) for new vehicles which satisfied the specified emission standards. The impact of the green car award program was positive, and this program raised the market share of green cars (with emissions of 50 g CO\textsubscript{2}/100 km or less); however, it is claimed that the majority of buyers would have purchased green vehicles regardless of the subsidies being offered (Huse & Lucinda, 2014).

The Swedish government plan is to reduce to 70% of the present level of greenhouse gas emissions from the transportation sector by 2030. To achieve this target, the government has further introduced a scheme of subsidies for low emission cars serviced before 2020 with CO\textsubscript{2} emissions of up to 60 g/km and vehicles serviced during 2020 or after with CO\textsubscript{2} emissions of up to 70 g/km, a grant of 60,000 SEK (approximately $6998.70). These subsidies are available for up to 25% of the new car’s purchase price. This scheme applies to both individuals and businesses. Similarly, the grants are available for heavy-duty vehicles, especially for public transportation agencies, municipalities, and small businesses, a grant of 20% of the EV bus purchase price is available.
Furthermore, the incentive covers 40% of the difference between the cost of an electric bus and a comparable diesel bus for private transportation businesses. The Swedish government is also focusing on the development of charging infrastructures. The number of charging units has increased from 500 to 10,000 between 2012 and 2020. The major cities in Sweden, such as Stockholm, Gothenburg, and Malmö, also provide local charging incentives for the EV owners. In Stockholm, free charging of BEVs and PHEVs is available for parking space subscribers; only non-electric vehicle owners have to pay the parking fee. The local government of Gothenburg has decided to install 500 new charging stations at the public parking areas around the city during the autumn and winter of 2020 and 2021. Malmö has more than 150 public charging stations. "The chargers have different power. Some "fast" chargers can provide the vehicle with up to 22 kWh of energy in one hour, whereas other slower chargers can only provide the vehicle's battery with up to 3.7 kWh." The local government of Malmö is planning to equip 20% of the parking spots with EV chargers (Asunción, 2021). However, while static charging is considered a reliable source of charging, EV drivers face technical standard problems with different sockets used at different charging stations for a plug-in to charge a vehicle. The absence of institutions and policymakers is prevailing. The role of institutions and policymakers is required to develop and implement a common standard plug connection for static charging. On the other hand, the dynamic solution (electric road technology) is still in the testing phase. Therefore, Sweden is located at level 7 in the political readiness of the multidimensional readiness index.

7.3.3 Societal Readiness Level in Sweden

Sweden is a well-educated society with substantial awareness of environmental concerns. Swedish society is rapidly adopting electric vehicles. In February 2020, the market share of electric and plug-in hybrid cars reached 24.3% in Sweden. The rapid adoption of electric vehicles has increased in Sweden since the Swedish government introduced a new subsidy scheme in January 2020.

In February 2020, around 6.4% of all Swedish new cars registered were battery electric vehicles (1,430), and approximately 18% of cars registered were plug-in hybrids (4,027). Compared with February 2019, the sale of electric cars has increased by 112% and plug-in hybrid vehicles by 59%. In January 2020, around 7.1% of all new cars registered were battery electric vehicles (1,269), and about 23.1% of cars registered were plug-in hybrids (4,113). Compared with January 2019, the sale of battery electric vehicles increased by 15% and plug-in hybrid vehicles by 160.8% (Randall, 2020). The adoption rate of plug-in hybrid vehicles is high in Sweden and is increasing faster than sales of fully battery electric vehicles. Therefore, Sweden is located at level 7 in the multidimensional readiness index in societal readiness levels.
7.3.4 Economic Readiness Level in Sweden

In 2018, Sweden introduced a new incentive scheme called "Bonus-Malus" to encourage buyers to buy electric cars, light trucks, and buses. The government announced 60,000 SEK (approximately $6998.70), a purchase incentive bonus to the buyers of fully electric vehicles, and a 25% climate bonus of the vehicle’s value. The government announced a 35% bonus on buying a climate-friendly vehicle for businesses. The incentive was a maximum of 35% difference between the new vehicle price and the similar fossil-fueled vehicle price. Six months after the car is registered, the incentive is paid straight to the owner, preventing the vehicle from being sold onward within that time frame. The bonus is decreased by 833 SEK (approximately $97.17) per gram of CO$_2$ over zero and up to 60 g/km (AG, 2019).

To make the operating cost affordable, the Swedish government started supporting the development of increased charging infrastructure. Therefore, the government introduced the climate shift program in the Swedish language called "Klimatklivet." This program aims to reduce CO$_2$ emissions at a local level. For this purpose, the government announced granting up to 50% of the installation cost for a single charging point to the local housing associations. Moreover, electric vehicles are much more affordable than fossil fuel-based vehicles in Sweden. The energy cost of running an electric car is SEK 2.25 (approximately $0.26) every 10 kilometers, compared to SEK 12 (approximately $1.40) for the same distance traveled in a fossil fuel-based vehicle (Gustafson, 2021).

Moreover, the maintenance cost of electric vehicles is lower than fossil fuel-based vehicles due to the fewer moving components (Dahlstrand, 2020). Additionally, electric vehicles are quiet and fun to drive due to their high-performance capabilities. Even though the government provides rebates on purchasing electric vehicles, the prices are still high. Because of the present lack of charging infrastructures, buying a fully electrified vehicle is not economical. Therefore, Sweden is positioned at level 7 in the economy readiness levels of the multidimensional readiness index.
7.4 Slovenia

Slovenia is a country situated in the south of Central Europe, which is one of the smallest countries in Europe, with a total land area of about 20,273 sq km. Slovenia is also smaller in population size in Europe, with approximately 2.1 million people in 2021. The GDP per capita in 2019 was €23,165 (approximately $24,052). That puts it in the European average, but it is wealthier compared to countries east and southeast of Slovenia. Slovenia is geographically diverse and has different climates. It is an intersection between the Mediterranean region with the Adriatic Sea, the Alps, the Pannonian region, and the Dinaric-Karst region. Slovenia has a good road but a poor rail infrastructure. The most populated regions of Slovenia are Ljubljana and Maribor with approximately 0.29 and 0.1 million people, respectively. The distance between Ljubljana and Maribor is around 130 kilometers. The most common mode of transportation is passenger cars, as shown in figure 37.

Road transportation is very common in Slovenia. Figure 37 represents that in 2018, about 86.4% of people traveled by passenger cars, and 11.8% traveled by buses and coaches throughout Slovenia. It means that 98.2% of road transportation contributes to commuting people from one place to another. The Slovenian government has set the target to achieve 130,000 battery-electric vehicles and 70,000 plug-in hybrid vehicles on roads to replace the fossil-fueled powered vehicles by 2030, following the European Union’s strategy to decarbonize road transportation. By the end of 2020, approximately 5,311 battery electric vehicles and 6,033 plug-in hybrid vehicles should have been on roads, according to the plan of the Slovenian government (Europe, 2022). Nevertheless, the Ministry of Infrastructure's registry of automobile registrations data indicated that 3,678 battery electric vehicles and 944 plug-in hybrid vehicles were registered as of December 31, 2020, which shows that Slovenia lags behind with its set target for the decarbonizing transportation.
The share of electric vehicles in Slovenia is comparatively low than in the northern European countries. Slovenia is a small country, and the distance between the most populated regions is short. Therefore, the better charging infrastructure enables Slovenia to be ideal for electric vehicles. Figure 38 represents Slovenia’s transformational readiness progress in the transportation system’s electrification.

