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ELECTRIFICATION OF THE TRANSPORTATION SYSTEM IN CHINA

A SYSTEM APPROACH TO ELECTRIFICATION OF TRANSPORTATION – AN INTERNATIONAL COMPARISON

Title: A System Approach to Electrification of Transportation - An International Comparison

Authors: Harrison John Bhatti^{1,2}, Mike Danilovic^{1,3,4}, Arne Nåbo²

¹ Halmstad University, School of Business, Innovation and Sustainability, Halmstad, Sweden.

² VTI, Swedish National Road and Transport Research Institute, Gothenburg, Sweden.

³ Shanghai Dianji University, Shanghai, China.

⁴ Lund University, Lund, Sweden.

E mails:

harrison_john.bhatti@hh.se or harrison.john.bhatti@vti.se

mike.danilovic@hh.se

arne.nabo@vti.se

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FOREWORD

All countries of the world are facing environmental and climate-related issues and challenges. Most countries are taking strong actions to fight the negative impact on the environment and climate changes due to emissions from transport, energy production, fossil oil products used in vehicles, etc. Advancements in technologies have enlightened many different solutions, such as biogas, battery-based vehicles, and hydrogen energy-based vehicles.

The dominant solution that has been seen so far is battery-based electric passenger cars and battery-based electric heavy trucks. Hydrogen as energy storage and energy source for electric vehicles has not yet been put into commercial and practical usage.

For a long time, the focus has been and still is on different technologies for electrification. Our research shows that the single-minded focus on technology is insufficient to explore and develop new solutions to electrification. Today technology is in place, and it is not impossible to argue that we need new technical solutions. Yes, technology can constantly be improved and very probably will do so.

Based on our research, we are proposing a multidimensional model focusing on technology, political, societal, and economic readiness to electrification. But the most critical aspect of electrification is the political readiness that determines and decides on the transformation, explores and identifies modes, and paths, and puts financial muscles in the transformation process that industry cannot and, due to risk level, will not do. This way, political decision-makers create a market for the industry to enter and exploit. When both technology and markets are in place, only then can the traditional market forces take it to growth and diffusion. Only the decision makers can and need to choose to invest in R&D when the industry is facing high risk, and politics open the market and support market development through subsidiaries. Gradually politics need to adjust the levels of engagement and adjust subsidiary levels.

It is our belief that we can learn from each other, with each other, and for each other. Through this learning, we can improve ourselves and develop new solutions that all of us benefit from in our struggle to improve our environment and fight climate challenges. To accomplish this, we need to have a reasonable understanding of what, why, and how different countries chose different paths to electrification.

In our paper “Multidimensional Readiness Index for Electrification of Transportation System in China, Norway, and Sweden,” we developed and presented the multidimensional readiness index model with four analyzing readiness scales: technology, political, societal, and economic. In this paper, we have taken two steps further. In the first step, our ambition with this paper is to apply the multidimensional readiness index model as an analytical approach to eight selected countries to analyze, evaluate and determine the readiness positioning of the countries in the transformation of the transportation system. In the second step, we have adopted the concept of four dimensions (technology, political, societal, and economic) but interpreted the term “dimensions” with “domains.” We are now not measuring or evaluating the readiness conditions of the countries but exploring and to understand the underlying forces acting on the processes of readiness of the countries in the electrification of the transportation system. For this purpose, we have used a systems approach that leads us to explore the elements held by each domain (technology, political, societal, and economic) and observe the dynamics of the electrification of the transportation system from a holistic perspective. Through this dynamic system approach, we can see how different forces act and influence each other, which can support and develop the readiness for achieving higher readiness levels within and between domains. We need to understand the forces within and between domains to apply a voluntaristic and interventionist approach.

Our ambition is to continue the analysis of different countries worldwide and learn about similarities and differences. This way, we can create a learning arena for how to learn from each other so that each country does not have to develop solutions from scratch.

Based on the analysis of those eight countries, we can confirm the key role of the political readiness for each country’s level and scope of electrification. The least level of readiness is noticed in Australia and Slovenia. Although Australia is a big and Slovenia is a small country, the political decisiveness is low, and the readiness is low in terms of decision-making for electrification. On the other hand, we see that China is taking the lead in the electrification mainly due to two factors; one is that Chinese actors control the entire value chain, and the other is that the Chinese decision makers show a strong capability to act as a high level of decisiveness to achieve their goals.

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ABOUT THE SWEDEN-CHINA BRIDGE PROJECT

This project funded by The Swedish Trafikverket (TRV), formally started the 1st of September 2020, and will last until the end of 2022.

Exploratory approach

This project is exploratory in nature and includes a step-by-step approach to knowledge development in the Swedish and the Chinese context. The project spans different areas of knowledge in which we will highlight what technologies and systems are prioritized in China, Sweden and in Europe, what drivers

and motives exists for them, what actors are involved in the transition to electrified, intelligent and integrated transport systems, and what conditions and business models look like to achieve this conversion to electrified and integrated transport systems in an intelligent and smart society.

The purposes of the Sweden-China Bridge Project

1. The project aims to establish and develop an academic knowledge-sharing and -transfer platform between Sweden and China for collaboration between universities and research institutes in the two countries, in order to contribute to increased understanding and information and knowledge sharing on the technical and commercial development of electrified vehicle systems, integrated transport system solutions, and energy supply infrastructure as a fully integrated system of intelligent and smart cities.
2. From this perspective, the project will explore the development and implementation of relevant technology for the electrification of vehicles, such as fuel cells, bio energy, battery storage, combinations of energy systems for hybrid vehicles, energy supply for integrated electrified vehicles, integrated electric road technology, associated charging infrastructure, and static and dynamic technology.
3. We also intend to explore the management of renewable energy supply systems, from the production of renewable electricity to its distribution to consumers of electrified transport systems, which is needed to ensure that electrified vehicles and transport systems.

Expected value creation

1. To create insights into the current and future status of electrification of transportation systems in Sweden and in China from technical, social, societal and economic perspectives.
2. To learn and mutually develop insights into how new knowledge, technology, system-based solutions, logistics and transportation systems can be developed, commercialized and operated according to a life cycle perspective in both Sweden and China.
3. To create a long-term learning context in which Sweden and China exchange experience for the benefit of both countries and their industries.
4. To develop a deeper understanding of how Sweden and China are managing the large-scale electrification of the road network using different technologies, including electric charging, energy production (fuel cells, hybrid vehicles, battery storage and electric roads): what do the short- and long-term potentials look like? How are they using long-term industry policy instruments to develop technology and implement it in society? How are they outlining business models for the large-scale roll-out of electrified transportation systems?

Research team

Mike Danilovic

Ph.D., Project leader, Professor, Halmstad University, Sweden & Distinguished Overseas Professor at Shanghai Dianji University Shanghai, China. Affiliated researcher at Lund University, Sweden.

Tomas Müllern

Ph.D., Professor, Jönköping University, Jönköping International Business School, Sweden.

Jasmine Lihua Liu (刘莉华)

Ph.D., Senior researcher at CIRCLE, Lund University, Shanghai Dianji University, China. & Affiliated researcher at MMTC, Jönköping University, International Business School, Sweden.

Arne Nåbo

Tech. lic., Research director, Swedish National Road and Transport Research Institute (VTI), Sweden.

Jeanette Andersson

Ph.D., Researcher, Swedish National Road and Transport Research Institute (VTI), Sweden.

Philip Almestrand Linné

Ph.D., Researcher, Swedish National Road and Transport Research Institute (VTI), Sweden.

Harrison John Bhatti

Ph.D., Candidate Halmstad University, Sweden and Swedish National Road and Transport Research Institute (VTI), Sweden.

Wang Junhua

Ph.D., Professor, Tongji University, Shanghai, China.

Liu Shuo

Ph.D., Assistant Professor, Tongji University, Shanghai, China.

Qiu Xiaoping

Ph.D., Professor, Southwest Jiatong University, Chengdu, China.

Susan Lijiang Sun

Ph.D., Professor, Shanghai Dianji University, Shanghai, China.

Ma Hongwei

Ph.D., Associate Professor, Shanghai Dianji University, China.

Academic partners in China

China Electric Power Research Institute (CEPRI), Beijing, China.

Zhejiang University, Deqing Research Center, Institute of Artificial Intelligence, Hangzhou, China.

Urban and Rural Construction and Transportation Development Research Institute, China.

Industrial partners in China

Beijing

Scania China Innovation Center, Beijing, China.

Shanghai

Shanghai Power Keeper, Shanghai, China.

Shanghai Jiulong Power, Shanghai, China.

Zhejiang VIE-Evatran Electronic Technologies Co., Ltd., Shanghai, China.

BYD, Shanghai, China.

Shenzhen

DST, Shenzhen, China.

Xieli innovation Center, Shenzhen, China.

Shenzhen Bus Group, Shenzhen, China.

Shenzhen Electric Vehicle Application and Promotion Center, Shenzhen, China.

Potevio New Energy, Shenzhen, China.

Haylion, Shenzhen, China.

Guangzhou Bus Group, Guangzhou, China.

Contact

Mike Danilovic, Ph.D.

Professor of Industrial Management Innovation, and
Technology Management.

Halmstad University

P O Box 823

SE18 301 HALMSTAD

SWEDEN

Phone:

+46708157588 (Sweden) | +8613761129945 (China)

E-mail:

mike.danilovic@hh.se

Visiting professor:

Distinguished Overseas Professor at Shanghai Dianji
University Shanghai, China.

Affiliated researcher at Lund University, Sweden.

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 element. 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

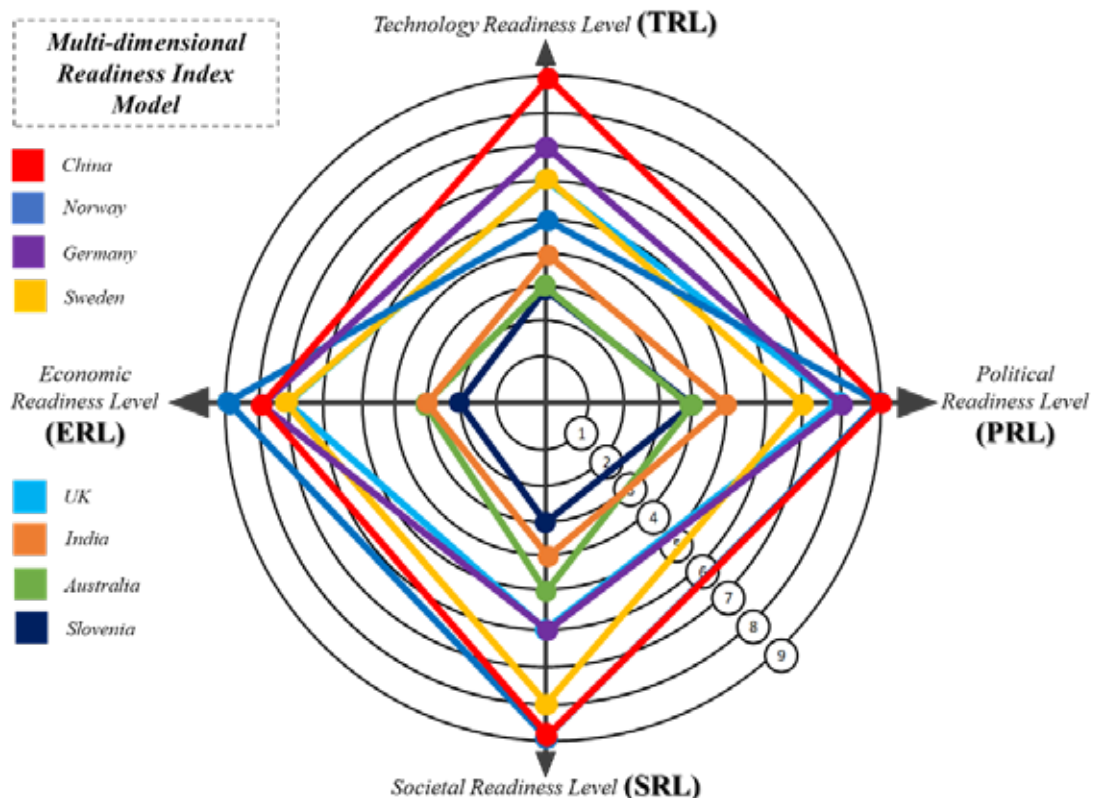


Figure 1: Multidimensional readiness index model for eight selected countries (authors)

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, System approach.

INTRODUCTION

The world is facing global transformation regarding energy towards renewable energy and the transportation towards electrification systems (Bhatti & Danilovic, 2018b). 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 (Bhatti, 2018). 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 CO₂ 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. Japan and South Korea are leading in the development of hydrogen-based vehicles whereas China, Europe and the USA are catching up fast.

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 2** 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).

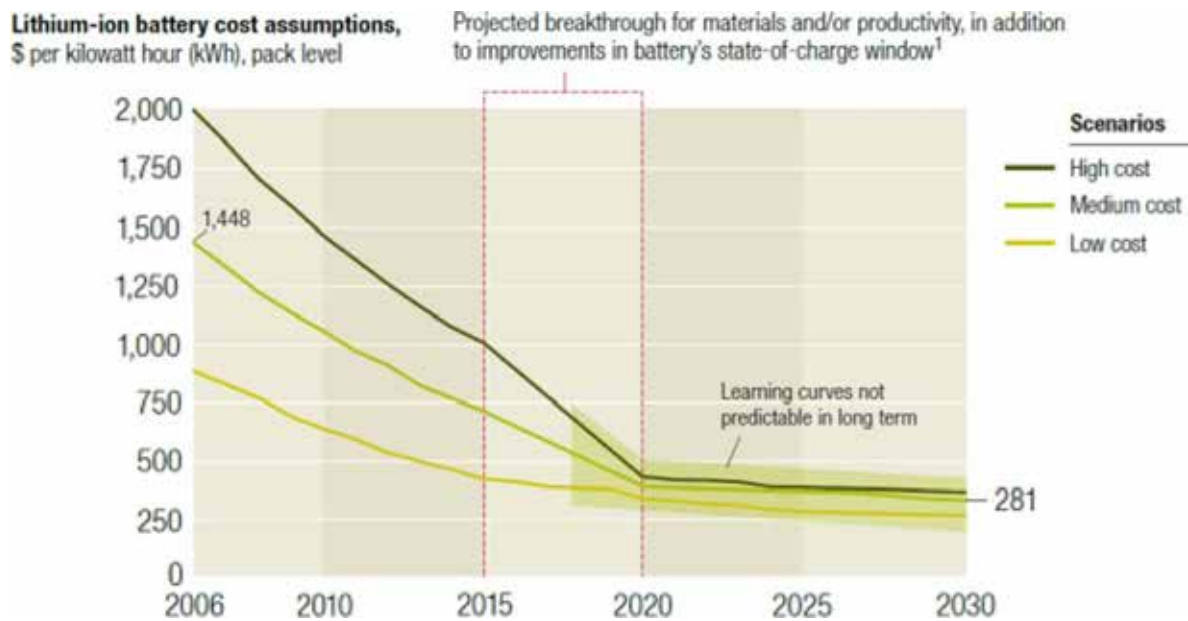


Figure 2: Projected cost (USD/kWh) of the batteries for electric vehicles from year 2006 to 2030.

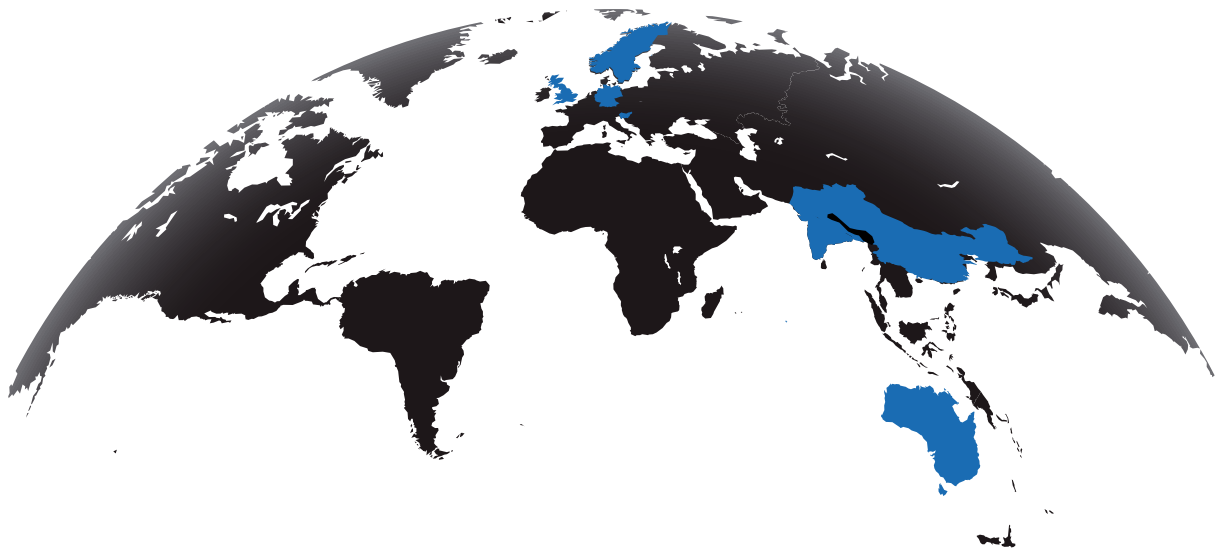
For a rapid entry into the market of pure battery electric vehicles, the battery price is significantly more than the targeted price of the USABC and IEA. We are at the early stage of battery electric vehicle technology, and technology development might change the economic conditions significantly in 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 (Bhatti & Danilovic, 2018a; Bhatti et al., 2019). 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.

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.



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.

The 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. These results have been used to plot a graph, 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.

Finally, we have adopted the concept of the multidimensional readiness index model into a system approach and interpret the term "dimension" with "domain," such as technological, political, societal, and economic domains, to explore and understand the underlying forces acting on the processes of readiness of the countries towards the electrification of the transportation system.

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 3** (Bhatti et al., 2022).

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.

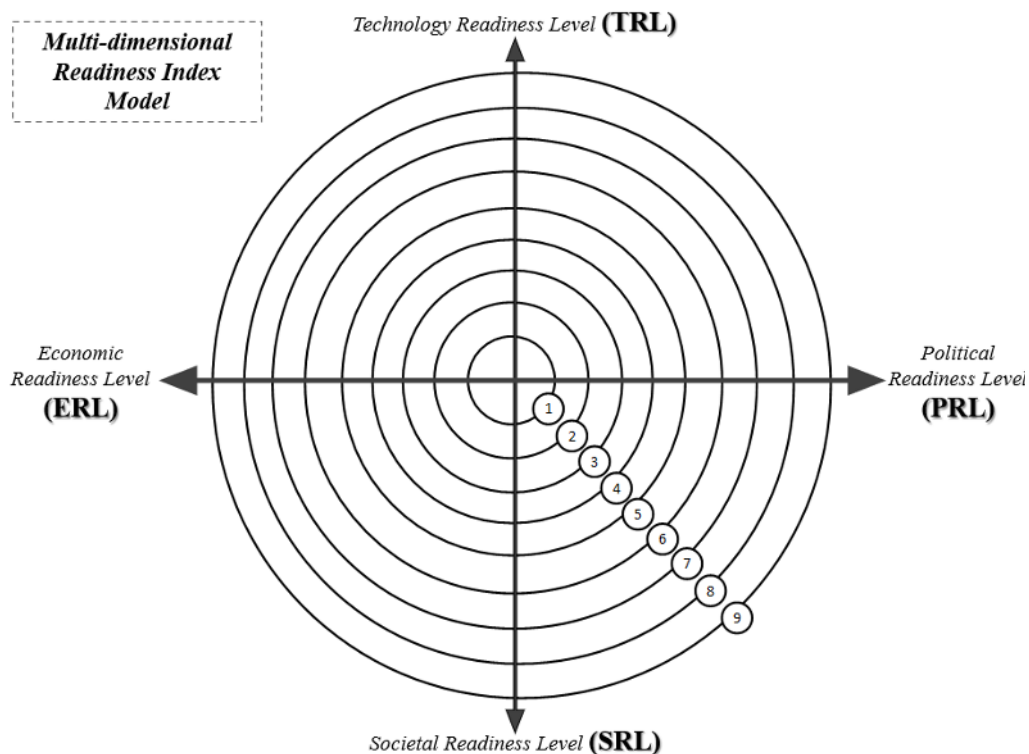


Figure 3: The Multidimensional Readiness Index Model (Bhatti et al., 2022)

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 4** demonstrates all nine levels of TRL.

