ACHIEVING A TECHNICAL TRANSITION FROM INTERNAL COMBUSTION ENGINE VEHICLES TO BATTERY ELECTRIC VEHICLES IN THE AUTOMOTIVE SECTOR IN EUROPE: CHALLENGES AND STRATEGIES

By

Fatih Mehmet ÖZEL

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School of Engineering, Cardiff University

Cardiff, United Kingdom

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DECLARATION

This work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is being submitted concurrently in candidature for any degree or other award.

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ABSTRACT

The European Union (EU) aims to reduce overall carbon dioxide emissions at least 80% by 2050. For road transport, this involves at least a 95% reduction target for 2050, compared to 1990 levels. Most commentators believe that achieving this target requires a transition from internal combustion engine vehicles (ICEVs) to battery electric vehicles (BEVs). However, such transition demands fundamental changes in the whole automotive value chain. This research argues that the required changes in the automotive value chain might be achieved by i) an industrial structure enabling the mass production of BEVs ii) understanding and supporting the development of newcomers that are in the majority of micro, small and medium sized enterprises (SMEs) in emerging BEV sector and iii) use of target instruments by governments to accelerate the development of BEV value chain and industrial structure.

Based on this strategy, three stage study was performed. This involved i) exploring the present BEV industry structure and compatible future structure ii) exploring the approach of SMEs to emerging BEV sector to understand and support these actors and iii) developing and trialling a novel framework enabling the pre-implementation analysis of putative policy measures. In each stage of the research, different methodologies were used. This included an analysis of supply chain for BEVs in North-West Europe (NWE); semi-structured in-depth interviews with SMEs throughout NWE and development and application of an “adaptive neuro-fuzzy inference system” (ANFIS) based framework.

This study contributes to the body of knowledge by investigating the implications of BEVs on the supply chains and exploring what competences and capacities might be needed for mass production of BEVs in Europe. Secondly, this research proposed that economic growth and emission reduction targets established in the existing economic strategy of the EU (Europe 2020 strategy) might be achieved, and a significant contribution to achieve the 2050 emission reduction target might be made by supporting SME development. Support areas for SMEs were also identified. Lastly, to support national governments in making informed decisions, an ANFIS framework providing an ex-ante impact of various innovation decisions was offered.

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LIST OF ABBREVIATIONS AND SYMBOLS

°C: Degree Celsius

2DS: United Nations Framework Convention on Climate Change `s 2 Degree Celsius Scenario

3PL: Third Party Logistics

6DS: United Nations Framework Convention on Climate Change `s 6 Degree Celsius Scenario