Based on our analysis Slovenia is positioned at level 3 in technology and societal readiness. At level 4 in political readiness and 2 in the economic readiness of the multidimensional readiness index of the transportation electrification system. Each of the dimensions is discussed below in the subsections.

7.4.1 Technology Readiness Level in Slovenia

Slovenia has the ambition to replace its transportation sector from the vehicles propelled by internal combustion engines with electric vehicles, in accordance with the European Union Strategy Fit for 55. Slovenia does not manufacture electric vehicles but imports from other countries. The top eight selling brands of battery and plug-in hybrid
vehicles in September 2018 were imported from Japan (Nissan Leaf), France (Renault), Germany (BMW and Daimler), and South Korea (Hyundai), as shown in figure 39.

Slovenia started constructing a car battery manufacturing company called "Tovarna Akumulatorskih Baterij" (TAB). In December 2020, due to the global supply chain crisis because of Covid-19, TAB stopped constructing its Lithium-ion battery factory, which was worth approximately $56.5 million (€50 million). In June 2021, TAB, with about 74% share, collaborated with a Chinese company called "Haidi Energy Technology" to construct a lithium-ion battery factory which is expected to be launched in the mid of 2022 (Raiev, 2021). However, the TAB car battery manufacturing company is still not ready yet to produce batteries on a larger scale.

Charging infrastructure is a challenge in Slovenia. At the end of 2016, approximately 137 public electric vehicle charging stations were available in Slovenia, which increased in 2017 and reached 228 publicly available charging points for electric vehicles (Kmetec & Knez, 2022). The installation of more charging stations in Slovenia has progressed during these years. At the end of 2021, Slovenia had 308 public electric vehicle charging stations with 637 charging ports for electric vehicles. Tesla also installed three supercharging stations among the 308 public chargers in Slovenia. They are located at the Ravne petrol station in the Primorska region, the petrol station in Dogoše near Maribor, and the Hotel Mons in Brdo. The government's primary focus on installing more charging stations can be seen in the most populated cities such as Ljubljana, Maribor, Kranj, and Koper. The Slovenian government also focuses on more chargers along the Adriatic coast and at tourist resorts such as Rogaška, Bled, Slatina and Podčetrtek.

Furthermore, the government's priority is to have more chargers along the border with Austria and the main highway that links Croatia and Austria (Kmetec & Knez, 2022). However, Slovenia is spread over 20,273 sq kilometers, and the average ratio of public electric vehicle

Figure 39: Top 8 selling brands and their sales of EVs in Slovenia in September 2018 (Watt, 2020)
chargers is significantly less per square kilometer, which is 0.015. Therefore, Slovenia is located at level 3 in the technology readiness of the multidimensional readiness index model.

7.4.2 Political Readiness Level in Slovenia

The role of the Slovenian government is significant as the government wants to achieve its target as announced to ban the sales of fossil-based powered vehicles from 2030. In 1993, the Slovenian government established a scheme called “Eco Funds” to promote the development of environmental protection by offering loans, grants, and financial incentives.

Between 2011 and 2014, the government announced another energy-efficient traffic program, approximately $528,268 (€500,000), funded by the Eco funds scheme. The primary focus of this program was to support electric vehicle buyers with subsidies. The approximate amount of $528,268 (€500,000) was divided into two categories of buyers. For the businesses or companies, approximately $315,793 (€300,000) was devoted, and approximately $210,529 (€200,000) was dedicated to the private buyers of electric vehicles. In 2015, the total amount was increased from the Eco Funds and became $528,268 (€500,000) for private buyers of electric vehicles and $2,105,600 (€2,000,000) for the company buyers electric vehicles. The individual buyer of an electric vehicle was offered from €2,000 to €5,000 (approximately $2,076 to $5,191) depending on the vehicle’s emitting the amount of CO\textsubscript{2} emission. In 2016, Eco Funds increased the incentives for individual electric and hybrid vehicle buyers, which varied between €3,500 and €7,500 (approximately $3,634 to $7,787) (Kurnik, 2018).

In 2017, the government increased the subsidy on plug-in hybrid vehicles from €3,500 to €4,500 (approximately $3,634 to $4,672), but the grant remains the same as the previous year on battery electric vehicles at €7,500 (approximately $7,787). Additionally, according to the Slovenian Motor Vehicle Charges Act, battery electric vehicles are exempted from the annual fee payment. In contrast, only a 0.5% lower tax rate is applied to electric vehicles under the Motor Vehicles Tax Act (Jandl, 2018). In recent years the government has decreased the National incentives from €7,500 to €4,500 (approximately $7,787 to $4,672) per new battery electric vehicle and €4,500 to €0 (approximately $4,672 to $0) on plug-in hybrid vehicles (Union, 2021). The government has announced to provide €335,774 (approximately $348,640) to extend charging stations in the protected areas and the Natura 2000 area in Slovenia. However, the Slovenian government’s steps so far are not enough to bring the prominent change toward the electrification of the transportation system. Therefore, Slovenia is located at level 4 in the political readiness of the multidimensional readiness index.

7.4.3 Societal Readiness Level in Slovenia

The adoption rate of electric vehicles has been slow in Slovenia between 2015 and 2017. The total number of registered passenger vehicles, including diesel, petrol, battery, and plug-in hybrid, is approximately 1,064,000 in Slovenia. In 2015, the market share of battery
electric vehicles was 0.21%, and the plug-in hybrid vehicle was 0.06%. In 2016, approximately 178 new battery electric vehicles and 94 new plug-in hybrid vehicles were registered. In 2017 the number of new registered battery electric vehicles increased and reached approximately 336, whereas new registered plug-in hybrid vehicles reached approximately 192 (Jandl, 2018). In the end of 2017, battery-electric vehicles’ market share reached 0.47%, and plug-in hybrid vehicles 0.27%. Thus, from 2015 to 2017, the adoption rate of batteries and plug-in hybrid vehicles was 0.26% and 0.21%, respectively, comparatively much lower than the total number of registered vehicles during these three years.

In 2018, a significant change occurred in the adoption rate of electric vehicles due to the increased subsidies provided by the Slovenian government. Approximately 2,161 electric and hybrid vehicles were sold in 2018, which increased the overall market share of electric and plug-in hybrid vehicles to 2.5% (News, 2019). The year 2020 was a good year for the sales of electric vehicles in Slovenia. In 2020, approximately 1.69 thousand, including battery and plug-in hybrid vehicles, were registered. However, a report issued in 2021 by the Statistical Office of the Republic of Slovenia mentioned that the total number of registered electric vehicles was below 4,000, and the total number of plug-in hybrid vehicles was approximately 9,000 by 2020. With the current adoption rate of electric vehicles, Slovenia is far behind achieving its target to have 200,000 battery electric vehicles by 2030. Therefore, Slovenia is located at level 3 in the societal readiness of the multidimensional readiness index model.

7.4.4 Economic Readiness Level in Slovenia

The initial purchasing cost of an electric vehicle is one of the significant barriers to the adoption of electric vehicles in Slovenia. The battery-electric vehicles are more expensive than the fossil fuel-powered vehicles for the average customer in Slovenia.