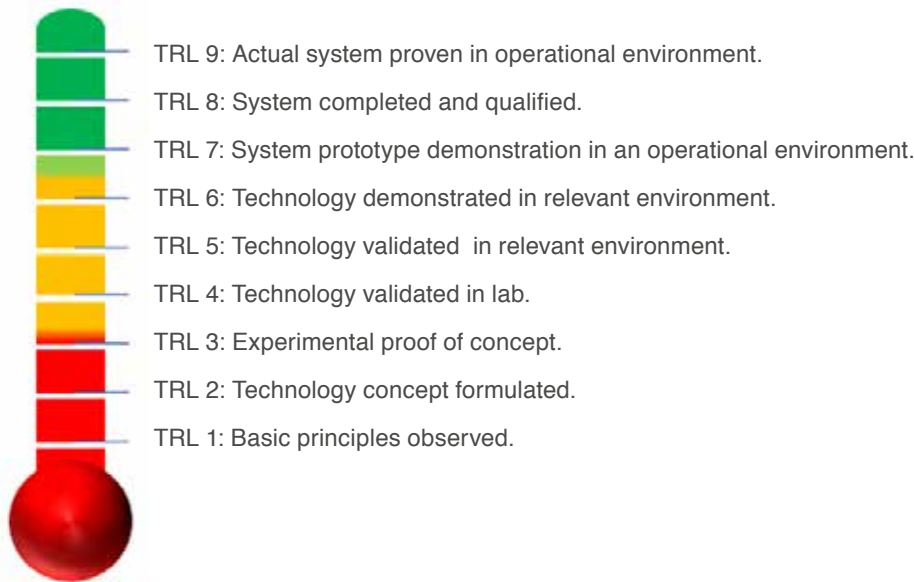


Figure 4: Technology Readiness Levels (Hirshorn & Jefferies, 2016)

The table below provides a detailed description of the nine technology readiness levels.

TRL	Description
9	Technology is ready to be deployed on a larger scale.
8	The evaluation of the evidence proves that technology works and is ready for deployment.
7	The fully functional technology is tested in the planned operational system and gathered evidence of its success.
6	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.
5	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.
4	The initial findings are collected, and multiple parameters are tested.
3	When active research and design starts on a particular technology.
2	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.
1	The beginning phase of any technology when the conceptual study is translated and reported for future research and development.

Table 1: Illustrates those 9 TRL levels in more detail (Hirshorn & Jefferies, 2016)

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.

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 5 explains the nine levels of PRL.

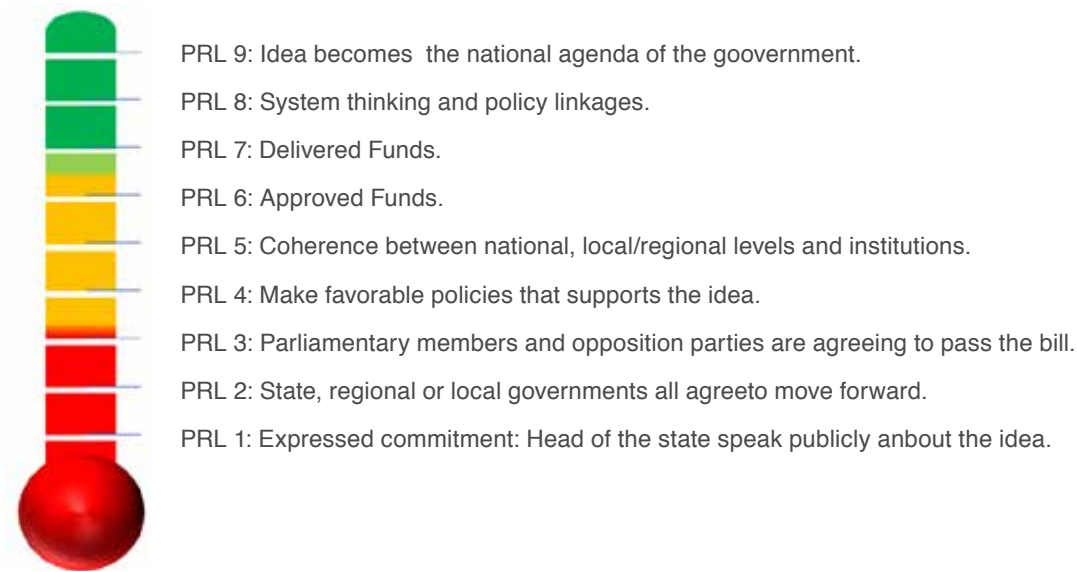


Figure 5: Political Readiness Levels (Bhatti et al., 2022)

The table below provides a detailed description of the nine political readiness levels.

PRL	Description
9	The government includes the idea in its national plan and monitors the development and implementation from the top level.
8	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.
7	The government provides the fund to the relevant stakeholders to begin the work.
6	The government approves the funds for converting the idea into a physical reality.
5	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.
4	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.
3	The new innovative idea and benefits are announced in the parliament, where the government and opposition parties mutually approve it.
2	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.
1	The head of the state publicly expresses his/her interest in moving towards new innovative ideas / new inventions or adopting new technology.

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.

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 6 demonstrates all nine levels of SRL.

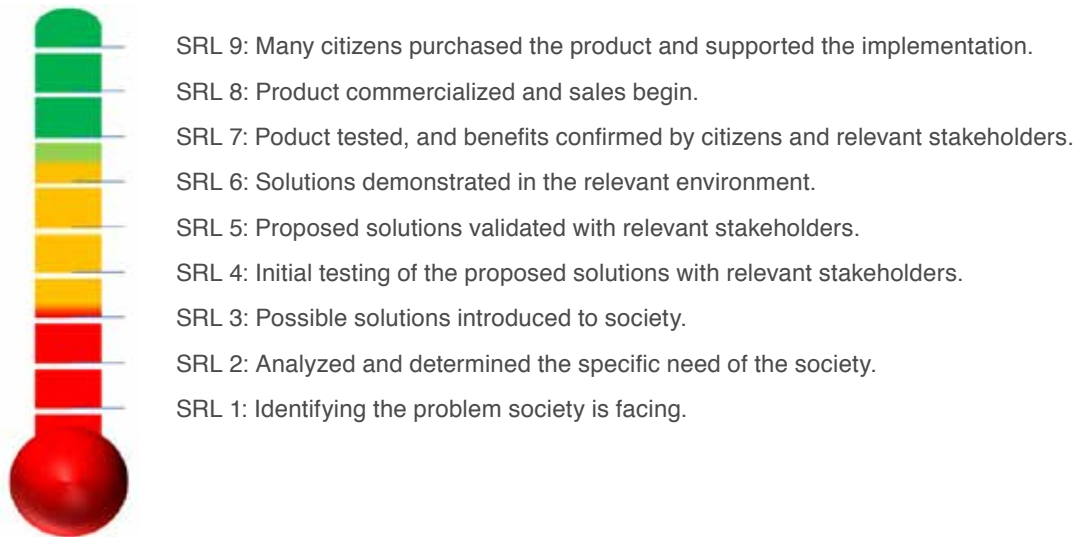


Figure 6: Societal Readiness Levels (Büscher & Spurling, 2019)

The table below provides a detailed description of the nine societal readiness levels.

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

Table 3: Description of societal readiness levels (Büscher & Spurling, 2019)

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.

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 7** demonstrates all nine levels of ERL.

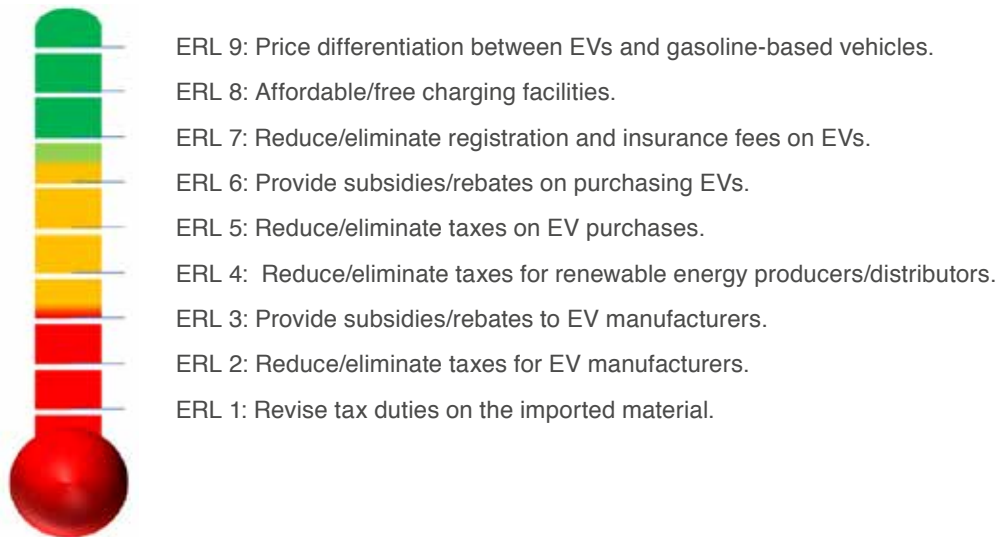


Figure 7: Economic Readiness Levels (Bhatti et al., 2022)

The table below provides a detailed description of the nine economic readiness levels.

ERL	Description
9	The EVs' purchasing and operational costs become equal to or less than gasoline-based vehicles.
8	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.
7	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.
6	The government provides extra support to encourage citizens to buy EVs by offering subsidies and rebates.
5	The government reduces/eliminate taxes on EV purchase for citizens to control the initial cost of EVs.
4	The government also supports renewable energy providers by eliminating/reducing taxes for those who provide energy to the EV infrastructure.
3	The government provides extra support to encourage automotive manufacturers to produce electric vehicles by offering subsidies and rebates.
2	The government reduces/eliminates taxes for companies producing electric vehicles and charging equipment.
1	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.)

Table 4: Description of economic readiness levels (Bhatti et al., 2022)

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.

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.

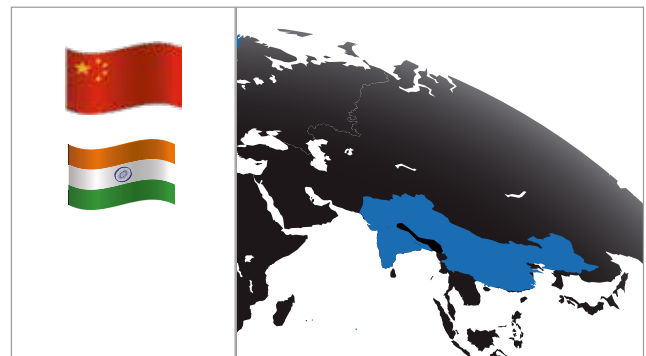


ASIA

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 auto-



motive 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 passenger 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 has a strong position in electric vehicles and battery manufacturing and market size, and Japan and South Korea are strong in automotive batteries technology and manufacturing. 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 8 represents the readiness positioning of China and India in the electrification of transportation systems.

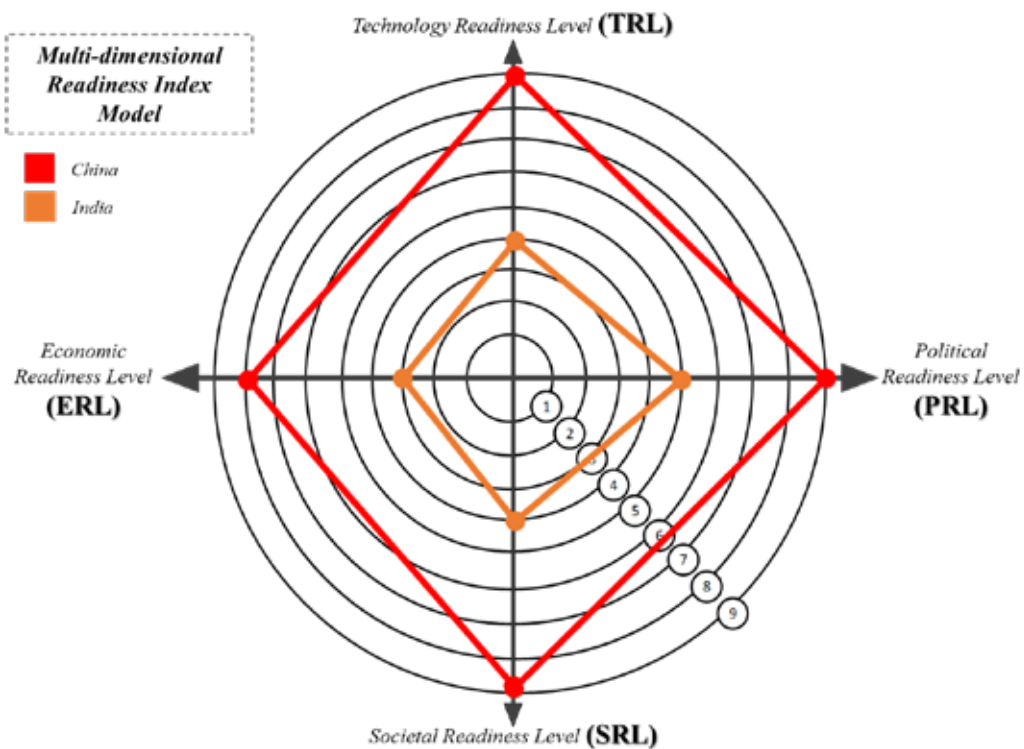


Figure 8: Multidimensional readiness index of China and India (Authors)

Figure 8 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.



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 2009, China was the home of the world's largest internal combustion engine (ICE) vehicle market, and within ten years, in 2019, China had the largest electric car fleet of 47% 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 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 9 shows that 59.5% of the population prefer to use automobiles for commuting from one place to another (Cox, 2019).

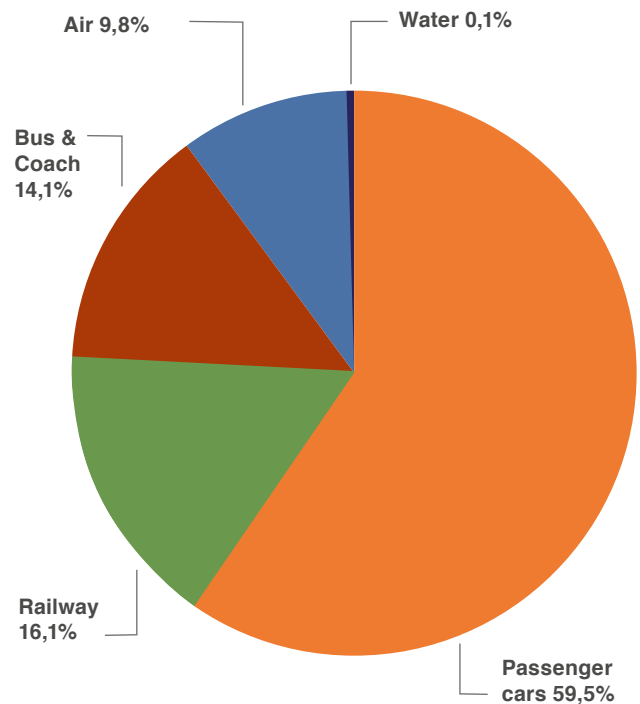


Figure 9: Different modes of transportation in China in 2019 (Cox, 2019)

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.

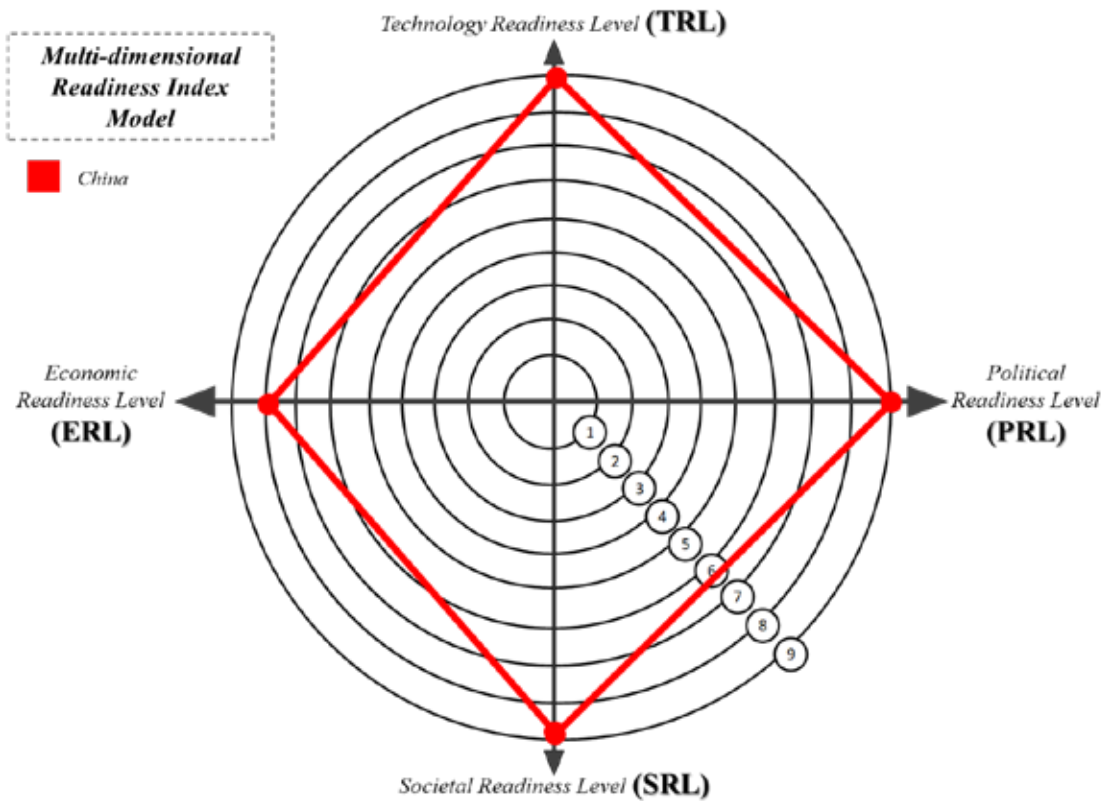


Figure 10: Multidimensional readiness index model of China (Bhatti et al., 2022)

Figure 10 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 10 represents the multidimensional readiness index model of China. Each level of readiness is analyzed below in the subsections.

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 11**.

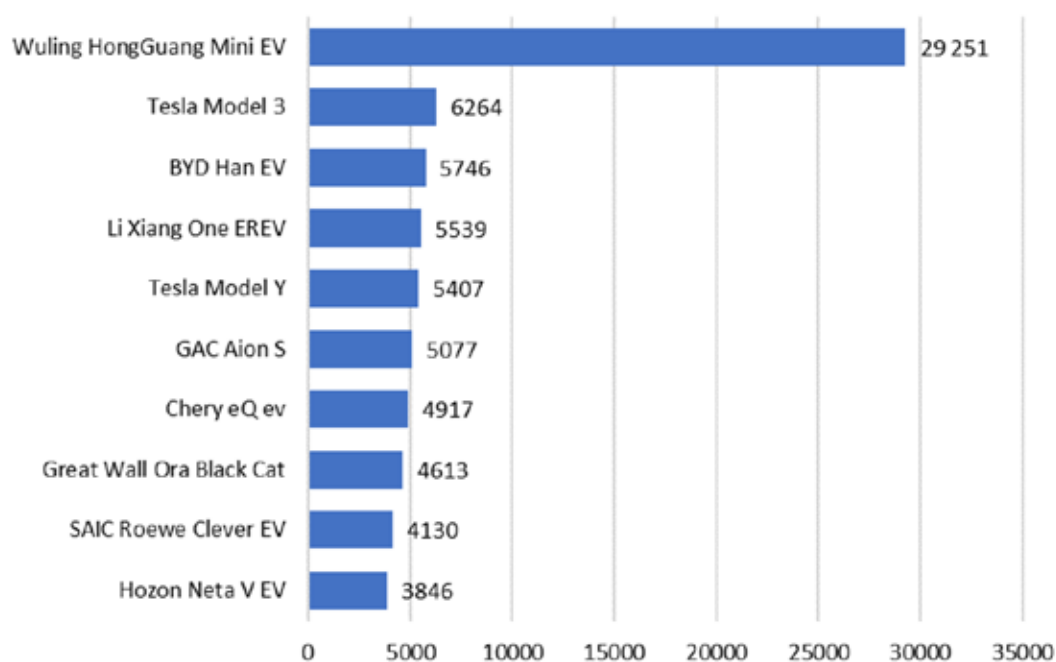


Figure 11: Top 10 selling brands and their sales of EVs in China in April 2021 (Kane, 2021b)

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 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 provinces and 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 12** (next page).