An Italian automobile manufacturer Fiat introduced its brand Fiat 500e. It is an electric vehicle with a 37.3 kWh battery and 320 km range on one full charge. In Slovenia, a Fiat 500e costs range from €35,000 to €39,000 (approx. $36,341 to $40,494). It costs €29,440 (approx. $30,568) to Slovenian customers after a subsidy provided by the government and a 3% discount from dealers. Whereas in Germany the price of the same brand is €29,950 (approx. $31,097). It costs €19,950 (approx. $20,714) to the German customers after the subsidy provided by the German government and a discount provided by Fiat dealers of €6,000 and €4,710 (approx. $6,229 to $4,890), respectively (Union, 2021). The cost of electric vehicles is higher in Slovenia than in Germany, even though the living standard and GDP per capita are lower in Slovenia. When it comes to fossil fuel vehicles, Slovenian have much better options for buying a car at the same or less price of €29,440 (approx. $30,568). Skoda Octavia Style powered by petrol costs from €21,120 (approx. $21,929) and Volkswagen Passat Business 2.0 TDI costs €29,518 (approx. $30,649). Therefore, Slovenia is lagging behind in the adoption of electric vehicles and is located at level 2 in the economic readiness of the multidimensional readiness index model.
7.5 United Kingdom (UK)

The United Kingdom (UK) is located on the northwestern coast of mainland Europe. It includes the entire island of Great Britain. The UK consists of England, Scotland, Wales, and Northern Ireland. The total land area of the UK is around 242,495 sq km. The population of the UK was recorded at about 67.22 million in 2020. The UK is renowned for manufacturing prestigious brands of automobiles. The UK automobile industry was the second largest in the world in the mid-20th century. The automotive industry has a significant role in the UK economy. In 2020, it contributes 15.3 billion British pounds (approx. $18.6 billion) to the country’s economy and employs more than 860,000 people working (Placek, 2021). In the UK, the five most populated cities are London, Manchester, Birmingham, Leeds, and Glasgow, with a population of around 9.3 million, 2.7 million, 2.6 million, 1.8 million, and 1.6 million, respectively (Clark, 2022). The distance between London to Manchester, Birmingham, Leeds, and Glasgow are around 340 km, 207 km, 313 km, and 667 km, respectively. London is a global hub for technology, financial services, and industries; therefore, people frequently travel from various cities of the UK to London. The most common mode of transportation in the UK is passenger cars as shown in figure 40.

![Figure 40: Most common mode of transportation in the UK in 2019 (Mazareanu, 2021)](image)

The UK has a total road network of about 422,100 kilometers. The road transportation is very common in the UK. Figure 40 shows that in 2019, about 86.1% of people traveled by cars and 4% of people traveled by buses and coaches throughout the UK. It means that 90.1% of the road transportation contributed to commuting people from one place to another. The UK has the ambition to decarbonize road transportation and shift away from conventional powertrains to the electrified transportation system. Therefore, the policymakers have decided to ban the sales of new diesel and petrol cars by 2030. In 2020, the UK was among the most prominent European electric vehicles market. The sales of plug-in electric vehicles
increased by about 140% year over year, whereas hybrid electric vehicle sales raised by about 12%. The demand for electrified cars among new car intenders has increased around 40% in the UK (Wagner, 2021b). Thus, the UK is the booming market for the electrification of the transportation equipment and systems.

Figure 41 represents the results of our analysis illustrates in a spider graph.

Based on our analysis, the UK is positioned in technology and societal readiness at level 6, political readiness at level 8, and economic readiness at level 7 in the multidimensional readiness index of electrification of the transportation system. Each of the dimensions is explained in detail below in the subsections.
7.5.1 Technology Readiness Level in the UK

The UK has had a long history of manufacturing prestige vehicles in the mid of the 20th century. Now a days, the vehicle manufacturing industry has shrunked and limited to focus on a few remaining British prestige brands and commercial vehicles. The leading British electric vehicles are MINI (which was founded in 1969 but now owned by German automotive company BMW since 2000), Vauxhall Corsa and MG ZS. Among the top 10 electric vehicles, the other seven brands are imported from US (Tesla), South Korea (Kia Niro, Hyundai), Germany (Volkswagen ID.3), Japan (Nissan Leaf), and Germany (Audi) as shown in figure 42.

![Figure 42: Top 10 electric vehicle sales in the UK in 2021 (Herincx, 2022; Phillips, 2022)](image)

Electric vehicles are dependent on battery technology. The UK has recently been considering building a Gigafactory to obtain a position as a future battery leader. In May 2020, two British start-ups, “AMTE Power” and “Britishvolt,” have announced to build the first large-scale battery factory to supply batteries for the domestic electric vehicle manufacturers (Statista, 2020a). The “Envision AESC UK Limited,” located alongside Nissan’s car factory in Sunderland, is currently the only British EV battery manufacturing company with an annual production capacity of 2GWh (Hill, 2021). However, to fulfill the demand of British electric vehicle manufacturers, the UK imports batteries from China and South Korea.

The charging infrastructure has a significant role in the transition of the transportation system towards electrification. In 2019, about 22,359 standard chargers of up to 22 kW were available in the UK. In 2020, the number of standard chargers increased and reached 27,222...
There were 3,000 fast charging points and almost 800 ultra-fast charging points for electric vehicles in the UK in 2020 (R. D. Statista, 2021). The installation of charging points continuously increased in the UK and reached above 28,458, including 3,874 fast chargers and 1,290 ultra-fast chargers at the end of 2021.

The top ten cities in the UK with the high number of chargers are Coventry, Sunderland, Newcastle, Leeds, Middlesbrough, Reading, London, Sheffield, Glasgow, and Cardiff. The bottom ten cities with the least number of chargers, although most populated cities in the UK, are Leicester, Portsmouth, Belfast, Liverpool, Stoke-on-Trent, Edinburgh, Bournemouth, Birmingham, Manchester, and Brighton. London is the most populated region in the UK, with 9.5 million people in 2021, having almost 32.3% of the total UK chargers installed. Based on the County Councils’ data, around 7,865 public charging points are available in London compared with 7,781 in the 36 county areas, which equates to one every mile on average in London, compared with one every 16 miles in the other 36 county areas (Kirby & Bawden, 2021). Driving an electric vehicle is more difficult in England’s counties compared to cities which could create a barrier for people to shift from petrol or diesel-based vehicles to electrified vehicles. Sam Corcoran, the County Council Network’s climate change spokesman, said: “Having a car is a necessity rather than a luxury in many county areas owing to a lack of public transport options, but we cannot incentivize people to switch to electric vehicles if the infrastructure is not readily available to support them.” Therefore, based on the analysis of the above data the UK is positioned at level 6 in the technology readiness of the multidimensional readiness index.

7.5.2 Political Readiness Level in the UK

In 2020, the UK government announced to ban the sale of new petrol and diesel-powered vehicles from 2030 and new hybrid vehicles from 2035. In connection with the announcement, the government has taken several initiatives that support transforming the transportation system from fossil-based to electrified. Some of these initiatives are to provide rebates and subsidies to the users and the manufacturers of electric vehicles, investments in the infrastructure and innovative digitalized energy technologies, and introduce new policies and regulations for supporting the adoption and diffusion of electric vehicles.