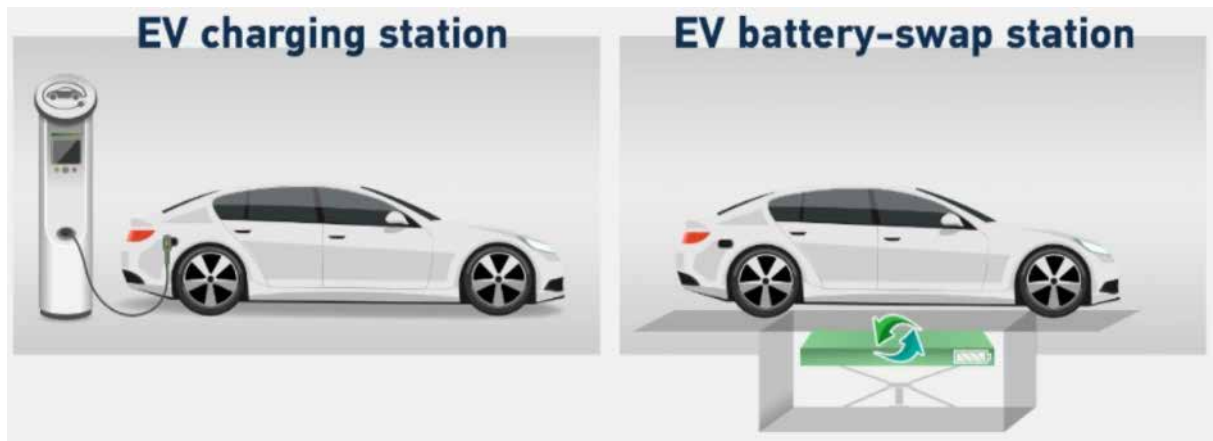


Figure 12: Patterns of Charging Electric Vehicles (Tianyu, 2020)

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.



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.

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 13** 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).

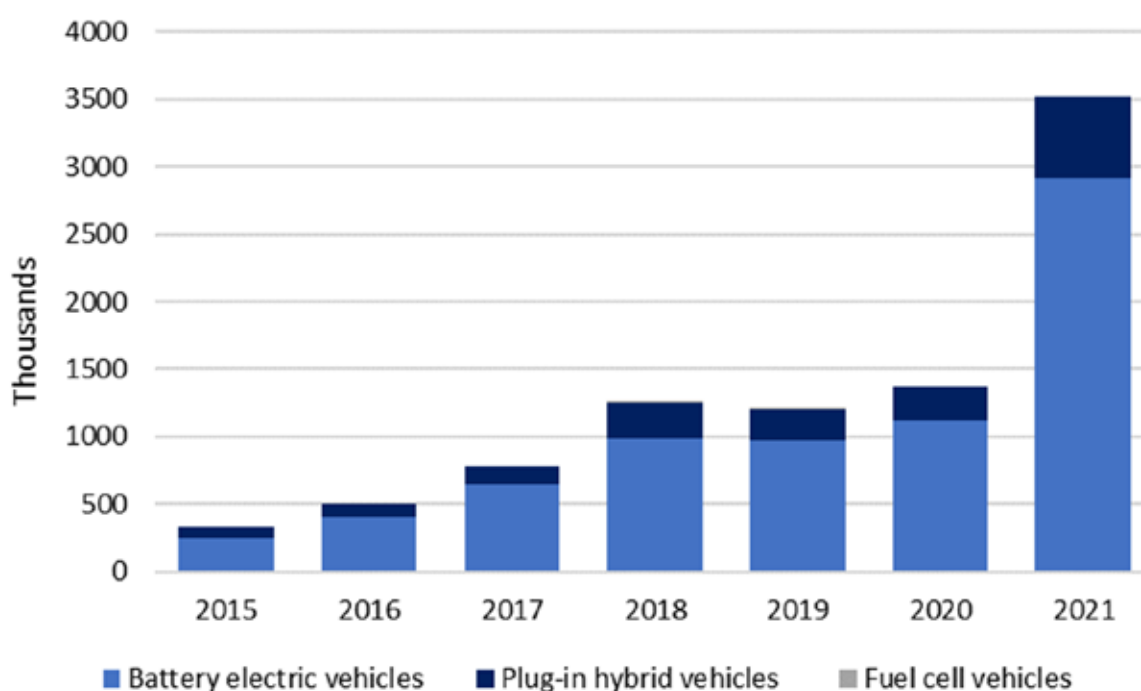


Figure 13: Annual sales of EVs in China from 2011 – 2021 (Wong, 2022)

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. 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.

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.



 **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 14**.

Figure 14 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

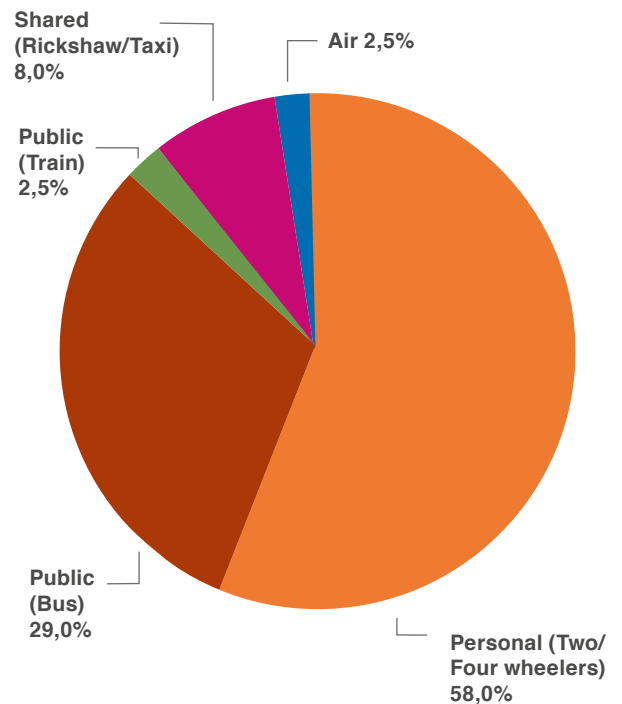


Figure 14: Different mode of transportation in India in 2018 (Sun, 2021e)

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 15 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.

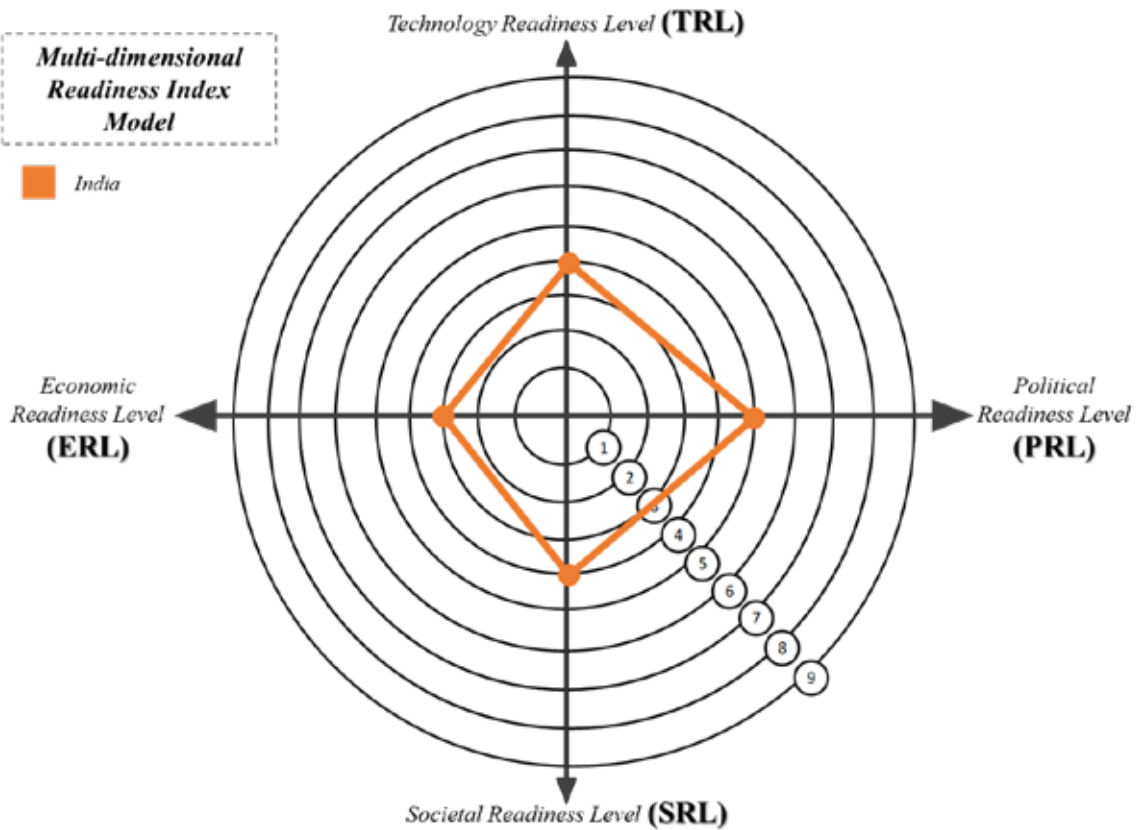


Figure 15: Multidimensional readiness index model of India (Authors)

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 16**.

Figure 16 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.

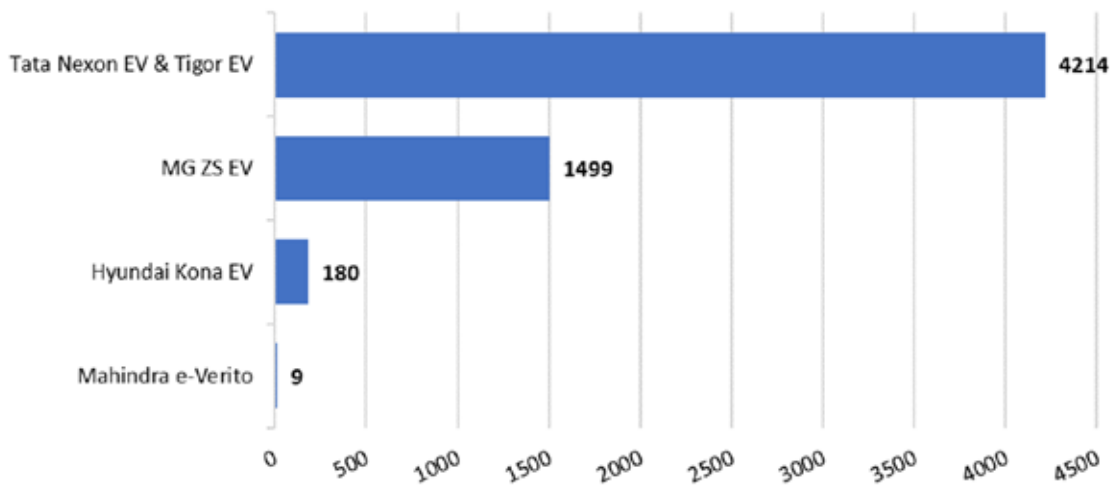


Figure 16: Top 4 selling brands and their sales of EVs in India in the financial year of 2021 (Sun, 2021c)

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 17**.

India’s top two-wheelers electric manufacturers are Hero Electric, Okinawa, Ampere, Ather Energy, Revolt Intellicorp, 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.

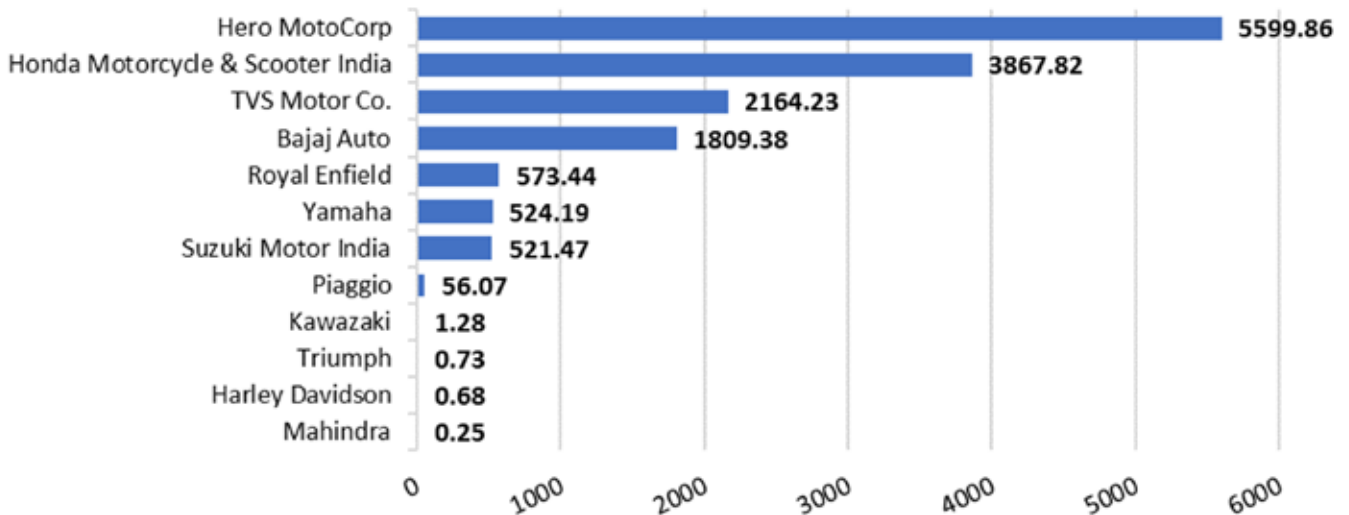


Figure 17: Top 12 selling brands and their sales of two-wheelers in India in 2021 (Sun, 2021f)

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.

Vehicles	Battery size (kWh)	Subsidy offered (\$)	Total subsidy (\$)
Two-wheeler EV	2	131	263
Three-wheeler EV	5	131	657
Four-wheeler EV	15	131	1,972

Table 5: Incentives available for EV buyers under FAME-II scheme (Saif, 2021)

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 18** represents the sale of battery-operated vehicles of two, three, and four-wheelers.

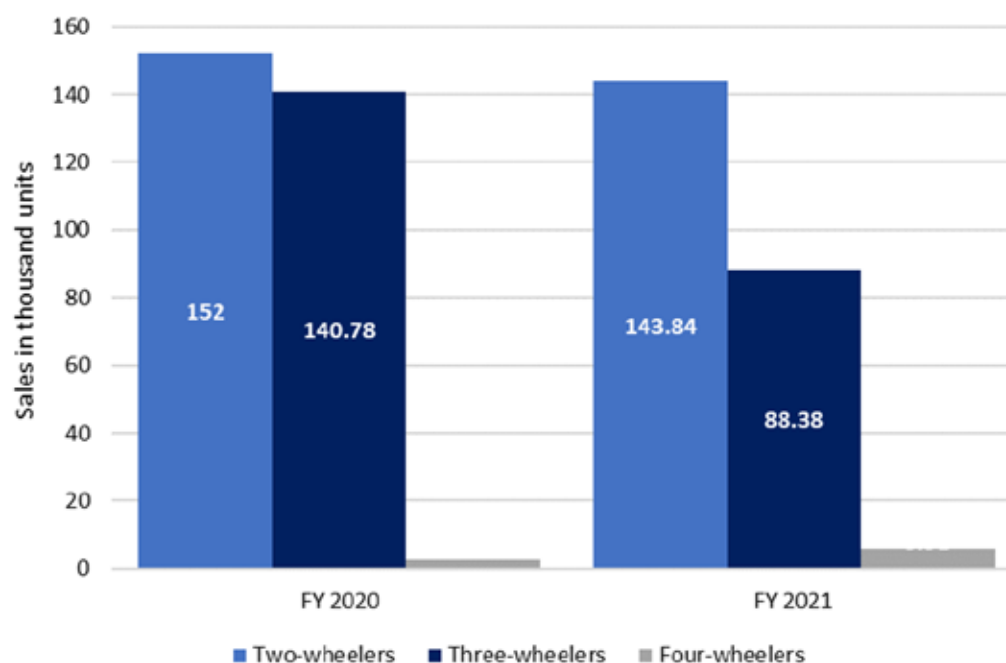


Figure 18: Sales of electric vehicles in India 2020 – 2021 (Sun, 2021d)

Figure 18 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.

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.

Particulars	Electric Two-wheelers	Petrol Two-wheelers
Vehicle price	\$ 1,510	\$ 1,102
Lifespan	10 years	10 years
Annual maintenance + insurance	\$ 39	\$ 56
Amortized annual battery cost	\$ 99	\$ 0

Table 6: Cost comparison of electric and petrol two-wheelers (Sun, 2021a, 2021b)

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.



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 19** represents the most common mode of transportation in Australia.

Figure 19 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).

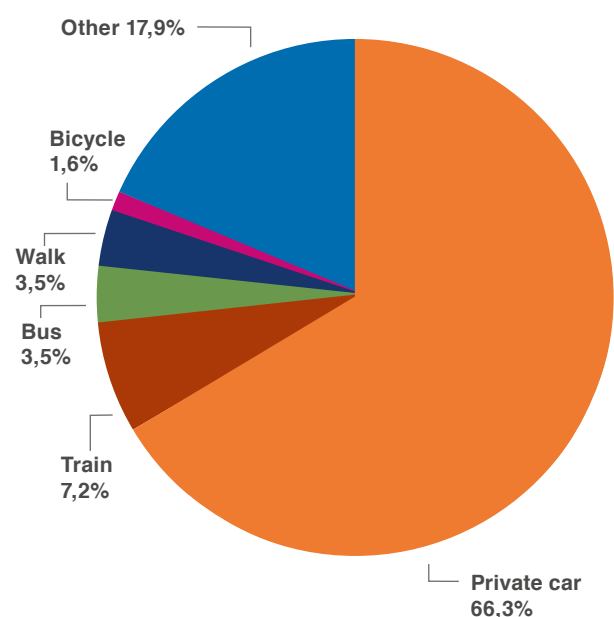
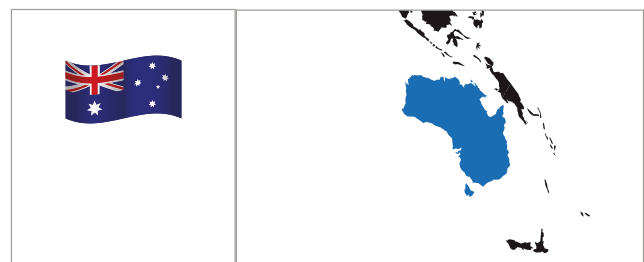


Figure 19: Modes of transportation in Australia in the year of 2016 (Australia, 2016)

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 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 20 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.