The UK government has established a team called the “Office for Zero-Emission Vehicles” (OZEV). The OZEV is part of the Department for Transport and the Department for Business, Energy & Industrial Strategy. The UK government has provided funds of about £900 million (approx. $1,097 million) to the OZEV, and the function of the OZEV team is to support the transition to zero-emission vehicles (ZEVs). They provide 1) grants to the electric vehicle buyers to reduce the upfront cost of new ultra-low and zero-emission vehicles, 2) grants to install charging points in homes, workplaces, and on residential streets, 3) support charging infrastructure on the wider roads network and 4) provide innovation support to develop zero-emission vehicle technology. In 2017, the OZEV has introduced different plans for the electric vehicles.
vehicle buyers to encourage them to buy electric vehicles than the gasoline-based vehicles. Table 8 shows the subsidy plan for the EVs buyers.

Table 8: Grants provided to the buyers on the purchase of plug-in-vehicles (GOV.UK, 2017)

<table>
<thead>
<tr>
<th>Grants</th>
<th>Purchase on Plug-in-Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to £3,000 (approx. $3,656)</td>
<td>35% of the cost of an electric car</td>
</tr>
<tr>
<td>Up to £1,500 (approx. $1,828)</td>
<td>20% of the cost of an electric motorcycle or moped</td>
</tr>
<tr>
<td>Up to £8,000 (approx. $9,751)</td>
<td>20% of the cost of an electric van</td>
</tr>
<tr>
<td>Up to £20,000 - £8,000 (approx. $24,378 - $9,751)</td>
<td>20% of the cost of a large electric van or truck (for the first 200 orders the grants would be up to £20,000 (approx. $24,381) after that £8,000 (approx. $9,751)).</td>
</tr>
<tr>
<td>Up to £7,500 (approx. $9,141)</td>
<td>20% of the cost of an electric taxi</td>
</tr>
</tbody>
</table>

The buyers do not need to do anything to obtain the grant (mentioned in table 1). The dealer will include the value of the grant in the vehicle’s price. The UK government has exempted annual road tax on the private pure electric vehicles costing less than £40,000 (approx. $48,763). The companies that buy electric vehicles can deduct 100% of the purchase price from their corporation tax liability if the vehicle produces less than 50 grams of CO$_2$ per kilometer (paying 1% tax in 2021 and 2% tax in 2022). In 2020, the UK government set a 16% tax on the business plug-in electric vehicles emitting less than 50g/km of CO$_2$, which is 4 to 8% lower than the tax on diesel company vehicles. Additionally, the UK government has started providing “green number plates” to the EV owners to benefit from local incentives. These benefits include using bus lanes, free parking, and accessing areas cut off from regular vehicles.

Along with the federal government of the UK, the local and regional governments have also introduced incentives to encourage vehicle buyers to buy electric vehicles to achieve the 2030 goals of decarbonizing road transportation. The Scottish government has introduced a new scheme, “interest-free loan,” to encourage vehicle owners to switch from gasoline-based vehicles to electric or hybrid vehicles. The loan can be taken up to £35,000 (approx. $42,668), which covers the cost of purchasing a new electric or hybrid vehicle. The duration of returning a loan is six years. The Northern Ireland local government offers €5,000 (approx. $5,187) grants for the private electric vehicle buyers and a maximum of €3,000 (approx. $3,112) for the commercial buyers. From 8 April 2019, the local government of London has exempted electric vehicles and plug-in hybrid vehicles from congestion charges until 2025 (Shale-Hester, 2018). Also, free and discount parking is available for EVs in some places in London.

The UK government has also announced “The Road to Zero Strategy,” which will support the transition to zero-emission road transport. The UK government has dedicated a £290 million (approx. $353 million) budget for this strategy to improve the use of low-emission vehicles. The main issues addressed through this strategy are considering the factors that are driving the global transition to zero-emission vehicles, focusing on the key strategic challenges for the UK and what government will do to address them, how to drive supply and demand of ultra-low emission vehicles, and the cleanest conventional vehicles, how to ensure a fit for
purpose infrastructure network and prepare the energy system and how to support leadership at all levels during the transition to zero-emission vehicles.

The UK government has taken a significant step in building the charging infrastructure for promoting electric vehicles in British society. In September 2019, the UK government announced to deliver £500 million (approx. $609 million) funds to develop “green technologies for a cleaner and healthier future,” The £400 million (approx. $487 million) was dedicated to building the new charging infrastructure (GOV.UK, 2019). In the UK, the installation of charging points is continuously increasing. The government has announced subsidies for those private buyers of EVs who install charging points at their homes will be eligible for 75% of the total purchase and installation costs of one EV charger at their home. The government has also announced subsidies for installing chargers at workplaces. From April 1\textsuperscript{st}, 2020, the firms that install chargers for EVs are eligible for 75% of the total purchase and installation cost for each socket up to a maximum of 40 across all sites. The local and regional governments of the UK have also introduced various subsidy schemes to encourage their citizens to install EV chargers at their homes. The Scottish government announced £300 (approx. $365) of the total purchase and installation costs of one EV charger for their home, with an additional £100 (approx. $121) available for rural Scotland areas. The Scottish government also announced funding for the purchase and installation costs of EV chargers at workplaces. Therefore, based on the analysis of the above data the UK is positioned at level 8 in the political readiness of the multidimensional readiness index.

### 7.5.3 Societal Readiness Level in the UK

The British society is aware of the environmental concerns regarding fossil fuels, and a large part of the society is willing to shift from fossil-based to electrified transportation systems. A British company called “Deloitte” surveyed in 2018 to discover the main reasons for British society to consider battery-powered electric vehicles. Altogether including male, female, and various age groups, 965 respondents participated in this survey. Almost 37% responded that they would buy an electric vehicle because of the lower operating cost. The other 25% of British consumers would consider using a battery electric vehicle for environmental reasons, and 22% would consider it for some other reasons such as rebates, tax incentives, and keeping up with the latest technology (Statista, 2022j). It means altogether 84% of vehicle consumers are ready to move towards electrification of transportation system, whereas only 16% of respondents would not consider it for any reason.

The sale of electric vehicles is increasing in the UK. In 2021, almost 190,727 battery electric vehicles and 114,554 plug-in hybrid vehicles were sold in the UK, raising the market share of about 5% battery electric vehicles and 2.8% plug-in hybrid vehicles compared to the market share in 2020. The difference between the market share of 2019 and 2020 was significant. The market share of battery electric vehicles increased about 10%, and plug-in
hybrid vehicles increased approximately 5.4% in 2021, respectively, which shows that the sale of battery electric vehicles was higher than the sale of plug-in hybrid vehicles in these years.

In January 2022, the sale of battery electric vehicles was 14,433, with a 12.5% market share. On the other hand, the combined sale of plug-in and plug-less hybrid vehicles was 43,178, with a total market share of 37.6%, which is 25.1% higher than the battery electric vehicles market share, as shown in figure 43.

Figure 43 represents that the highest sales of automobiles in the UK are petrol vehicles. The sales of petrol vehicles were 51,468, which was 44.7% of the market shares in January 2022. Approximately 79.6% of passenger vehicles, a large part of the vehicles sold in the UK, were not electric in January 2022. Even though the sales of fully electric vehicles have increased in the last few years in the UK, the adoption rate of electric vehicles is slow. Therefore, the UK is positioned at level 6 in the societal readiness of the multidimensional readiness index model.
7.5.4 Economic Readiness Level in the UK

A British company called "Shell" surveyed in October 2019, investigating the "main barriers to electric car ownership in the United Kingdom." The age group of the respondents was 18 years and older. Approximately 1,003 respondents responded to the survey in which 80% of the respondents answered that the high cost of purchasing an electric vehicle is the most significant barrier, whereas 62% of the respondents responded that the higher electricity bills of charging an electric car at home are the prominent barrier (Mathilde Carlier, 2022c).

A German brand Volkswagen ID.3 was the most selling electric vehicle brand in the UK in 2021 after Tesla Model 3 and Kia Niro. In the UK, the price list of an electric vehicle, Volkswagen ID.3, is from £29,580 to £38,760 (approx. $36,070 to $47,264), whereas the price list of its counterpart Volkswagen Golf 1.0 TSI (Petrol) is from £23,625 to £27,275 (approx. $28,808 to $33,259). There is a pricing difference between electric cars and vehicles that run on fossil fuels. An electric vehicle buyer has to pay £5,955 (approx. $7,261) extra to buy Volkswagen ID.3. The British government is aware of the cost differences between electric and fossil-based vehicles. Therefore, to compensate for the price gap, the British government announced providing £3,000 (approx. $3,658) to electric vehicle buyers. However, it still costs £2,955 (approx. $3,603) more than buying Volkswagen Golf 1.0 TSI, which runs on petrol.

Despite the higher purchasing cost of an electric vehicle, the operational cost is much lesser than the vehicle runs on petrol or diesel. The UK government has exempted taxes from those electric vehicles that cost less than £40,000 (approx. $48,776). Electric vehicles are also exempted from congestion charges. In contrast, the owner of the fossil-based vehicle has to pay £14 (approx. $17) every day if driving through the congestion charging zone in London. Additionally, charging an electric vehicle cost less than the petrol prices in the UK, and the moving components in electric vehicles are fewer, which saves money on the maintenance cost. Therefore, the UK is located at level 7 in the economic readiness of the multidimensional readiness index model.
8. Analysis and Discussion

The data discussed in the above disclosure is based on the factors involved in assessing the state of global readiness for the electrification of all modes of electric transportation equipment and supporting systems for each country. This discussion leads us to conclude that merely relying on technological development and analysis of the electrification will not lead us towards the complete system of transportation readiness towards electrification. We need other such as political, societal, and economic perspectives to explore, understand, utilize, and support the whole system for the successful transformation of the transport system towards electrification. Figure 44 represents three multidimensional readiness index models applied to three continent analyses. Each model represents the readiness achievement in transforming the transportation system towards electrification in all four dimensions (technology, political, societal, and economic) of the eight countries (China, India, Australia, Germany, Norway, Slovenia, Sweden, and the UK) from three continents, Asia, Australia, and Europe.

As a result, to attain a high degree of diffusion of an electric transportation system, additional factors such as political, societal, and economic readiness also must be considered and balanced alongside the available technology. Our research has noted that the major dimension in the public discussions of electrification has been globally focused on technology. Until all the readiness factors have been globally given their due consideration, the introduction of complete and effective electrification of all modes of transportation equipment and their associated systems will not proceed effectively or expeditiously. From our point of view, all those four dimensions of the states of readiness are complementary and thus equally important, and all are needed to be fully integrated and implemented to support the development and diffusion of electrification of transportation system.

To evaluate each country's readiness level of technology, political, societal, and economic, we have used TRL, PRL, SRL, and ERL readiness scales. Each country is placed in the multidimensional readiness index model based on the evaluation of the readiness scales, as shown in figure 44. We have further calculated the percentage of the scores obtained from each country's multidimensional readiness index model to represent the results in the graphical format. Table 9 shows the scoring result of the eight countries (China, Norway,
Germany, Sweden, UK, India, Australia, and Slovenia) in all four dimensions of readiness levels (technology, political, societal, and economic) in developing electrification of the transportation equipment and supporting systems.

<table>
<thead>
<tr>
<th>Countries</th>
<th>Readiness scoring scale from 0 to 9.</th>
<th>Total score of each country</th>
<th>In Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Technology</td>
<td>Political</td>
<td>Societal</td>
</tr>
<tr>
<td>China</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Norway</td>
<td>5</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Germany</td>
<td>7</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Sweden</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>UK</td>
<td>6</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>India</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Australia</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Slovenia</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 9: Represents the countries’ scoring results in the development of transportation electrification system (Authors)

The obtained results from the eight countries shown in table 9 are then further plotted for a graphical representation in figure 45, which shows the eight countries' positioning in the transportation system's transformation process towards electrification.

Figure 45: Countries positioned in the development of transportation electrification in the year of 2022 (Authors)
Figure 45 represents that China scored 97%, followed by Norway at 89%, Germany at 81%, Sweden at 78%, the UK at 75%, India at 44%, Australia at 42%, and Slovenia at 33% in the development of transportation electrification.

8.1 Analysis across Countries on Electrification of Transportation

China is a leading country in the field of electromobility technology, industry, and market, according to the electric vehicle index in 2021. China is at the forefront of the transition from fossil-fueled vehicles to electric vehicles. China is leading in manufacturing pure battery electric vehicles as well as in battery along with South Korea which is ranked 1st in innovation, according to Bloomberg (Jamrisko et al., 2021). Of the top 10 fully battery-electric vehicle manufacturers, nine are Chinese companies, and the other one, Tesla, is a US brand that is also manufactured in China. By the end of June 2021, 1.947 million charging piles and 716 battery swapping stations were available for charging electric vehicles in China. One key system for electrified road transportation is batteries. Asian companies are leading the electric vehicle battery industry. They are expanding their manufacturing capacity in Europe and the USA to gain profitable contracts and secure their market positioning from the international electromobility manufacturers. LG Chem and Samsung SDI are the largest South Korean battery manufacturing companies.
From January 2020 to August 2020, the South Korean LG Chem was the top leading company in manufacturing lithium-ion batteries worldwide. Contemporary Amperex Technology Limited (CATL) and BYD are two of the leading Chinese batteries manufacturers. CATL is ranked second with a market share of over 29%. CATL is the biggest international electric vehicle battery exporter to BMW, Honda, Hyundai, Tesla, and Volkswagen. China and South Korea are leading in battery manufacturing for electric vehicles beside the Panasonic which is a Japanese battery-making company. China has a complete value chain in the electromobility industry from the initial reception of materials through its delivery to market and everything in between, as shown in figure 47.

Figure 47 represents three main development strategies and patters for some countries.

**Buyers**: The first category consists of the countries that early on invested in electrifying the transport system by purchasing electric cars from various suppliers, including Norway, Iceland, the Netherlands, Sweden, Canada, the UK, Italy, and India. The majority of these countries do not have their own automotive industry, limited industry size or companies have struggled against this technology development.
**Stuck in the middle:** This includes countries such as France, Germany, Japan, South Korea, and the US. The new technology threatened these countries as they are traditionally strong in the automotive industry and wanted to maintain their leading position as developers and manufacturers of high-quality fossil fuel-based cars. The hybrid technology was seen as a reasonable balance and compromise initially. Gradually, the political climate in the EU has hardened, various decisions have been made to steer towards BEV, and the traditional automotive industry has been forced to adopt the new technology.