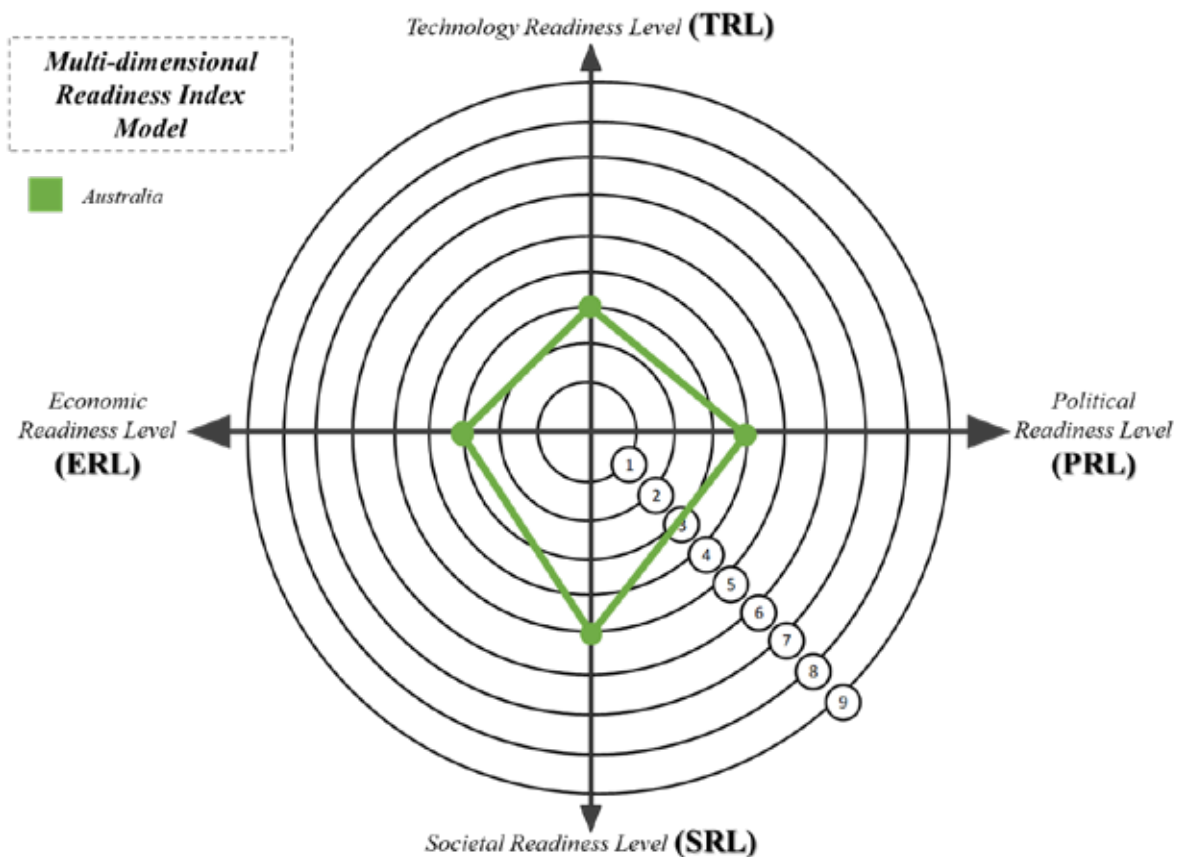


Figure 20: Multidimensional readiness index model of Australia (Authors)

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 21**.

Figure 21 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).

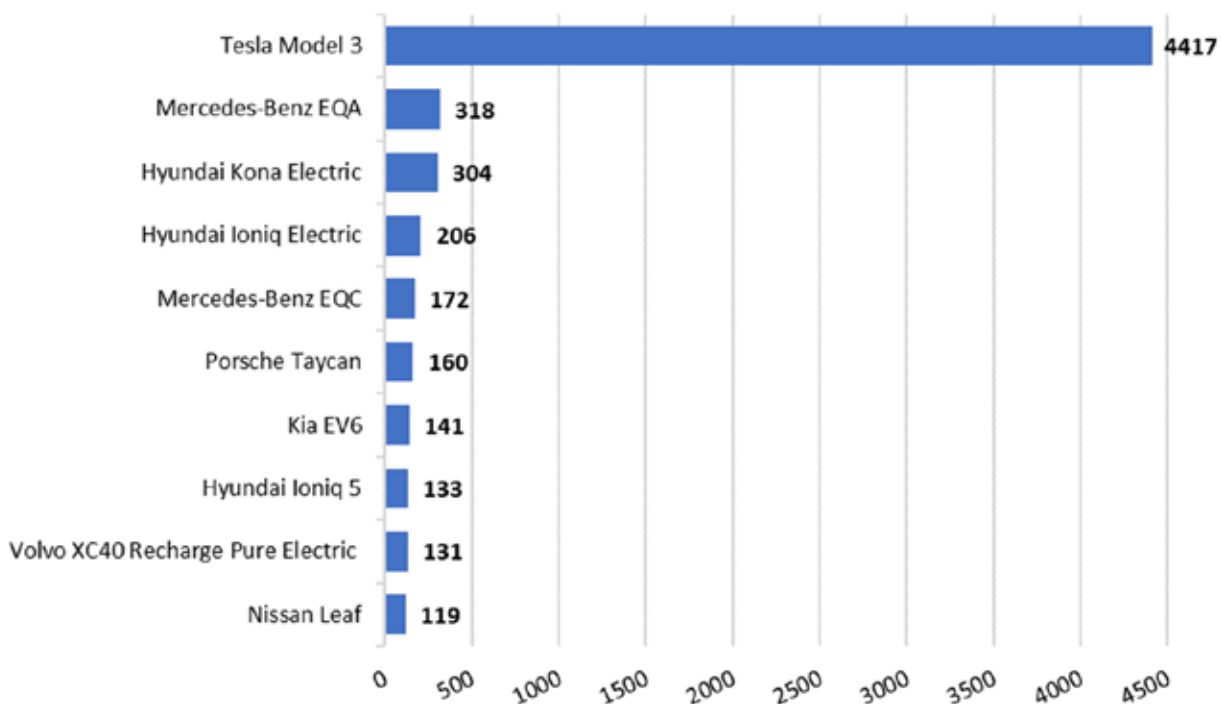


Figure 21: Top 10 selling brands and their sales of EVs in Australia from January - March 2022 (Misoyannis, 2022)

In Australia, there are several electric scooters suppliers such as Fonzarelli, Bzoma, 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 22** represents the charging stations distributed in various states of Australia.

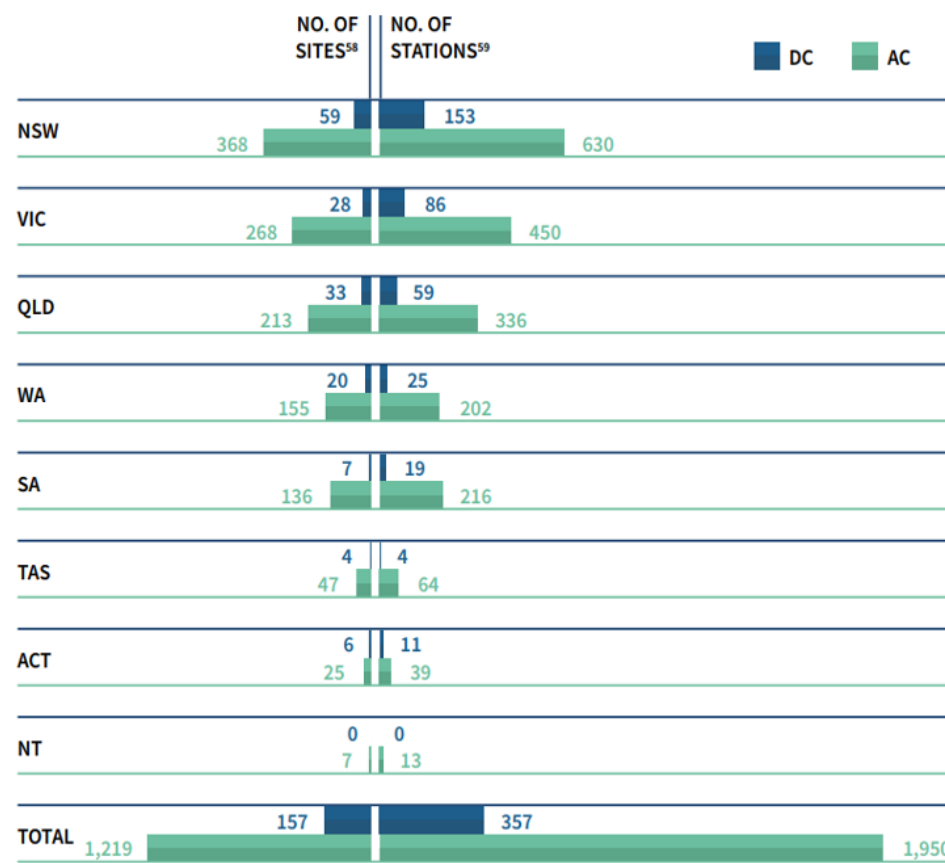


Figure 22: Number of charging stations in various states of Australia (E. V. Council, 2019)

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 22**. 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.

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 23**.

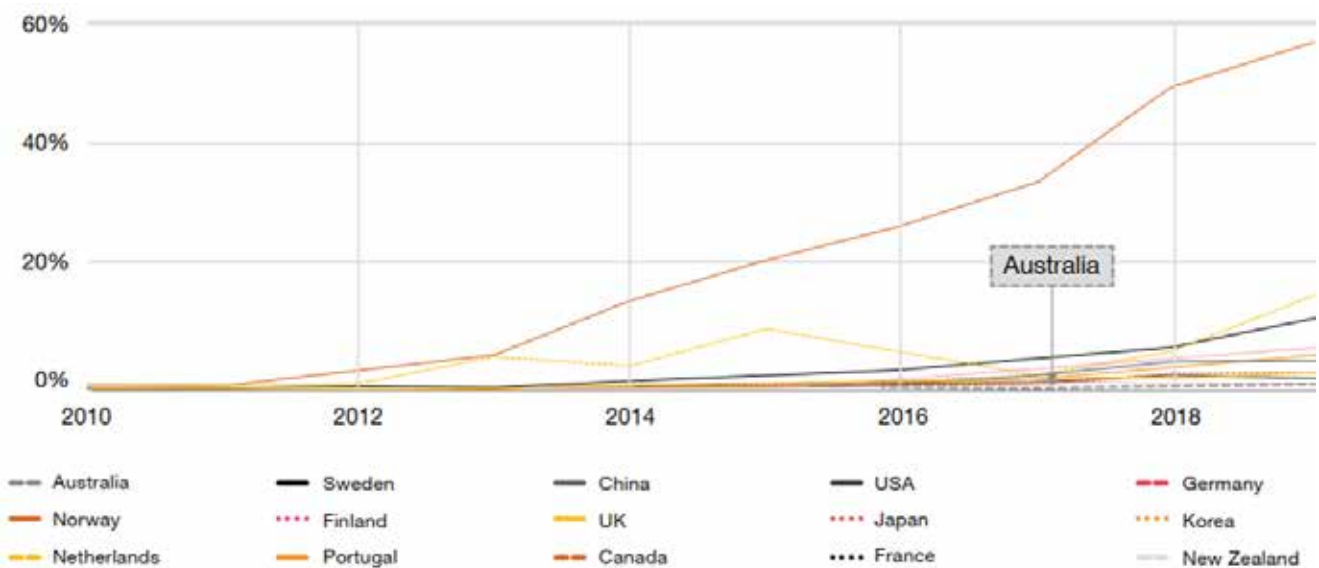


Figure 23: Australia lags behind in the adoption of electric vehicles (Outlook, 2019)

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.

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 24**.



Figure 24: Sales of Electric Vehicles in Australia from 2011 to 2019 (E. V. Council, 2020)

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 25** shows the number of electric vehicles sold during 2019 according to different states and territories of Australia.

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.

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 25**. 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.

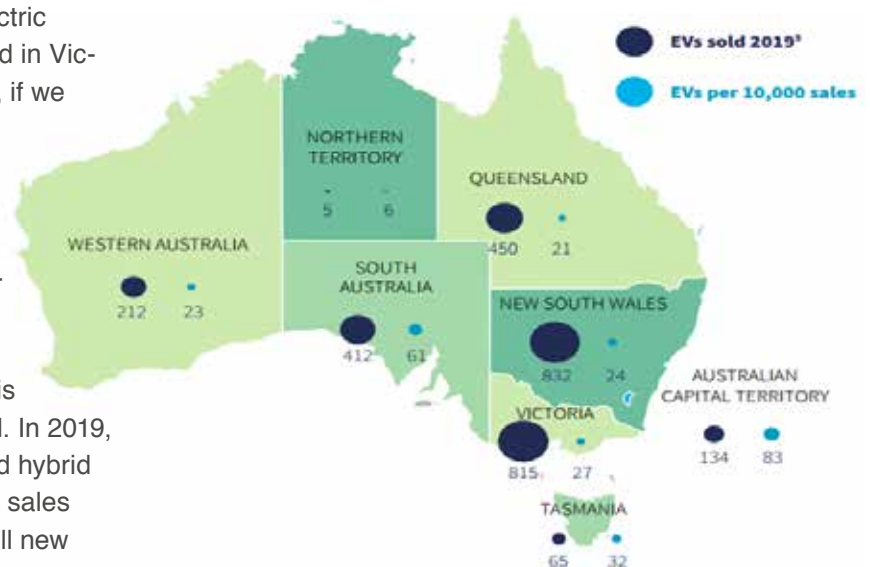


Figure 25: EVs sold in 2019 in different states and territories of Australia (E. V. Council, 2020)

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

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 26**.

Figure 26 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 multi-dimensional readiness index.

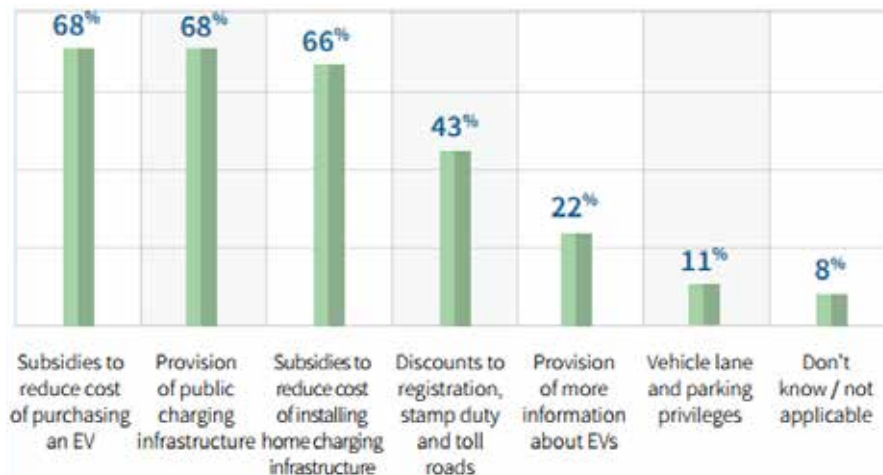


Figure 26: Survey result of Electric Vehicle Council, Australia, 2020 (E. V. Council, 2020)

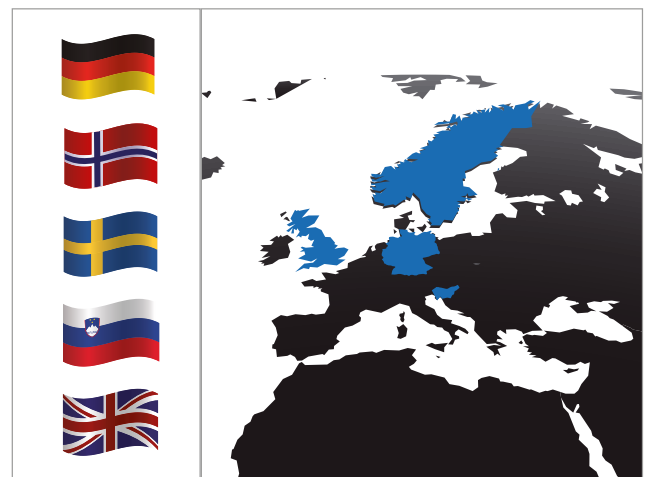


EUROPE

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 shrank 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 27 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.

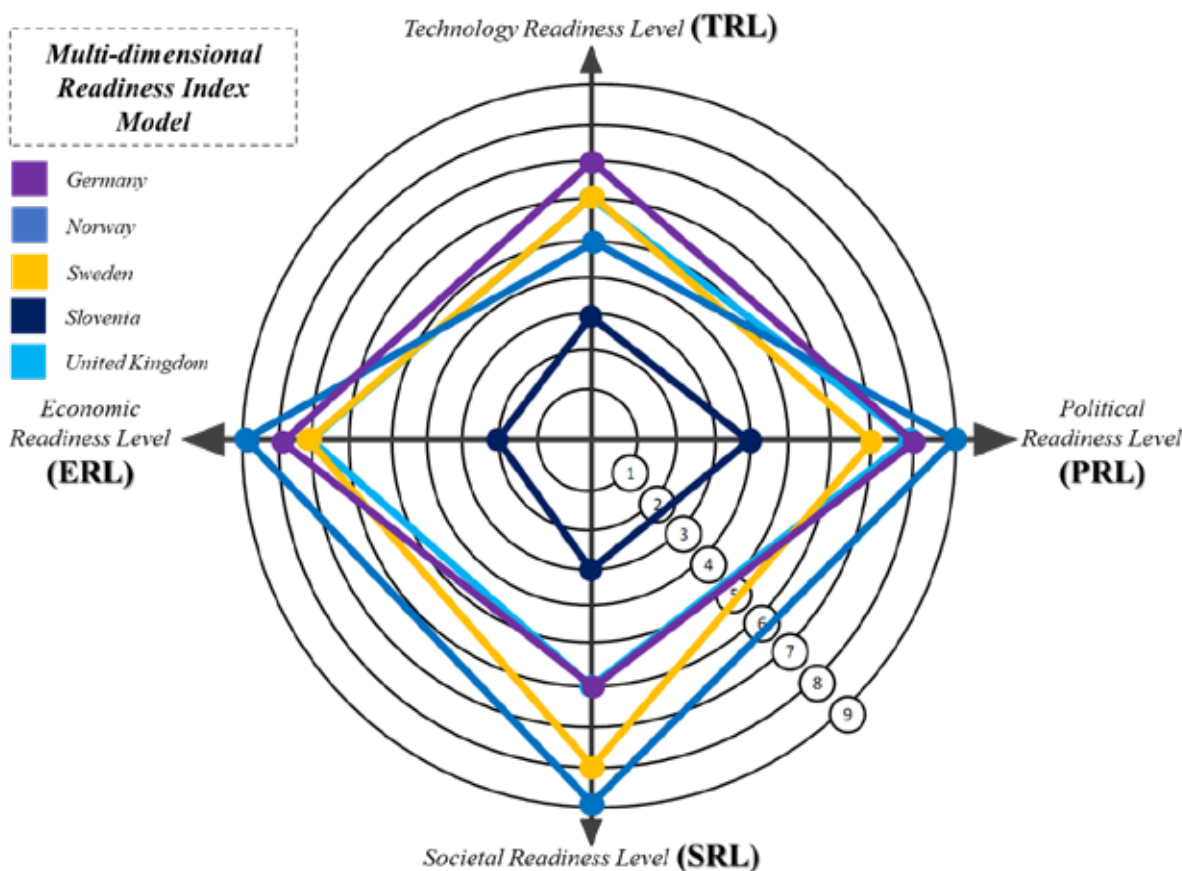


Figure 27: Multidimensional readiness index model of the selected European countries (Authors)



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 28**.

Germany has a total road network of around 643969 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.

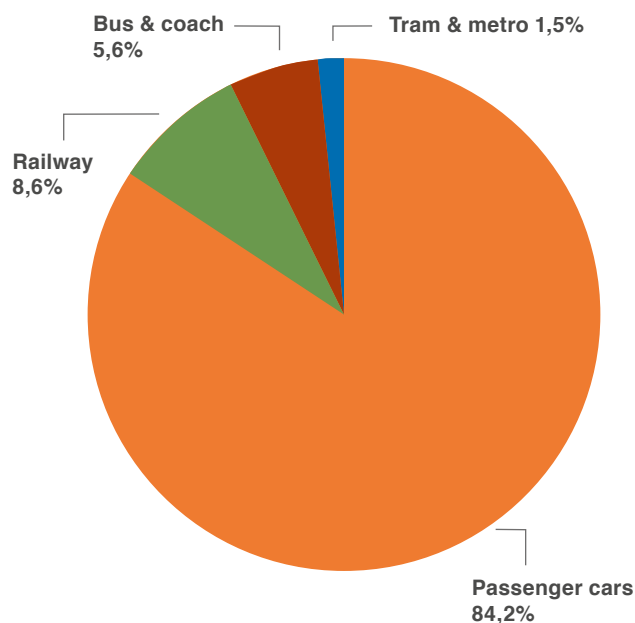


Figure 28: Most common mode of transportation in Germany in 2017 (Statista, 2020b)

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 29 shows the readiness positioning of Germany in the electrification of the transportation system.

readiness at level 8, whereas in societal readiness at level 6 in the multidimensional readiness index of electrification of the transportation system.