**System integrator:** By seeing the possibilities of technology and making political decisions at an early stage, the Chinese industry, on a broad front, has embraced the new technology with BEV. Figure 47 represents that China stands alone in its position as the country that has both large market volumes of electric cars, even though lower relative volumes than, for example, Norway, Iceland, and the Netherlands, but at the same time has developed a complete industry that has control over the entire value chain, the full range of technologies from batteries, electric motors, software to system integration in complete BEV.

The consequences of this are significant. The countries that have quickly established BEVs through purchases from abroad improve their local environment and living conditions in the short term but in the long-term contribute to creating lasting value in the countries that produce and sell complete BEVs, initially China. This creates extensive value transfers from buyer countries to system integrators. Changes in these positionings of different countries are a difficult and slow process as it requires the establishment of mines, battery factories, electric car production facilities, and significant changes in the country’s workforce in terms of education, experience, and skills, and not least service and maintenance of the new electric cars to the scope and different from fossil cars due to simpler technology.

Norway does not manufacture electric vehicles or electric vehicle batteries, but it imports from other countries such as the US, South Korea, Japan, and China. NIO Norway (Chinese BEV supplier) has also started its sales in 2021 and several other Chinese brands such as XPeng, LiAuto, BYD and other are moving to Europe. Norway is a small but geographically long country, and people need to travel long distances for their daily life activities. Almost 96% of electric vehicle owners have access to a charging station in their own homes or apartment. However, long-distance travelers or tourists with their electric vehicles need public charging stations, which presently lack in number and distribution. The government has started funding to construct at least two multi-standard fast-charging stations at every 50 km along all of Norway’s major highways.

Germany is the most prominent country in Europe in manufacturing fully battery electric vehicles, with its top five selling brands such as Volkswagen, Mercedes-Benz, BMW, Smart, and Audi. However, Germany imports batteries from Asia, especially China and South Korea, to manufacture luxury electric vehicles like BMW, Mercedes-Benz, and Audi. Germany imported 106 million lithium-ion batteries worth approximately US$ 1.5 billion from China in 2019 (Xinhua, 2020). Germany also aims to become the center of European battery production. The federal government is funding around $ 506.7 million (€ 436.8 million) for the project (Manthey, 2021a). In 2020, the German and French governments collaborated “German-French battery consortium” to initiate a pilot plant and establish a factory in...
Germany and France. Even though Germany is working to develop its strength to produce batteries for electric vehicles domestically, this process is still in its initial phase. At the end of 2020, the total number of public charging stations was 44,669, of which 37,213 were slow and 7,456 were the fast-charging stations available in Germany. However, Germany is still lagging behind in its charging infrastructure. The charging stations are not evenly distributed in Germany. Hamburg is the second biggest city in Germany with 1.9 million people, whereas Munich is the third biggest city in Germany with 1.5 million people. However, as of 2021, Munich has the highest number of charging stations than Hamburg, approximately 1,694 and 1,310, respectively. Germany has introduced its first electric road of about 10 km long in the south of Frankfurt. The electric road charging solution faces standardization issues, and the road charging technologies are still in their early testing phases.

Sweden is one of the top innovative countries in the world and the number one in EU. According to the Bloomberg innovation index 2021, Sweden is ranked 5th in the innovative countries worldwide, while in the EU Innovation Scoreboard, it is ranked as 1st. However, in the field of electromobility, Sweden still lags behind, despite manufacturing its own electric vehicles in Belgium and China. The Swedish Volvo manufactures its prestigious electric vehicle (Polestar) in China. The new Volvo XC-40 launched in 2021 is manufactured in Belgium and China. However, Sweden yet does not have its own battery manufacturing and thus Swedish EV manufacturers purchase batteries mainly from Asia, Europe, and the US. Volvo in the majority, manufacturers hybrid vehicles rather than fully electric vehicles. Scania and Volvo have launched their first electric trucks in 2020/2021. In Sweden, several charging technologies are in the testing phase, such as electric roads (conductive and inductive), and the government is considering to further looking into battery swapping solutions. Static cable-based charging is considered a relatively mature technology that is primarily used to charge passenger vehicles. However, static charging faces a standard technical problem in that there is no standardized charging plug.

The UK automobile industry was the second largest in the world in the mid-20th century. However, in the field of electromobility UK is lagging behind in manufacturing its own electric vehicles. The British brand MINI was founded in 1969 but is now owned by German automotive company BMW since 2000. The other MG British automotive company was founded in 1920 but is now owned by SAIC Chinese motor corporation limited since 2007. Among the top ten selling brands of electric vehicles in 2021, only Vauxhall Corsa is the British brand. The other nine brands are imported from the US, South Korea, Germany, and Japan. The UK also imports batteries from China and South Korea to fulfill the demand for British electric vehicle manufacturers. The UK has lately considered developing a Gigafactory to establish itself as a future battery leader. The "Envision AESC UK Limited" is currently the only British EV battery manufacturing company with an annual production capacity of 2GWh. The other two British start-ups, "AMTE Power" and "Britishvolt," have announced building the first large-scale battery factory to supply batteries for the domestic electric vehicle manufacturers. The UK is catching up in its charging infrastructure with approximately 28,458 charging points, including 3,874 fast chargers and 1,290 ultra-fast chargers were available at the end of 2021. However, 32.3% of the total UK chargers are installed in London, whereas according to the County Councils' the other 36 county areas are lagging behind in the charging infrastructure.
India is different when it comes to the electrification of transportation as the most common mode of transportation in India is two and three-wheelers. Indians prefer to have two-wheelers as they are convenient for short distances and efficient transport on narrow and busy roads with heavy traffic. India is the largest two-wheelers manufacturer in the world. In 2019, approximately 295 million two-wheelers were registered in India. Hero MotoCorp is the market leader in producing two-wheelers and has taken the initiative of producing electric bikes and scooters. In 2021, approximately 5,600 electric bikes were sold by Hero MotoCorp. Honda Motorcycle & Scooter India is also catching up with India’s electric two-wheeler market share, with approximately 3,868 electric bikes sold in 2021. An Indian automotive manufacturing company, TATA, has also introduced Tata Nexon and Tata Tigor electric vehicles. These two TATA brands had the highest sales among the electric cars, with approximately 4,214 electric vehicles sold in India in 2021. However, India does not manufacture batteries for its two, three, and four-wheelers but instead imports from China, Hong Kong, and Vietnam. The most significant challenge for India is to have a suitable charging infrastructure. India only has 1,640 public electric vehicle chargers installed, of which 940 chargers are only installed in 9 megacities. These chargers are not enough for the country with the second biggest population in the world. Even though the Indian government has taken some initiative to expand the public electric vehicle charging stations, these efforts are not enough until now.

Australia is far behind in the electrification of transportation systems compared to the other developed nations such as China, Germany, Norway, Sweden, the UK, etc. Australia does not manufacture electric vehicles but imports from the USA, Germany, South Korea, Sweden, and Japan. Australia is rich in lithium mines production. In 2021, approximately 55,000 metric tons of lithium came out of Australian soil. In contrast, Chile and China ranked second and third in producing lithium, with approximately 26,000 and 14,000 metric tons, respectively (Garside, 2022). However, Australia has not been manufacturing lithium-ion batteries till 2021. In 2020, the Australian government funded $28 million for the first time to start a lithium-ion battery manufacturing facility in Australia (Hartmann, 2020). In 2021, Australian Prime Minister Scott Morrison announced additional funding of $1.5 billion to boost Australian battery production (Carroll, 2021). The battery production facility is still at an early stage in Australia. Australia is lagging behind in electric vehicle charging infrastructure. At the end of 2021, approximately 3,001 public charging stations were available in Australia, of which 1,017 were only in New South Wales. Charging an electric vehicle is a challenge for people who cannot charge their vehicles at home, especially for tourists who travel from one state to another. Therefore, highways, metropolitan areas, and tourist attractions need public charging facilities in Australia.