Based on our analysis Germany is positioned in technology readiness at level 7, political and economy

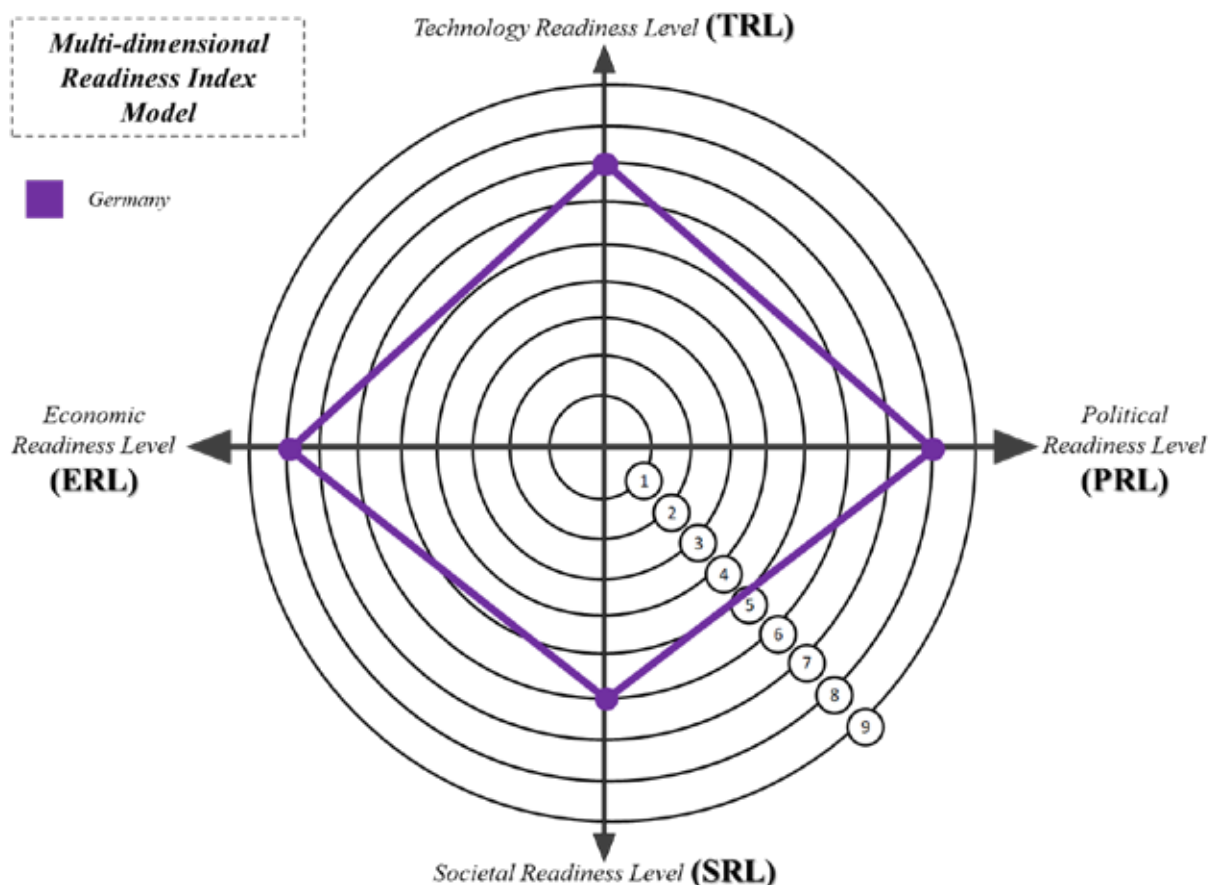


Figure 29: Multidimensional readiness index model of Germany (Authors)

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 30**.

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.

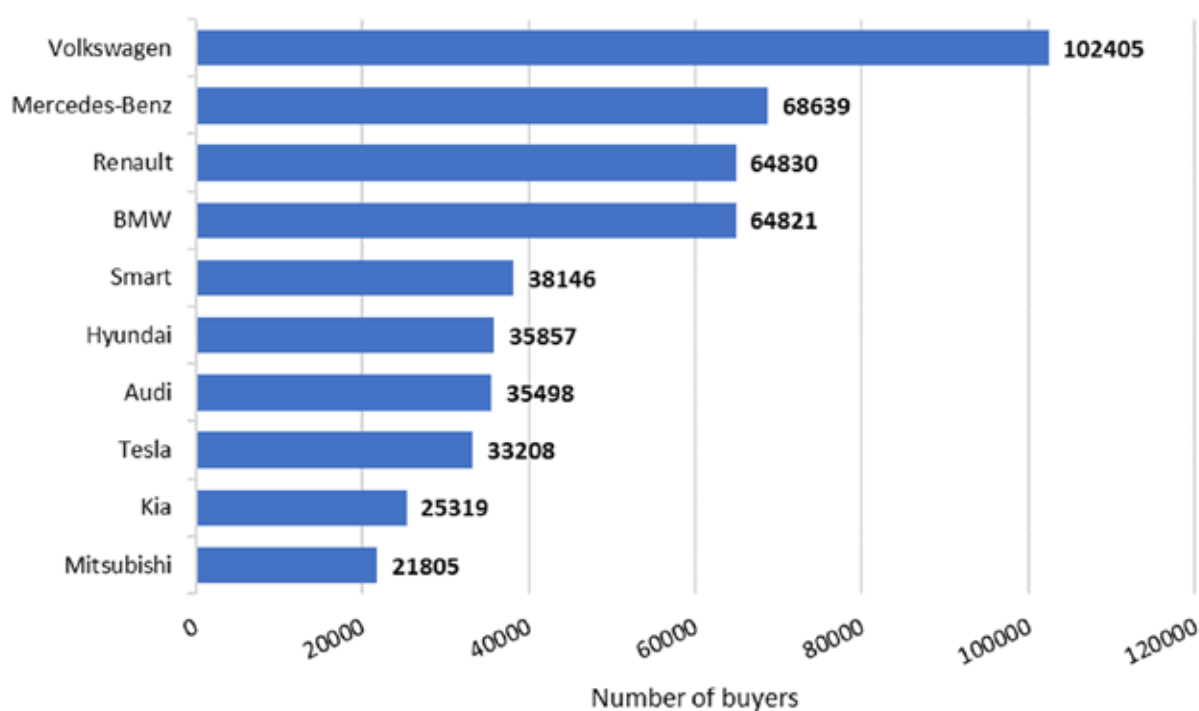


Figure 30: Top 10 electric vehicle manufacturers in Germany in 2021 (Koptuyug, 2021c)

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 (Koptuyug, 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 (Koptuyg, 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 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.

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 \$7,788), 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**.

Grants	Charging conditions
Up to €4,000 (approx. \$4153)	Per AC/DC charger of 3.7 to 22 kW
Up to €16,000 (approx. \$16,613)	Per DC fast chargers of 22 to 50 kW
Up to €10,000 (approx. \$10,383)	For low voltage
Up to €100,000 (approx. \$103,832)	For medium voltage grid connection

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.

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.

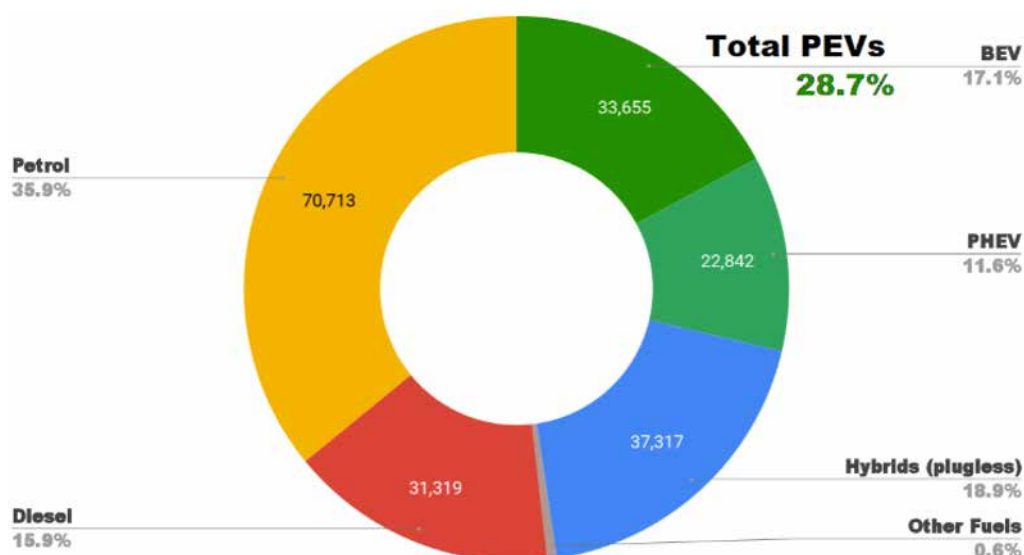


Figure 31: Registration of passenger vehicles in Germany in September 2021 (Holland, 2021)

Germany is the largest automotive market in Europe.

Figure 31 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 31 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.

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.



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 32**.

In Norway, road transportation is widespread. **Figure 32** shows that in 2021, about 88% of people traveled by cars, and 5.7% of people traveled by buses and

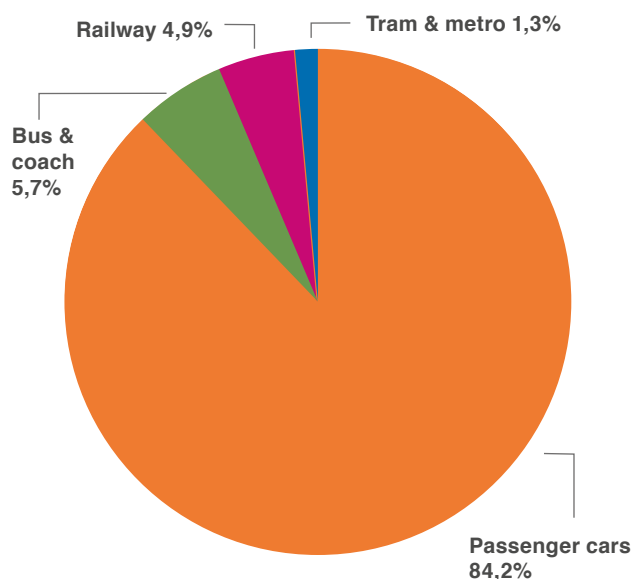


Figure 32: Most common mode of transportation in Norway in 2018 (Statista, 2021a)

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

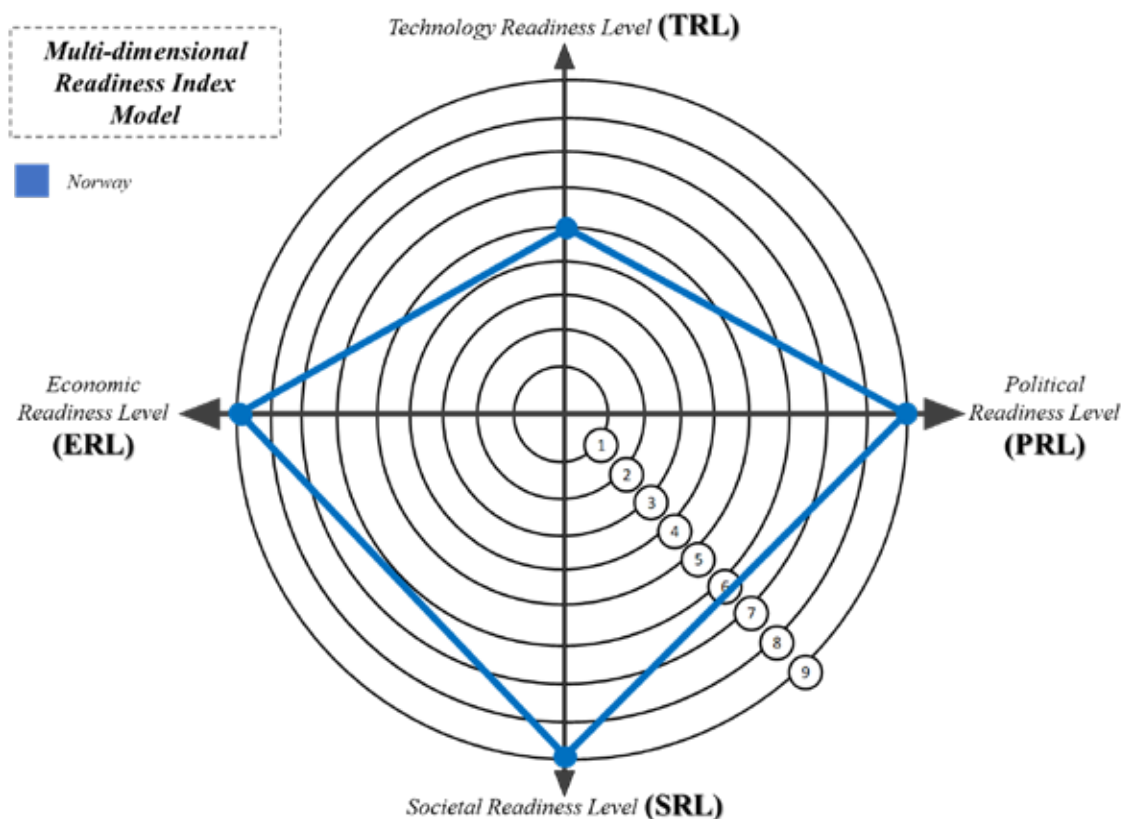


Figure 33: Multidimensional readiness index model of Norway (Bhatti et al., 2022)

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 transpor-

tation sector by exempting BEVs from taxes imposed on ICE.

Figure 33 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.

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 34**.

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.

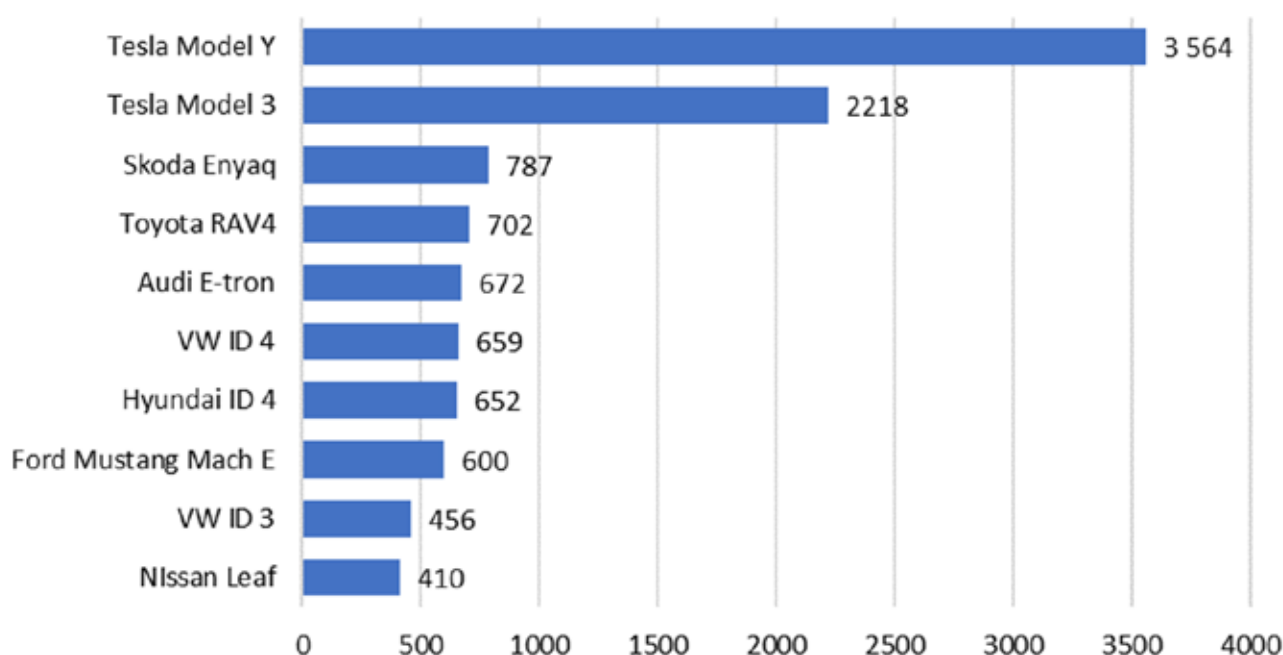


Figure 34: Top 10 selling brands and their sales of EVs in Norway in September 2021 (Kane, 2021c)

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 station 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.



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.

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.

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.



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

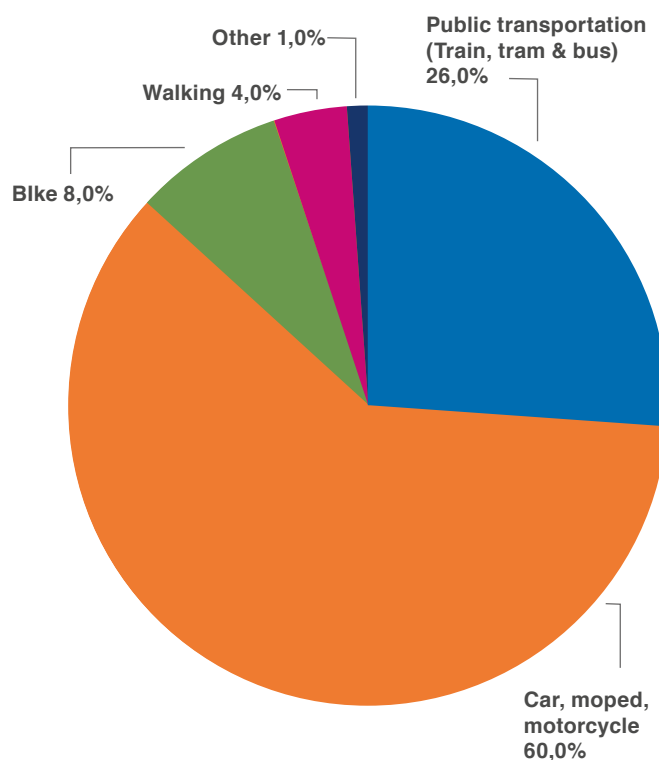


Figure 35: Most common mode of transportation in Sweden in 2019 (Wagner, 2021a)

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 35**.

Figure 35 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 36 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). 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.

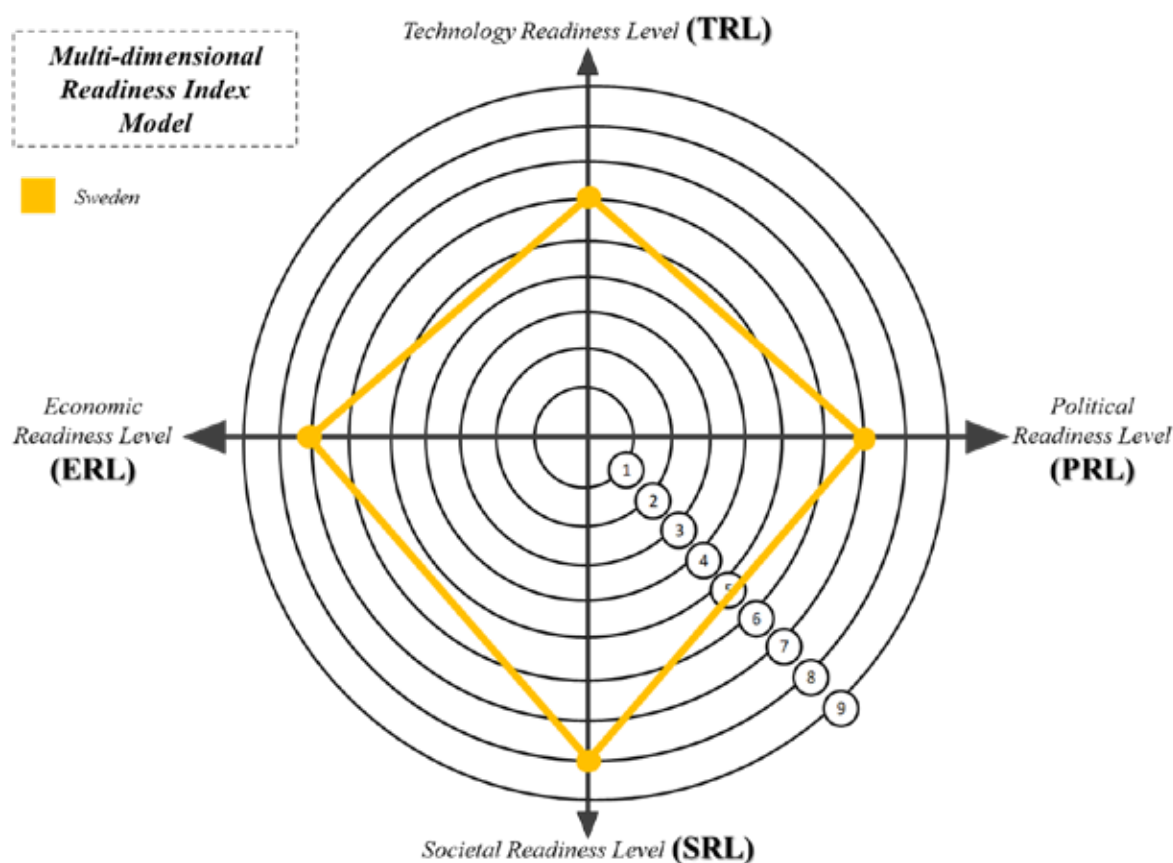


Figure 36: Multidimensional readiness index model of Sweden (Bhatti et al., 2022)

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 37**.

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).

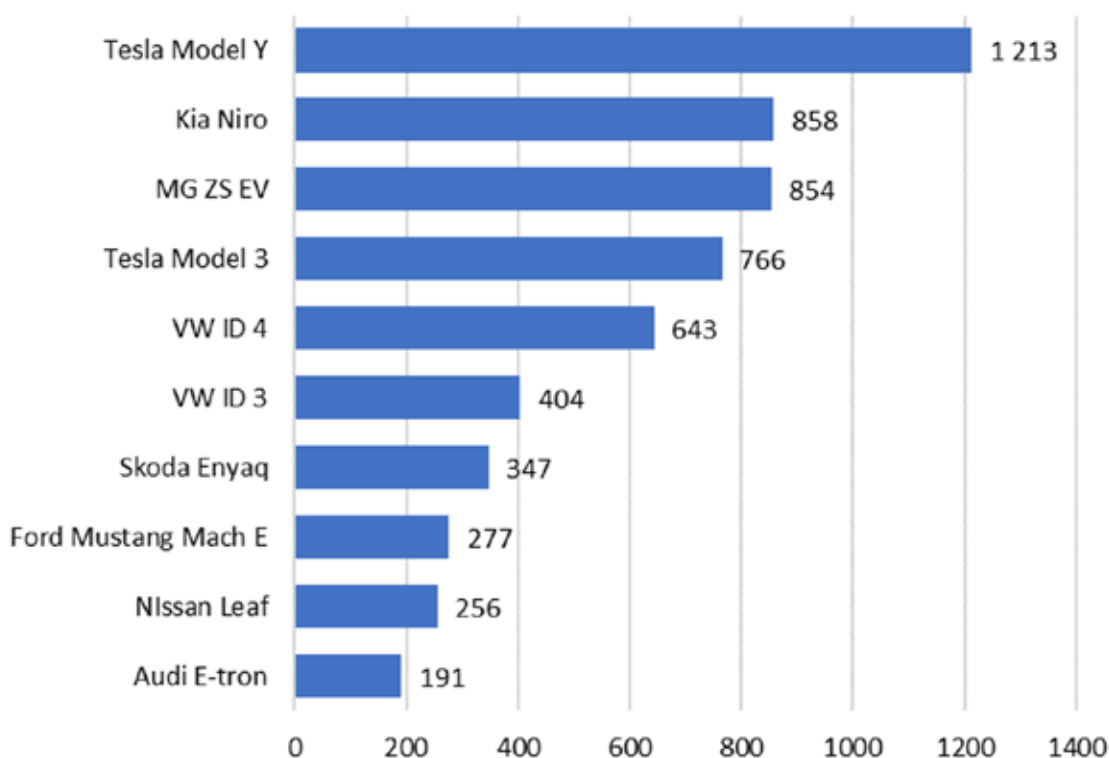


Figure 37: Top selling brands and their sales of EVs in Sweden in September 2021

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 & Näsström, 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 pur-

poses 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.

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 CO₂/100 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 CO₂ emissions of up to 60 g/km and vehicles serviced during 2020 or after with CO₂ 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.

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.

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 CO₂ 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 CO₂ 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.



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 38**.

Road transportation is very common in Slovenia. **Figure 38** 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

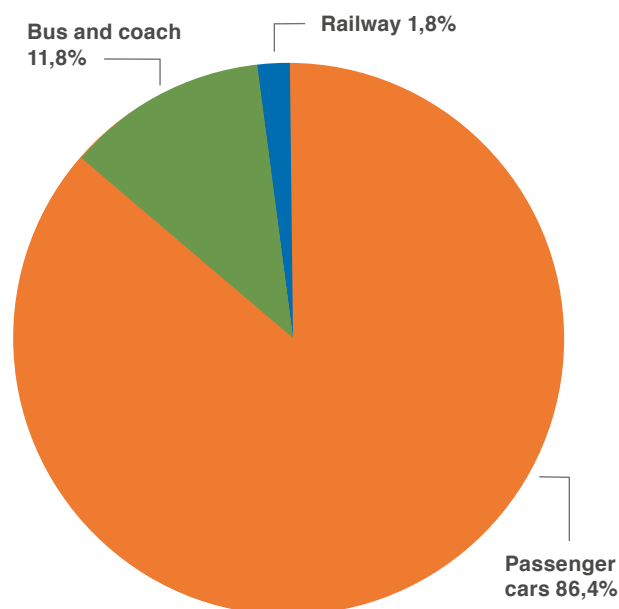


Figure 38: Most common modes of transportation in Slovenia in 2018 (Mathilde Carlier, 2022a)

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

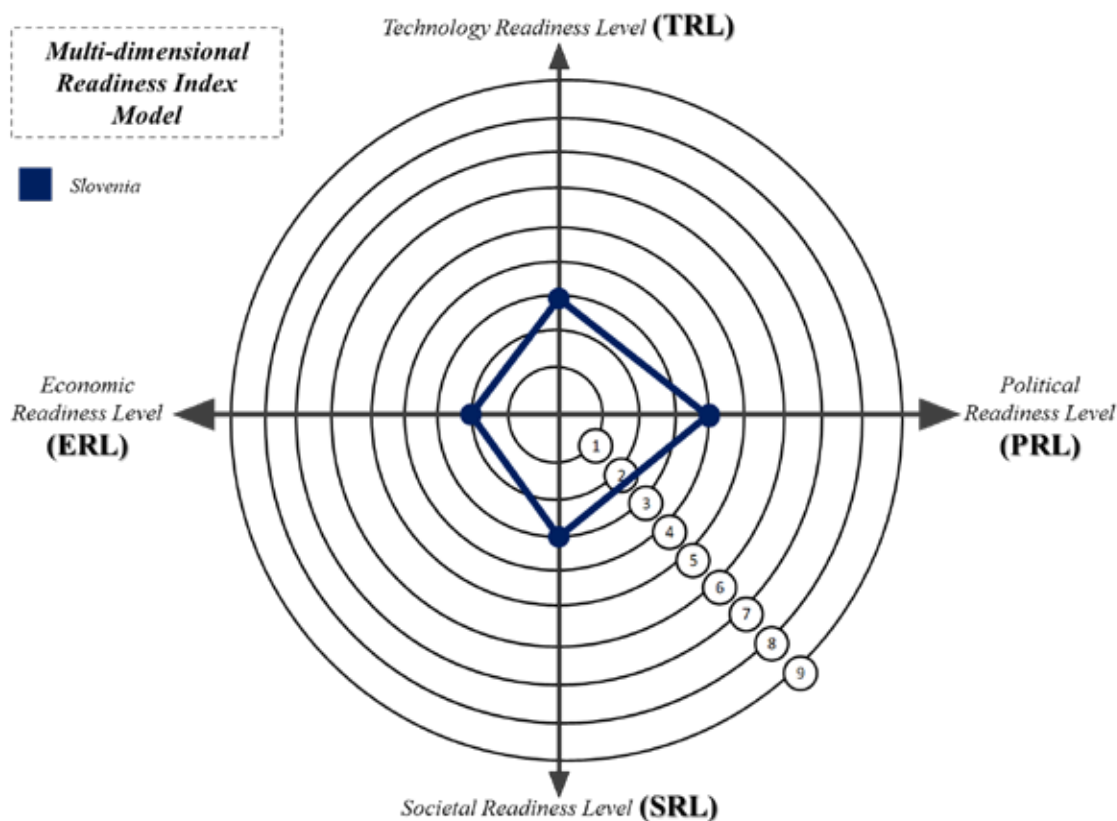


Figure 39: Multidimensional readiness index model of Slovenia (Authors)

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 39** 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.

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 40**.

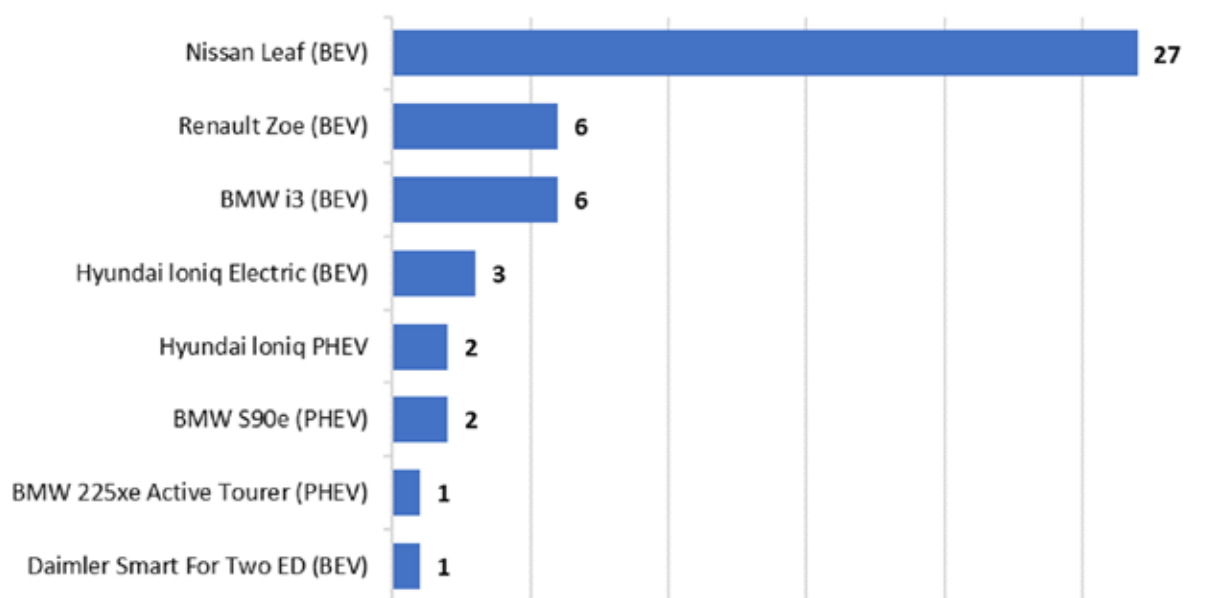


Figure 40: Top 8 selling brands and their sales of EVs in Slovenia in September 2018 (Watt, 2020)

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 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.



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 CO₂ emission. In 2016, Eco Funds increased the incentives for individ-

ual 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.

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.

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.



United Kingdom (UK)

The United Kingdom (UK) is located on the north-western 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 41**.

The UK has a total road network of about 422,100 kilometers. The road transportation is very common in the UK. **Figure 41** shows that in 2019, about 86.1%

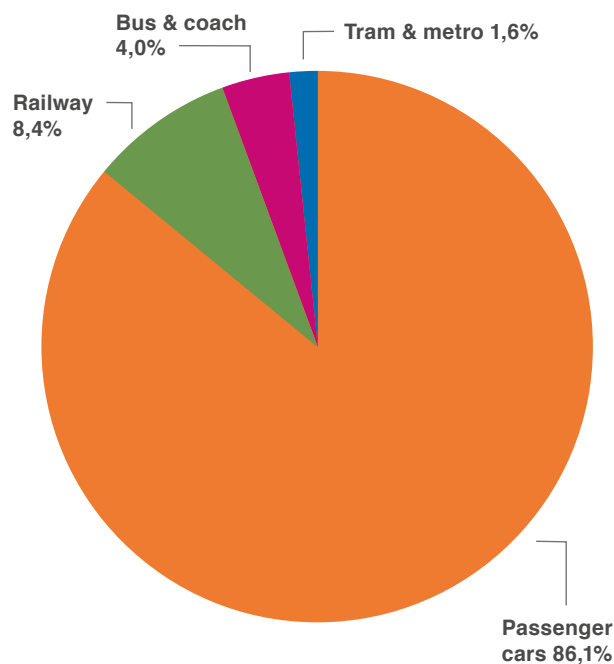


Figure 41: Most common mode of transportation in the UK in 2019 (Mazareanu, 2021)

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 42 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.

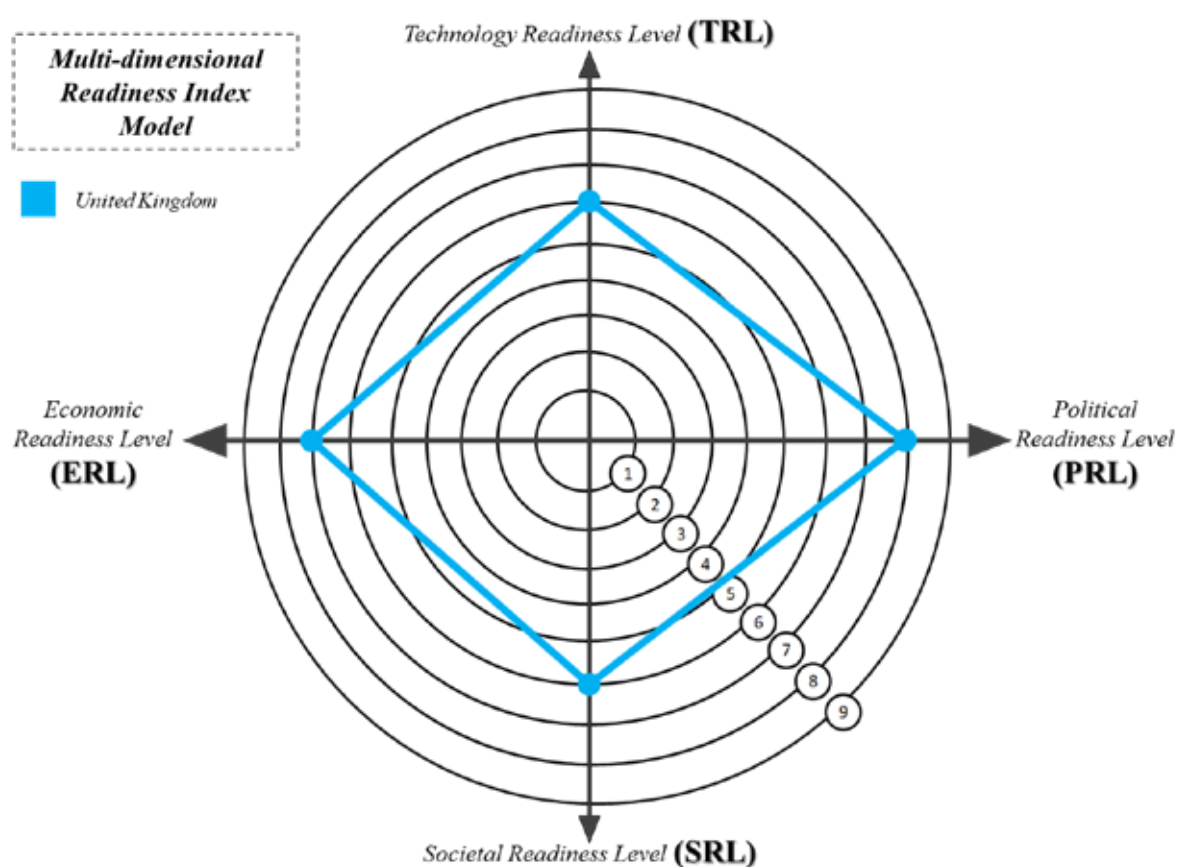


Figure 42: Multidimensional readiness index model of the UK (Authors)

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 shrunk 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 43**.

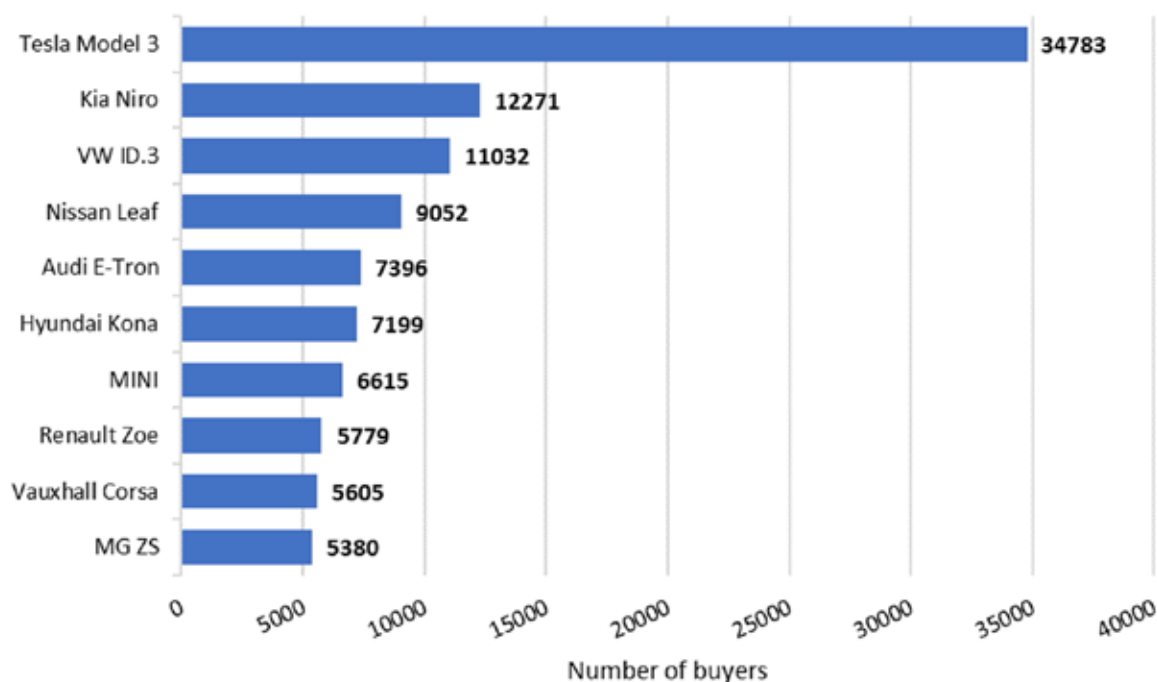


Figure 43: Top 10 electric vehicle sales in the UK in 2021 (Herincx, 2022; Phillips, 2022)

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 (R. D. Statista, 2022). 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.

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 vehicle buyers to encourage them to buy electric vehicles than the gasoline-based vehicles. **Table 8** shows the subsidy plan for the EVs buyers.

Grants	Purchase on Plug-in-Vehicles
Up to £3,000 (approx. \$3,656)	35% of the cost of an electric car
Up to £1,500 (approx. \$1,828)	20% of the cost of an electric motorcycle or moped
Up to £8,000 (approx. \$9,751)	20% of the cost of an electric van
Up to £20,000 - £8,000 (approx. \$24,378 - \$9,751)	\$ 99 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)).
Up to £7,500 (approx. \$9,141)	20% of the cost of an electric taxi

Table 8: Grants provided to the buyers on the purchase of plug-in-vehicles (GOV.UK, 2017)

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 CO₂ 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 CO₂, 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 1st, 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.

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 44**.