Slovenia is lagging behind its goal of decarbonizing the road transportation sector. The Slovenian government has set the goal to have 130,000 battery electric vehicles and 70,000 plug-in hybrid vehicles on roads replacing fossil fuels. To achieve the goal, Slovenia should have been 5,311 battery electric vehicles and 6,033 plug-in hybrid vehicles on roads by the end of 2020, whereas 3,678 battery electric vehicles and 944 plug-in hybrid vehicles were registered as of December 31, 2020. Slovenia does not manufacture electric vehicles. All of the top-selling electric vehicle brands in 2018 were imported from Japan, France, Germany,
and South Korea. Slovenia is planning to gain in-house battery manufacturing capability. For this reason, Slovenian battery manufacturing company Tovarna Akumulatorskih Baterij (TAB) collaborated with a Chinese company Haidi Energy Technology. However, this project is not ready yet to produce batteries on a larger scale. Slovenia does not have a suitable public charging infrastructure yet, that supports the transformation of fossil-based to clean transportation and enables the government to achieve its targeted goals set for 2030 of replacing gasoline-based with electrified vehicles. Slovenia only had 308 public charging stations by the end of 2021. These charging stations are mainly available in the populated cities of Ljubljana, Maribor, Kranj, and Koper. It is difficult for the people driving across Slovenia or tourist to find public charging stations on the main highways.

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Based on the technical analysis of the above eight countries, we can see that only China has complete control over manufacturing electric vehicles, batteries, equipment, and systems for transportation electrification. In contrast, Germany is catching up with its five prestigious brands of electric vehicles and gaining the capability to start in-house battery manufacturing along with Sweden and France. The other five countries, Australia, Norway, Sweden, Slovenia, and the UK, are mainly the buyers of electric vehicles and their supporting equipment and systems for electrification of transportation. India has been stuck in the middle with its few electric two-wheelers and one known TATA electric vehicle manufacturer. Therefore, buyers of new electric vehicles to the new ones controlling the whole value chain from EVs to batteries to charging infrastructure. We can see that some countries are mainly buyers, whereas only China today has control over the entire value chain. Germany is now catching up, although Germany started later, which impacts EV diffusion and value creation for the country and people. Countries with the entire value chain and the related more substantial control also significantly influence people, technology, industry, and wealth creation.
8.2 Comparison and Analysis of Sales and Market Share of Electric and Plug-in Hybrid Vehicles across Countries

China has the biggest population globally, with 1.4126 billion in 2021, as shown in table 10. Therefore, the size of the automotive market is bigger too. In 2021, approximately 21.48 million passenger vehicles were sold in China (Statista, 2022h). Meanwhile, the market size of electric vehicles is also expanding in China.

<table>
<thead>
<tr>
<th>Countries</th>
<th>Size of Population – 2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>1.4126 billion</td>
</tr>
<tr>
<td>Germany</td>
<td>83.2 million</td>
</tr>
<tr>
<td>UK</td>
<td>68.2 million</td>
</tr>
<tr>
<td>Sweden</td>
<td>10.41 million</td>
</tr>
<tr>
<td>Norway</td>
<td>5.39 million</td>
</tr>
</tbody>
</table>

Table 10: Population size of the five selected countries

The variation in electric vehicles sale of China, Norway, Germany, the UK and Sweden from 2019 to 2021 can be seen in figure 48.

Figure 48 represents that the sales of electric vehicles are continuously increasing in China compared to every previous year between 2019 – 2021. In 2021, approximately 3 million battery and six hundred thousand plug-in hybrid cars were sold in China. Chinese society is rapidly moving towards BEVs. Figure 49 represents that in 2021, approximately 9% of the
electric vehicles market share increased in one year and reached 15% at the end of 2021. The success behind China’s leading in electromobility is the Chinese government’s implementation power of favorable electric transport policies and strategic positioning of EVs in upgrading the automotive industry, communication technology, and smart-city development. The Chinese central government considers it a vital national policy matter to promote the country’s development and diffusion of electric transportation. In 2019, when the Chinese government stopped providing subsidies on EV purchases, the EV manufacturing industry reported five months of decreasing sales in the second half of 2019. Once the government revived the subsidies on EVs in 2020, EV sales sharply increased and reached 1.3 million units in 2020 compared with the 1.2 million units sold in 2019. The Chinese government provides rebates, subsidies, and tax exemptions and keeps the charging rates low for electric vehicles to promote clean electric transportation in China.

The market share variation of Norway, Sweden, Germany, the UK, and China can be seen in figure 49 for battery and plug-in hybrid vehicles from 2019 to 2021.

In Norway, the sales of electric vehicles are rapidly increasing over those of fossil-fueled vehicles, with a staggering 54% of new cars sold in 2020 being powered by electricity. At the end of 2021, the sales increased, and the total market share of battery and plug-in hybrid vehicles reached 86.4%, which is the highest market share of any country worldwide. The reason behind it is the Norwegian government policies which are the game-changer positioning Norway as the global leader in EV adoption despite lacking in electromobility technology. The goal of the Norwegian government is to sell 100% electric cars by 2025. The cost of purchasing and operating fully electric vehicles is more reasonable than fossil-fueled
or hybrid vehicles. Even though Norway is an oil-producing country, the government has imposed high purchase and CO₂ taxes on fossil-fueled vehicles; in contrast, electric vehicles are exempted from purchase, VAT, road tolling taxes, and free parking. The dedication of the Norwegian government in the ways that it has introduced electric transport in society is maintaining Norway’s position as a successful global leader in the world in the transformation of a clean transportation system.

Sweden has maintained its second position in the market share of electric vehicles since 2019 among the five leading countries in the sales and market share of electric vehicles as shown in Figure 49. However, Sweden has crossed Norway since 2020 in the market share of plug-in hybrid vehicles. In 2021, the market share of plug-in hybrid vehicles in Sweden was higher than in Norway, approximately 26% and 22%, respectively. There is a considerable gap between Sweden and Norway in the market share of battery electric vehicles. Sweden stands at 19.1%, and Norway is leading globally with 64.5% in 2021. One reason is that Sweden has double the population size with 10.41 million people than Norway with 5.39 million people in 2021. Norway has the edge over Sweden to gain a higher market share in less time with its less than half population size. To achieve a significant market share, Sweden requires multiple charging solutions (fast charging stations, battery swapping) that encourage vehicle buyers to buy fully battery electric vehicles to cover longer distances without considering finding charging facilities on the highway or thinking of longer charging duration. However, purchasing an electric vehicle and operational costs are still expensive in Sweden despite government rebates and the exemption of taxes.

Germany has changed its market position among the five countries, as shown in Figures 48 and 49 in electric vehicles' sales and market share during 2020 and 2021. In 2019, Germany had 3% of the total market share, including battery and plug-in hybrid vehicles. Germany stood at the fifth position among the five leading countries in the market share of electric vehicles. In 2020, a rapid increase can be seen in the market share of batteries, and plug-in hybrid vehicles, which reached 13.6% due to the subsidies for purchasing electric vehicles provided by the German government under the scheme of 'environmental bonus.' At the end of 2020, the German government announced giving grants for leasing and used cars and further offered a 19% tax reduction on the purchase of new electric vehicles. After this, the market share of electric vehicles increased and reached 26%, which doubled the market share size compared to 2020, and Germany changed its position from fifth place to third place in 2020 and 2021 and reached after Norway and Sweden. Thus, the German government policies and actions played a significant role in adopting electric vehicles in Germany. However, Germany is still lagging behind in its charging infrastructure, and variations in the charging prices from place to place create uncertainty for the consumers to buy electric vehicles.

The UK stands continuously at the fourth position since 2019 among the five leading countries in electric vehicles' market share, as shown in Figure 49. In 2019, the UK had 3.1% of the market share of electric vehicles, including battery and plug-in hybrid vehicles. In 2020, the sudden increase can be seen in the market share of electric vehicles when the British government announced to ban on the sales of new fossil-based powered vehicles. Additionally, besides purchasing subsidies for EVs, the British government reduced 8% taxes
on electric vehicles and provided green number plates to the electric vehicle owners to benefit from local incentives. In 2021, the market share of electric vehicles increased and reached 18.5%. The UK’s adoption rate of electric vehicles is slow compared to Germany, even though the conditions are similar and have no significant difference in the size of the population between these two countries. Even though the British government has included the development of electrification of the transportation system on its national agenda, the UK is still lagging behind in its charging infrastructure. The initial cost of electric vehicles is higher than fossil-based powered vehicles.

We can see that governmental policies and actions can change the game to decarbonize road transportation and gain a higher market share of electric vehicles even if a country lags behind in technology, e.g., Norway. On the other hand, if a country has both, China is an example of its technology and government support. The country can reach a larger market share by selling many electric vehicles worldwide and dominating the electromobility industry. Based on the analysis done above in section 8.1, we can see that Australia, India, and Slovenia are far behind in the technology associated with the electrification of the transportation system and lagging behind in the sales and market share of electric vehicles. One pervasive thing in these countries is the lack of governmental support and actions. It can also be seen by not having supporting charging infrastructure for electric vehicles on a larger scale and enough support from their governments to strategically deviate the purchasing price of electric vehicles in favor of vehicle buyers.

The technological element is merely one of the key aspects of the business concept. Technology has been incorporated and embedded in the proper and relevant environment for businesses to be successful. An electric vehicle is a technology that requires adequate infrastructure and governmental policies that can enable EVs to be commercialized. If any country does not have the infrastructure and supporting governmental policies, then the success is low for the electrification of that country’s transportation system.
9. Conclusion

The development and implementation of electrification of the transportation system depend on society's readiness to pursue development, adoption, and diffusion of electric transport. The technology itself is a crucial foundation for electrification and must be viewed and understood when commercialization and value creation to business, people, and benefits to the entire society are also considered. Technology cannot be diffused in society and create value without a well-developed interplay of industry, academia, politics, economic institutions, and policy systems pushing and supporting economic and policy tools and regulatory tools.

Focusing on technology is not enough:

Our analysis shows that only focusing on technology will not lead us to the successful complete transformation of electrification of the transportation system. Basically, technology for electrification of transportation is fully available and can be obtained from many global suppliers. There is nothing in the technology that is not ready for commercialization and that is a barrier for diffusion of EVs. Technology development will continue and improve and be even more advanced, cheaper, comprise more functions etc. Therefore, to achieve a high level of diffusion of electric transportation systems, it is important to balance the political dimension focusing on government support to develop and implement policies that promote the electrification of the transportation system. The other factors involved are the degree to which societal readiness to switch from fossil fuel to electric vehicles has been enrolled. The fourth is the economic readiness in which subsidiaries have met the transformation financial needs to compensate for any price difference. The motivation of people to preserve until the scale of the costs involved in the adaption and adaption of the new technology meets or betters the costs incurred for old fossil-based technology must be diligently fostered.

Political readiness is probably the main dimension of electrification of transport:

Our analysis shows that political readiness is one of the most crucial dimensions of the readiness to support the transformation to electric transport, followed by societal and economic readiness. The political readiness is demonstrated in the political willingness to reshape regulatory aspects, introduce, and change subsidiaries and use public fundings for R&D and building the charging infrastructure. The political readiness can be observed on the rhetoric level and in the action level. Our focus is on the real action level of politics and policy making.

A dynamic, complex system approach is needed to understand the societal transformation:

We view the electrification of the transportation system from a complex system perspective. The electrification of transportation is not an isolated system that can be handled independently as a single technological entity. This system is interconnected and interdependent on the other subsystems such as electricity production, distribution and storage that form the whole technical system embedded in each country's political, social, and
economic context. Therefore, a system approach is required to see the electrification of the transportation system from a holistic perspective. Other subsystems need to be brought into consideration besides technology alone, i.e., politics, society, and the economy. To help achieve this understanding, we have introduced the Multidimensional Readiness Index Model based on those key dimensions.

The penetration of electric transportation systems in society is still in the early diffusion phases:

Thus, it still mainly relies on the government's economic policies, including new infrastructure economics, identifying the barriers, and finding solutions to electrified public transportation systems, providing rebates for EVs and tax exemptions, and further imposing high taxes on CO₂ emission vehicles. Government commitment is the key to success for the rapid transition from fossil fuels to electric transport. The strong government and institutional execution power initially focusing on electrification of the public transportation sector, are the success story behind China's leading in the electrification of the transportation system in the world. Norway is the second leading country in the diffusion and adoption of electric vehicles because of its favorable government policies for transport electrification, even though Norway itself does not manufacture electric vehicles and charging equipment. Germany takes third place with its prestigious manufacturing electric vehicle brands such as Volkswagen, Mercedes Benz, BMW, Smart, and Audi. However, the diffusion rate of electric vehicles is slow primarily because of not having sufficient charging infrastructure and a slow move of government actions towards it. Sweden is still lagging behind China and Germany in manufacturing electric vehicles, even though Sweden is one of the world's most prominent countries in innovation. But due to the Swedish government not taking rapid actions, it has been held back in the electrification of the transportation system. However, Sweden has built its own luxury hybrid electric vehicles. Volvo Cars are manufacturing electric cars in China. Scania trucks and Volvo has started to market their first generation of electric trucks. Volvo has declared strategic collaboration with Daimler regarding the fuel cell technology for their ICE vehicles, while Scania officially goes for battery-based heavy trucks. Sweden is also catching up with Norway in the sales of electric vehicles. The UK is also catching up with its other European countries in transforming the transportation system with its strong government support. The British government has kept transportation electrification on its national agenda and considering building a Gigafactory to obtain a position as a future battery leader. However, the UK's adoption rate of electric vehicles is still slow compared to fossil-based vehicles. India, Australia, and Slovenia are far behind in the process of transportation transformation compared to China, Norway, Germany, Sweden, and the UK. One of the common reasons in all of these countries is the baby steps taken by their governments even though they have high ambitions. Their governments require a revolutionized, system approach to enable remarkable change in the transformation process. As we can see, without the willingness of people and companies to use EVs, the desired shift from fossil-based transportation to fully electric might be complicated.
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