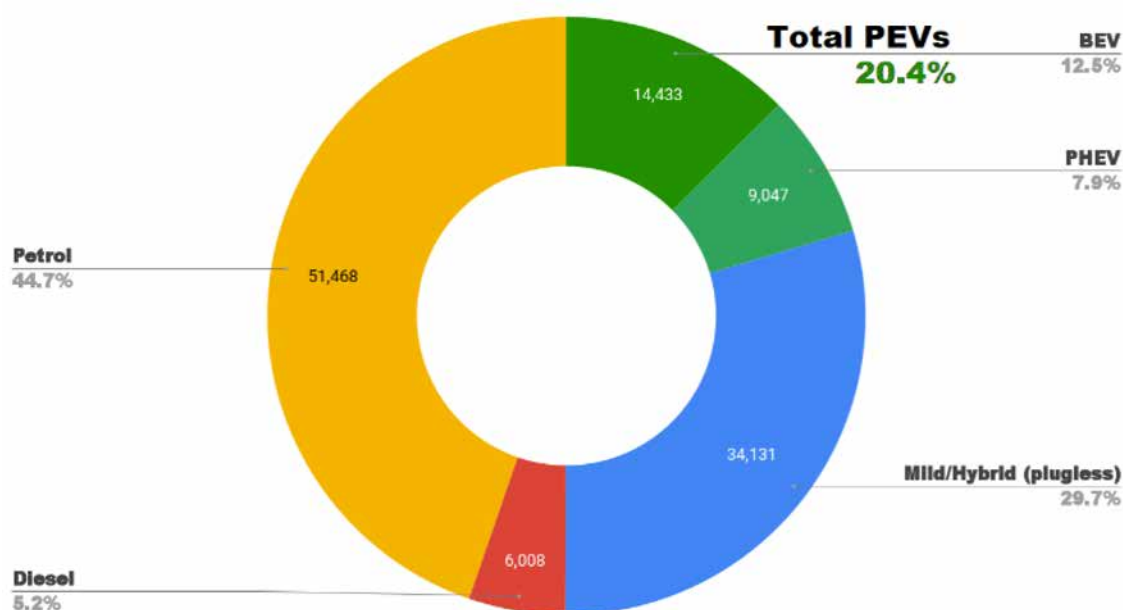


Figure 44: Registration of passenger vehicles in the UK in January 2022 (Holland, 2022b)

Figure 44 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.



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.

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 45 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 45**. 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.

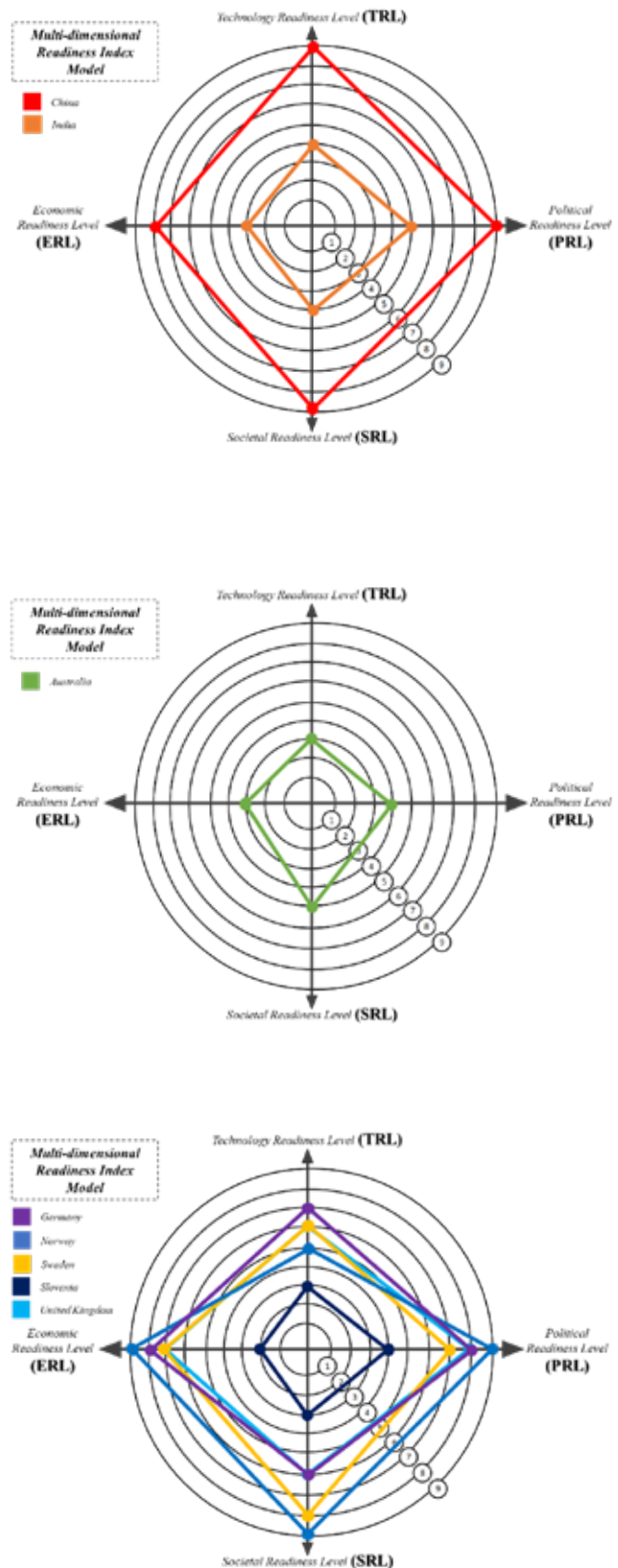


Figure 45: Multidimensional Readiness Index Model - Asia, Australia, and Europe (Authors)

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.

SCORING INDEX OF TRANSPORT ELECTRIFICATION SYSTEM FOR ASIA, AUSTRALIA, AND EUROPE						
Countries	Readiness scoring scale from 0 to 9.				Total score of each country	In Percentage (%)
	Technology	Political	Societal	Economy		
China	9	9	9	8	35	97%
Norway	5	9	9	9	32	89%
Germany	7	8	6	8	29	81%
Sweden	6	7	8	7	28	78%
UK	6	8	6	7	27	75%
India	4	5	4	3	16	44%
Australia	3	4	5	3	15	42%
Slovenia	3	4	3	2	12	33%

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 46**, which shows the eight countries' positioning in the transportation system's transformation process towards electrification.

Figure 46 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.

Countries Positioned in the Development of Transportation Electrification, 2022

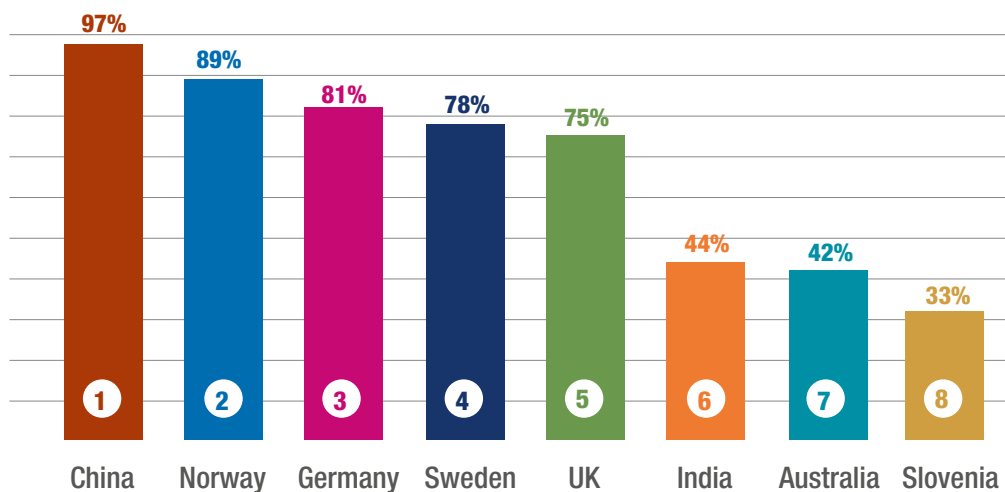


Figure 46: Countries positioned in the development of transportation electrification in the year of 2022 (Authors)

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, approximately 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.

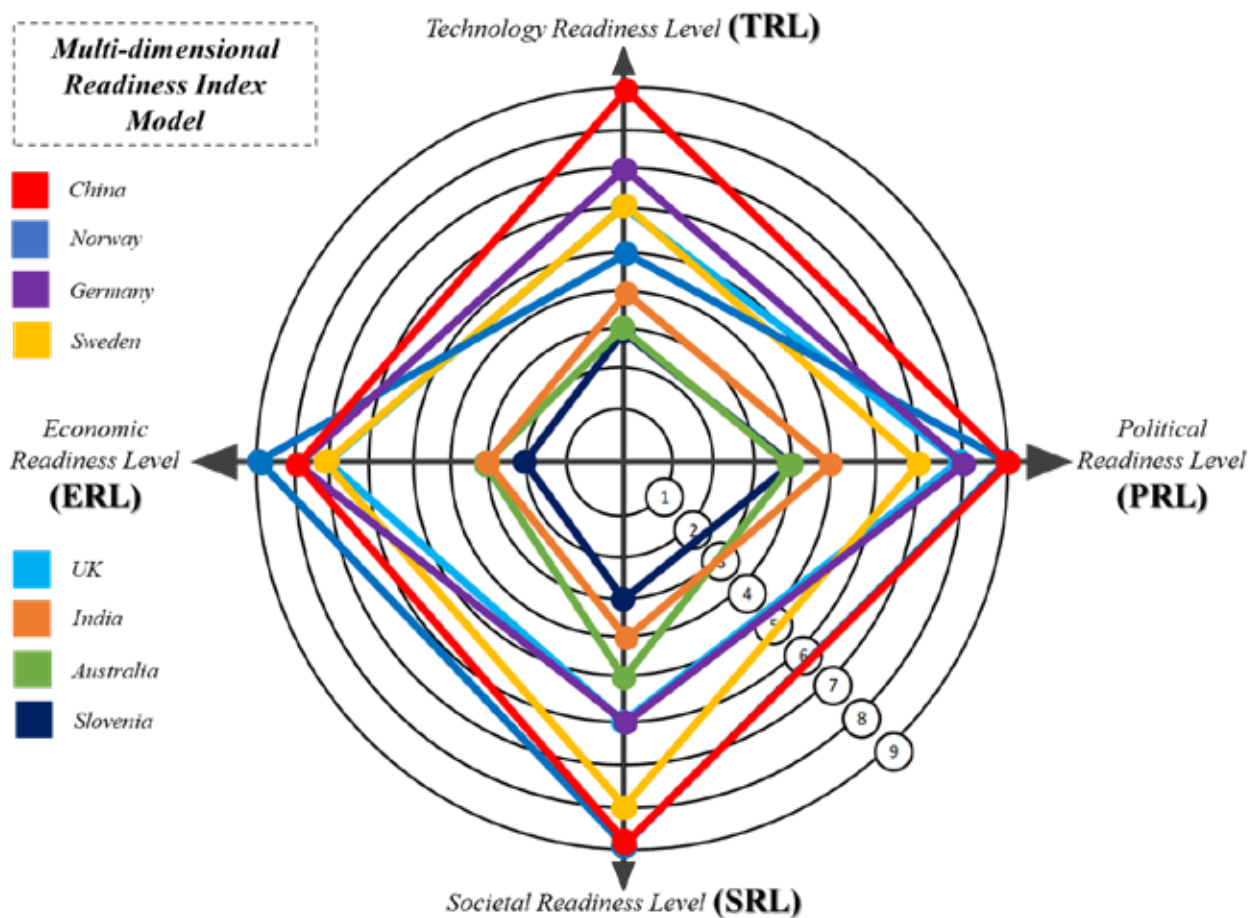
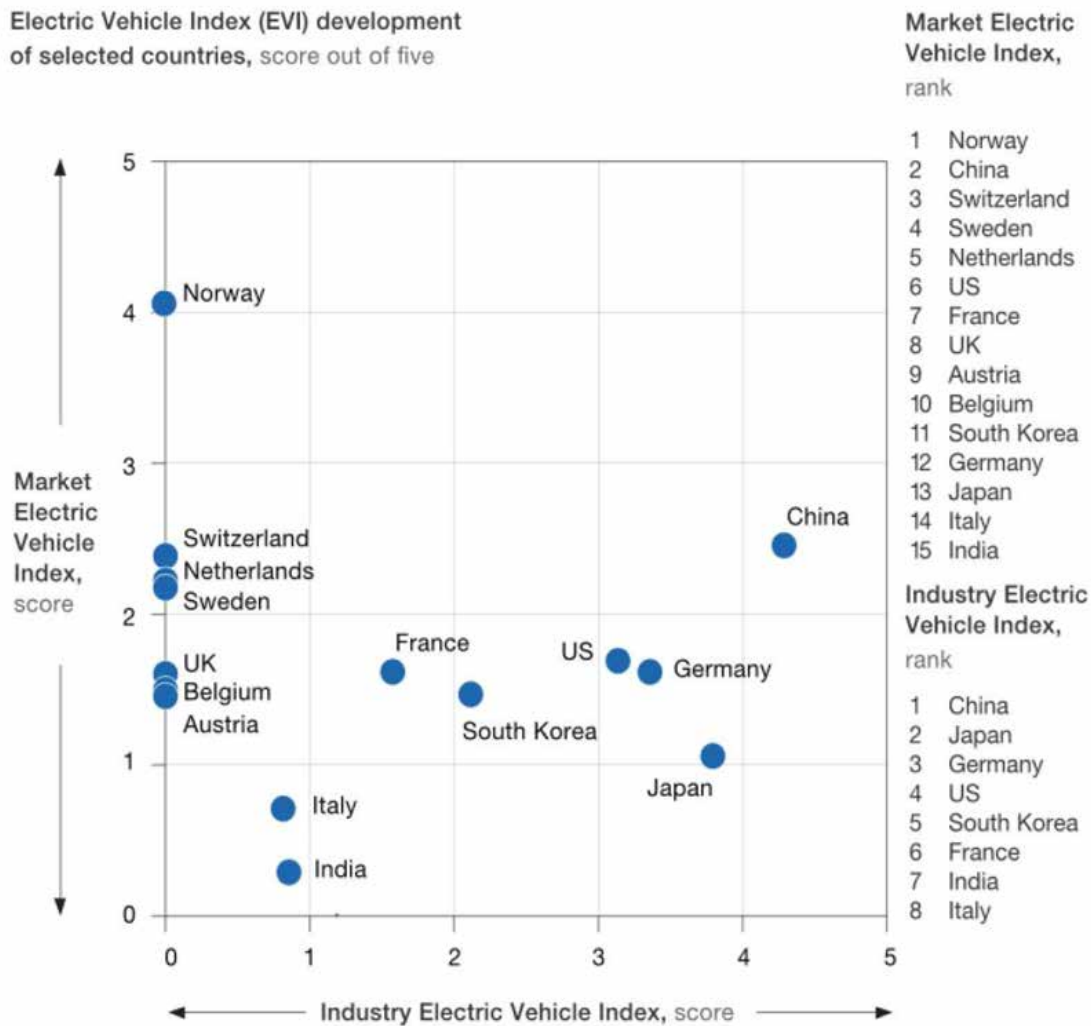


Figure 47: Multidimensional readiness index model of eight selected countries (Authors)

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 48**.



Source: [McKinsey Center for Future Mobility](#)

Figure 48: Index level of the countries developing in the electric vehicle market (Möller et al., 2019)

Figure 48 represents three main development strategies and patterns 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 48** 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 approx-

imately 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 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.

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 four countries, Australia, Norway, 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.

System Approach to Exploring the Dynamics of Electrification of Transportation

Systems approach supports managing complex systems. Systems approach advocates that problems should be seen as whole rather than in parts. Systems approach can be applied to all complex and dynamic domains such as technology, political, societal, and economic. The domain concept comes from a computer engineering perspective, 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).

or treated as an isolated technical system. Therefore, we have adopted the system approach to explore the significance of the various actors and their relationships based on their role in transforming the transportation system. However, for this purpose, we have inherited the concept of four dimensions (technology, political, societal, and economic) (Bhatti et al., 2022) but interpret the term ‘dimension’ with ‘domain’ to explore further the interdependency of the elements within and across the domains. These elements are embedded in technological, political, societal, and economic domains. These domains are interconnected and interdependent and form a whole system.

Electrification of the transportation system is not a single technological element that can be understood

Figure 49 illustrates the conceptual holistic view of the electrification of the transportation system with its various domains and elements.

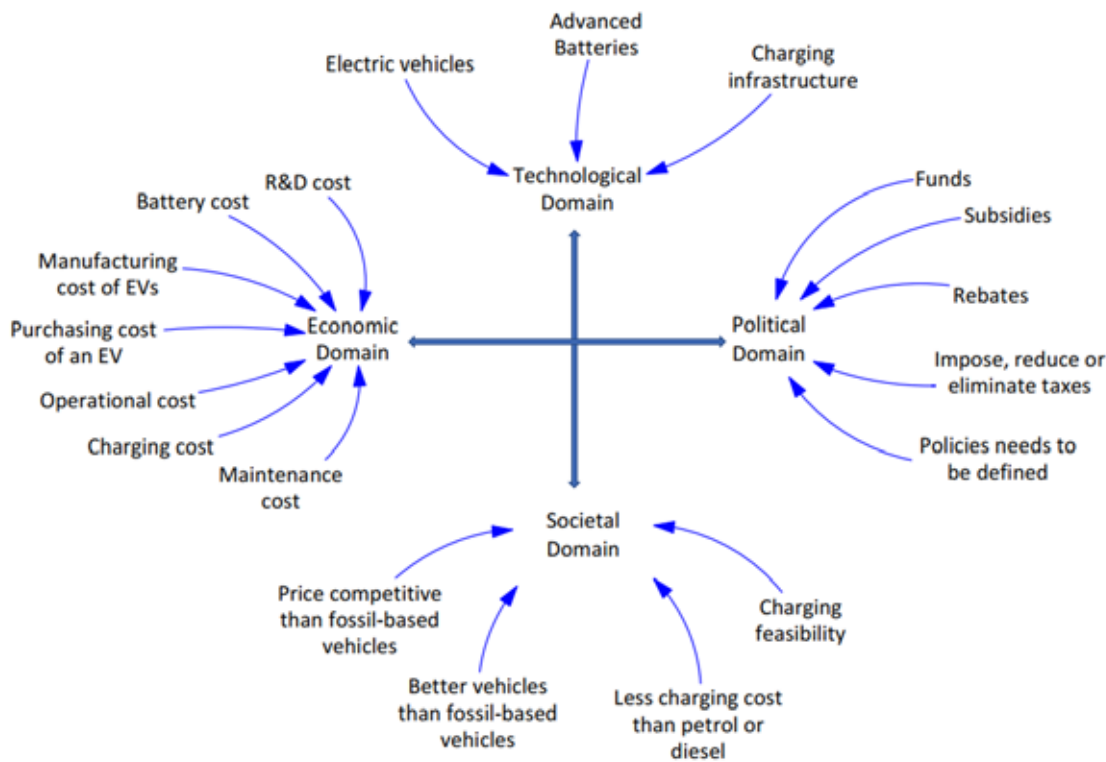


Figure 49: Elements and dimensions of transportation electrification

The old fossil-based transportation is facing transformational challenges towards electrification of transportation. Electrification of transportation is a combination of dynamic elements where fossil-powered vehicles shift towards electric vehicles. A new digitalized charging infrastructure is required to support the new transportation fleet system. The government

has to introduce new economic policies to strengthen and handle the diffusion of the new electrified transportation system. Thus, all these elements are interconnected and interdependent and require a systems approach to understand the new electrified transportation system from a holistic perspective.

The systems approach supports understanding how elements of a system influence other domains and within a domain of the entire system. It enables policymakers to design efficient policies for the smooth transition of the transportation system towards electrification and prevent the ripple effect of their policies on the other part of the system.

We have chosen the dimensions (technological, political, societal, and economic) of our multidimensional readiness index model as domains in the context of the systems approach. We have analyzed the dynamic behavior of the elements of these domains to understand the relationships among the domains and their elements within the entire system of transportation electrification.

Technological Perspective of Transportation Electrification System

The advancement of technology has revolutionized the transportation system from fossil-based to electric system and embedded various systems (energy system, information, and technology system, etc.) within a system. These systems are interconnected and interdependent on political policies, social and economic behaviors. **Figure 50** represents its fundamental relationship among the systems.

The electrification of the transportation system relies on three main elements: electric vehicles, batteries, and infrastructure from a technological perspective. These three elements are interdependent and interrelated to perform a function. However, the technology system of electrification of the transportation

is dependent on being developed and operated by the other systems (political, societal, and economic) to function according to the desired expectation. Manufacturing electric vehicles is a costly business. The manufacturing cost of electric vehicles primarily depends on buying or importing batteries. If the price of electric vehicles is higher than the cost of petrol or diesel-based vehicles, then society’s willingness to buy electric vehicles is uncertain. Therefore, the electric vehicle manufacturers are dependent on governmental policies that ensure them by providing subsidies and rebates to society to encourage vehicle buyers to buy electric vehicles or support the vehicle manufacturers by reducing or eliminating the import/export tax duties.

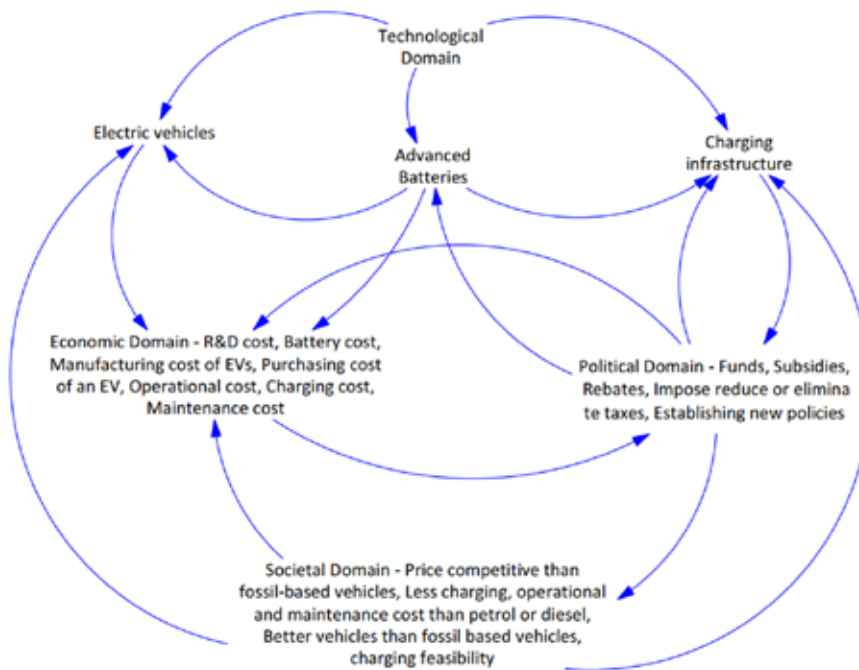


Figure 50: Relationship of various domains within the transportation electrification from technological perspective

Based on the data of the eight countries discussed above, China is the only country with a complete value chain, which means that electric vehicles and

their components and batteries and their associated materials are mined and manufactured within China. 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 electromobility manufacturers are dependent on governmental 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.

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. 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. 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. The prices of these imported electric vehicles are higher than those of fossil-based vehicles. One of the reasons is the lack of coordination between technology and political systems. The import tax duties are high, which increases the initial price of the electric vehicles compared to its 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 energy 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.

Political Perspective of 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 the transportation system is a complex system as it combines various industries such as electromobility, energy, IT, and socio-economic systems. These industries and systems work under government-influenced institutions and are dependent on government policies. The technological, political, societal, and economic systems are intertwined and function with the feedback of their dependent systems, as shown in **figure 51**.

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 51 represents the correlation and coordination with its feedback loop among the political, technological, societal, and economic domains within the whole system of transportation electrification.

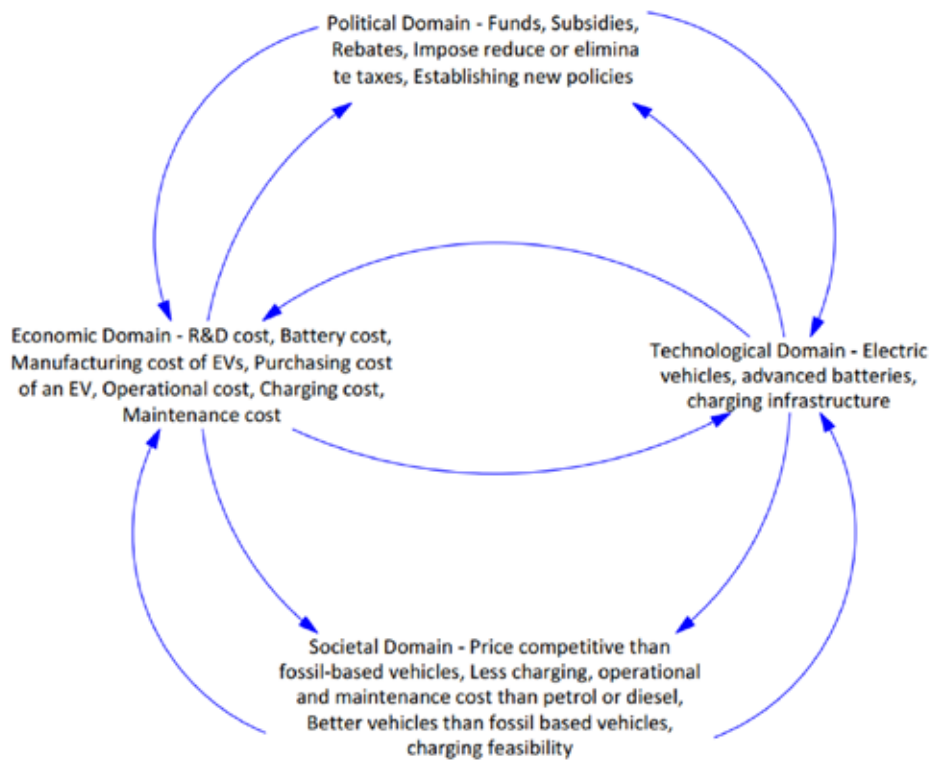


Figure 51: Relationship of various domains within the transportation electrification from political perspective

The political role is significant for the development of the society, transformation processes, and diffusion of system solutions of the transportation electrification. Without government decisiveness and support, the transformation of transportation towards electrification is complicated 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 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 energy 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. However, government policies can have an adverse effect on the other parts of the system of transportation electrification. In 2019, China dropped a 20% subsidy on electric vehicles, and the electric vehicles sale declined 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. But import 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 low 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 trans-

formation 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 an almost similar traditional approach shifting towards electrification of the transportation system. Germany is ahead of Sweden and the UK in electric vehicle manufacturing technology with its top five selling brands, including 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, the emergence of the system of transportation electrification is not according to the desired expectation in India, Australia, and Slovenia.

Societal Perspective of Transportation Electrification System

Society is a domain and a part of the entire system of transportation electrification. The diffusion of transportation electrification in society mostly depends on the four elements mentioned below based on the data of the eight countries discussed above.

- 1) the better-charging facilities,
- 2) customers demand to have better vehicles than what they already have,
- 3) electric vehicles should have a lower price than fossil-based vehicles and

- 4) lower charging and operational cost, as represented in **figure 52**.

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.

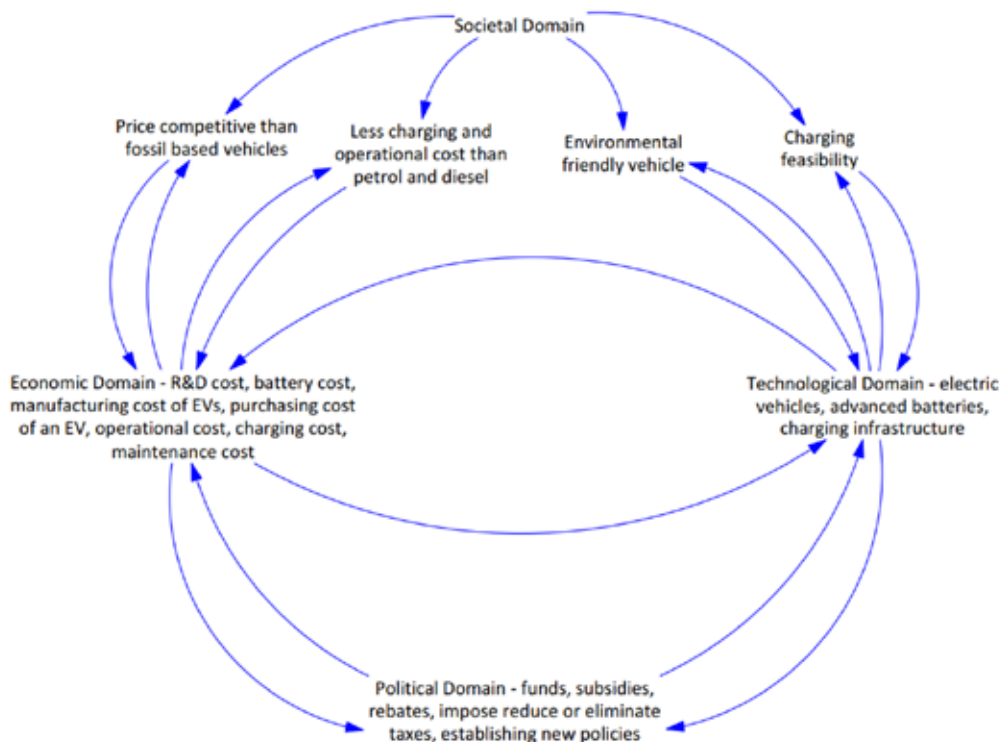


Figure 52: Relationship of various domains within the transportation electrification from societal perspective

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 the 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 the 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 above 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, we can see the positive

outcome in electric vehicles' sales and market share in those countries represented in figures 53 and 54, respectively.

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.

Countries	Size of Population – 2021
China	1.4126 billion
Germany	83.2 million
UK	68.2 million
Sweden	10.41 million
Norway	5.39 million

Table 10: Population size of the five selected countries (Statista, 2022h)

Total Sales of Battery and Plug-in Hybrid Vehicles in the year of 2019, 2020 and 2021

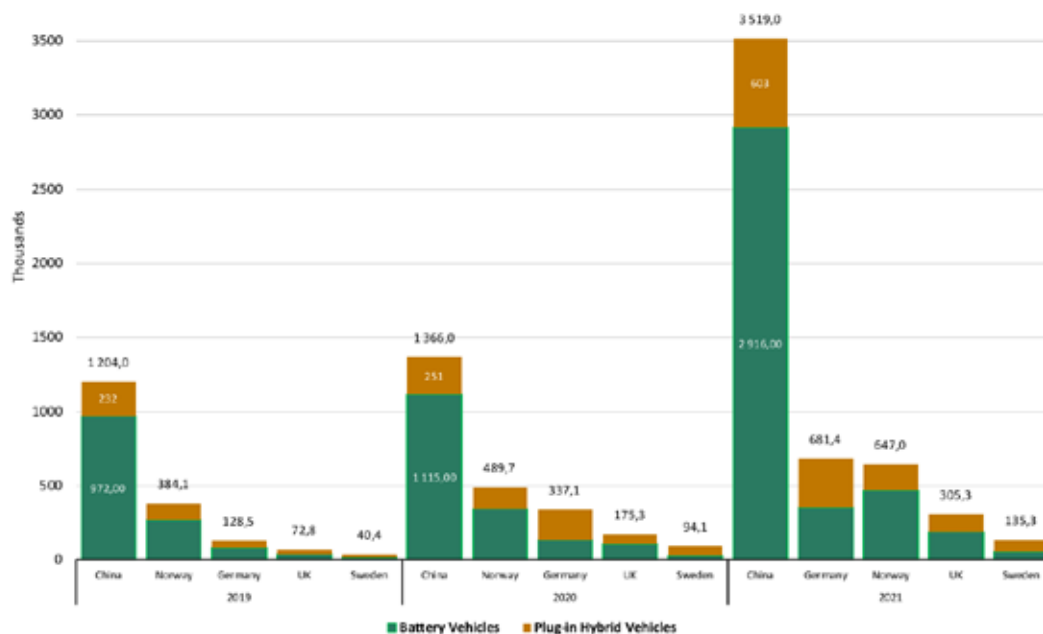


Figure 53: Total sales of battery and plug-in hybrid vehicles in the year of 2019, 2020 and 2021 (Based on the data collected in the above sections)

The variation in electric vehicles sale of China, Norway, Germany, the UK, and Sweden from 2019 to 2021 can be seen in figure 53.

Figure 53 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 54 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 54** for battery and plug-in hybrid vehicles from 2019 to 2021.

Market Shares of the Battery and Plug-in Hybrid Vehicles in the year of 2019, 2020 and 2021

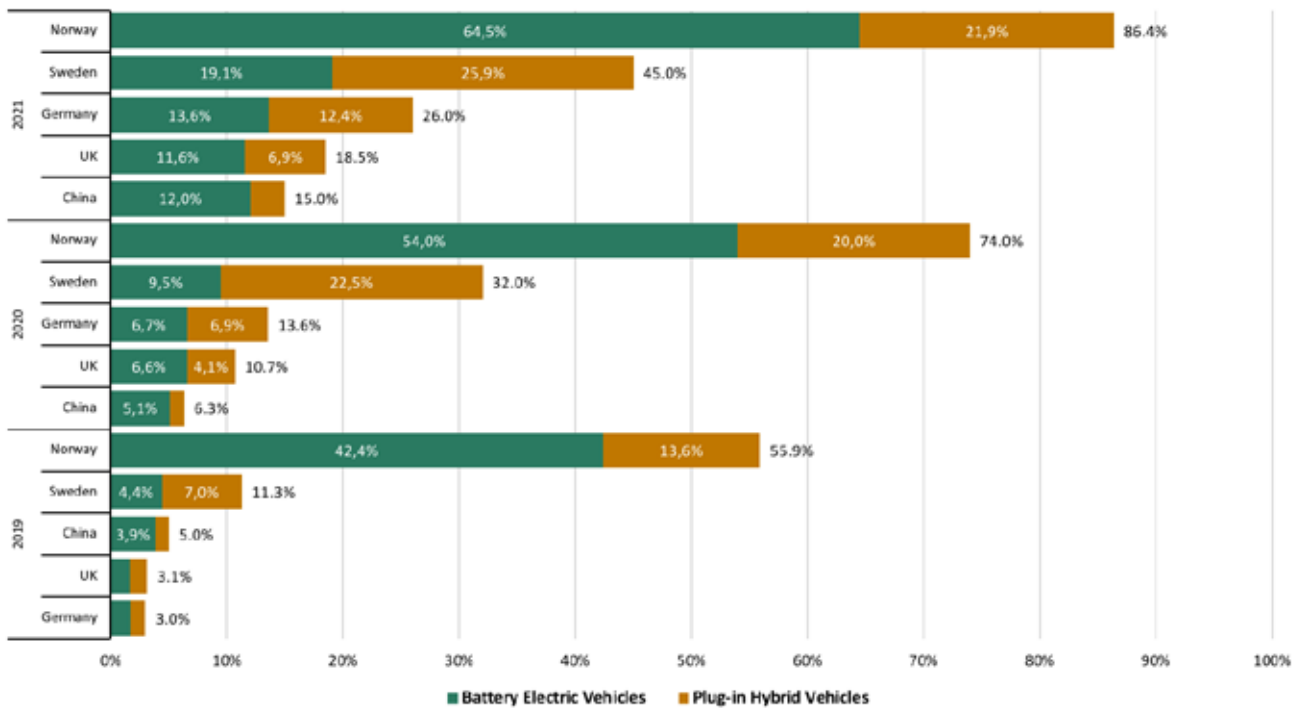


Figure 54: Market share of the battery and plug-in hybrid vehicles in the year of 2019, 2020 and 2021 (Based on the data collected in the above sections)

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 54**. 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 53 and 54** 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 54**. 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.

Economic Perspective of Transportation Electrification System

The economic domain primarily relies on governmental policies and is connected with society and technology in the system of transportation electrification, as represented in **figure 55**.

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 the 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 the petrol or diesel-based vehicles.

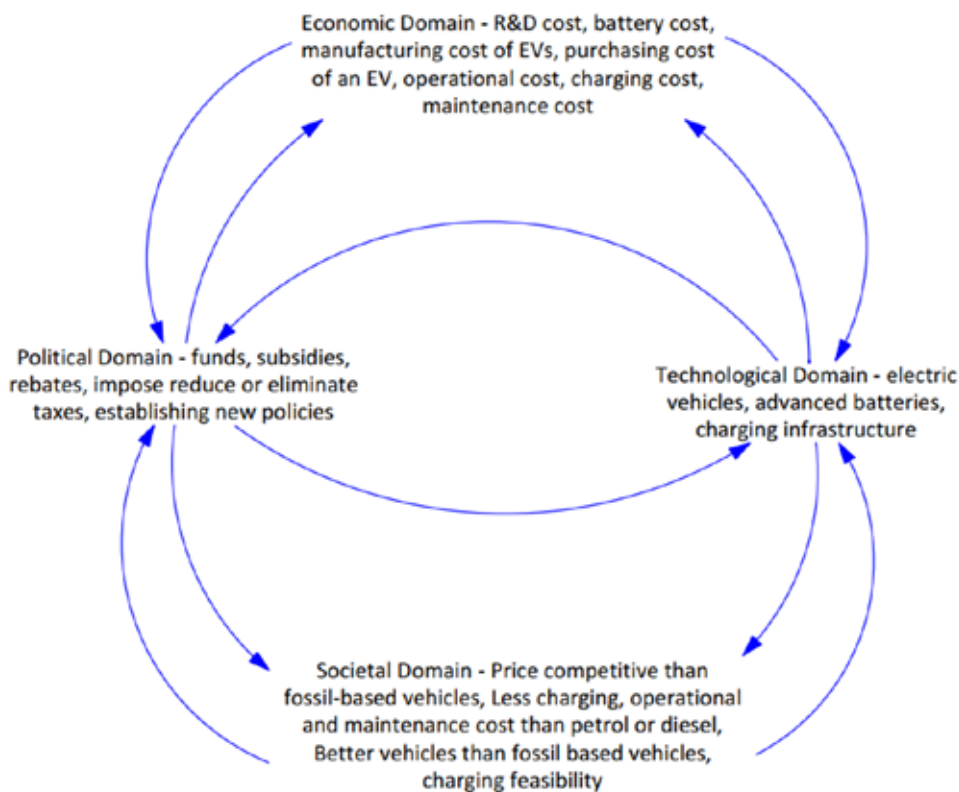


Figure 55: Relationship of various domains within the transportation electrification from economic perspective

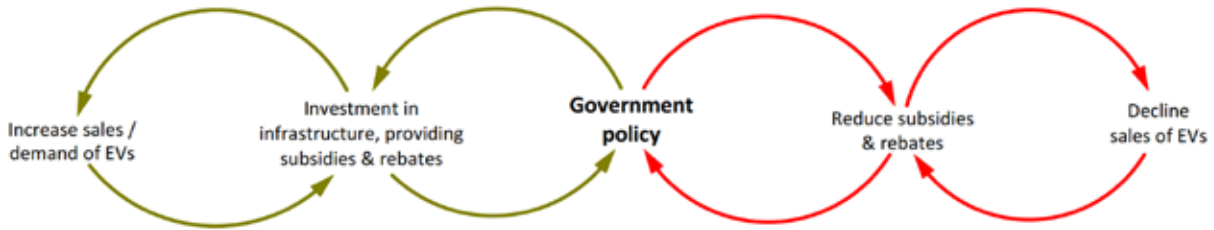


Figure 56: Interplay of governmental policies on the entire system of transportation electrification

Figure 56 illustrates that when the government introduces its policy to reduce the subsidies and rebates on electric vehicles, society reacts, and the sales of electric vehicles decline. When China reduced 20% of subsidies and rebates on electric vehicles, it was reported that the sales of electric vehicles declined in 2020. But when the government uses its economic means, invests in charging infrastructure, and provides 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 ele-

ments 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 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.

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, to use the opportunities of the

public transport to push electrification to key areas and this way creating a market for electric vehicles, and to 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 and real outcome 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 element. This system is interconnected and interdependent on the other elements 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 aspects of electrification 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 diffusion 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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