A3PS: Austrian Association for Advanced Propulsion Systems

ACEA: European Automobile Manufacturers' Association

ADEME: French Environment and Energy Agency

ANFIS: Adaptive Neuro-Fuzzy Inference System

ANN: Adaptive Neural Network

ARRA: American Recovery and Reinvestment Act

ATVM: Advanced Technology Vehicles Manufacturing

BCR: Benefit–Cost Ratio

BEV: Battery Electric Vehicle

BIS: Department for Business, Innovations and Skills

CAA: Clean Air Act

CAFE: Corporate Average Fuel Economy

CARB: California Air Resources Board

CBA: Cost-Benefit Analysis

CENEX: Centre of Excellence for Low Carbon and Fuel Cell Technologies

CHAdeMo: Charge Move

CIP: Competitiveness and Innovation Framework Programme

CNG: Compressed Natural Gas

CO_2: Carbon Dioxide

DECC: Department of Energy and Climate Change

DfT: Department for Transport

DOE: Department of Energy

EC: European Commission

ECTF: European Clean Transport Facility

EGVI: European Green Vehicles initiative

EIB: European Investment Bank

EISA: Energy Independence and Security Act

EIT: European Institute of Innovation and Technology

EJ: Exajoules

ENEVATE: European Network on Electric Vehicles and Transferring Expertise

EPA: Environmental Protection Agency

EPAct: Energy Policy Act

EPO: European Patent Office

ERTRAC: European Road Transport Research Advisory Council

EU: European Union

EV: Electric Vehicle

FCEV: Fuel-Cell Electric Vehicle

FFG: Austrian Research Promotion Agency

FIS: Fuzzy Inference System

FP: Framework Programme

G: Grams

G/km: Grams per Kilometre

GCO_2/km: Grams Carbon Dioxide per Kilometre

GCO_2/mile: Grams Carbon Dioxide per Mile

GGEMO: Joint Agency for Electric Mobility

GHG: Greenhouse Gases

GM: General Motors

$GtCO_2$: Gigatonnes of Carbon Dioxide

$GtCO_2e$: Gigatonnes of Carbon Dioxide Equivalent

HCCI: Homogeneous Charge Compression Ignition

HEV: Hybrid Vehicle

ICE: Internal Combustion Engine

ICEV: Internal Combustion Engine Vehicle

IEA: International Energy Agency

IP: Intellectual Property

IPC: International Patent Classification

JARI: Japanese Automotive Research Institute

JSCA: Japan Smart Community Alliance

KERS: Kinetic Energy Recovery System

Km/L: Kilometres per Litre

L/100-km: Litres of Gasoline per Hundred Kilometres

LCVIP: Low Carbon Vehicles Innovation Platform

LCVPP: Low Carbon Vehicle Public Procurement Programme

LDV: Light-Duty Vehicle

LED: Light-Emitting Diode

LPG: Liquid Petroleum Gas

LRR: Low Rolling Resistance Tyre

MAC: Mobile Air Conditioning

METI: Ministry of Economy, Trade and Industry

MITI: Ministry of International Trade and Industry

MLP: Multi-Level Perspective on Socio-Technical Transitions

MOA: Memorandum of Agreement

Mpg: Miles per Gallon

MY: Model Year

NAIGT: New Automotive Innovation and Growth Team

NEDC: New European Drive Cycle

NEDO: New Energy and Industrial Technology Development Organization

NHTSA: National Highway Traffic Safety Administration

NPE: National Electric Mobility Platform

NWE: North-West Europe

OEM: Original Equipment Manufacturer

OLEV: Office for Low Emission Vehicles

PATSTAT: Worldwide Patent Statistical Database

PHEV: Plug-in Hybrid Vehicle

PLC: Product Life Cycle

PNGV: New Generation of Vehicles

PPP: Public-Private Partnership

R&D: Research and Development

REEV: Range-Extended Electric Vehicle

RPI: Relative Performance Index

SD: Standard Deviation

SIPO: State Intellectual Property Office of the People's Republic of China

SME: Micro, Small and Medium Sized Enterprise

SQL: Structured Query Language

SUV: Sport Utility Vehicle

T2W: Tank-to-Wheel

TCO: Total Cost of Ownership

TSB: Technology Strategy Board

UK: United Kingdom

UNFCCC: United Nations Framework Convention on Climate Change

US Drive: Driving Research and Innovation for Vehicle efficiency and Energy sustainability

USA: United States of America

USABC: United States Advanced Battery Consortium

USPTO: United States Patent and Trademark Office

VVT: Variable Valve Timing

W2W: Well-to-Wheel

WENET: World Energy Network

WIPO: World Intellectual Property Organization

ZEV: Zero Emission Vehicle

CHAPTER 1– INTRODUCTION

1.1 Background

The Earth has experienced an altering climate since the beginning of time. However, during the last century, human activity has resulted in important climate change over a moderately short time period. The term "global warming" is well recognised in literature and describes the measured increase in the World's average temperature. This is caused by the build-up of key greenhouse gases (GHG) in the atmosphere accumulated from incessant combustion of fossil fuels and land-use changes over the 20th century [1].

In response, the Kyoto protocol, an international agreement under the United Nations Framework Convention on Climate Change (UNFCCC), was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. During its first commitment period, from 2008 to 2012, thirty seven industrialized countries and the European Community (now the European Union (EU)) committed to take a significant role in climate action by reducing their GHG emissions by at least 5% below 1990 levels. A second commitment period for the Kyoto Protocol was decided in 2012. It was designed to reduce emissions of participating countries by at least 18% below 1990 levels between 2013 and 2020 [2]. For 2020, the EU has made an individual commitment to reduce overall GHG emissions from its 28 Member States by 20% compared to 1990 levels which is now one of the headline targets of the European economic strategy (EU 2020 strategy) [3].

Since oil is the dominant fuel source for transportation with road transport accounting for 75% of total energy use by the transport sector, transport in particular road transport is a major contributor to GHG emissions [4]. For the EU, transport was responsible for approximately 25% of the GHG emissions in 2012. Road transport alone contributed nearly 20% of the EU's total emissions of carbon dioxide (CO_2), the main GHG [5]. The transport sector is also susceptible to oil supply disruption and price instability [6].

In response, and also to comply with its commitments under the Kyoto Protocol, the EU aims to reduce overall CO_2 emissions by 20% by 2020 and by at least 80% by 2050 [7]. For transport, this involves at least a 60% reduction target for 2050, compared to 1990 levels [8]. Achieving at least 80% decarbonisation overall by 2050 also translates into at least 95% decarbonisation of the road transport sector compared to 1990 levels [9].

To enshrine this commitment, a legislative framework was introduced with specific CO_2 reduction targets: In April 2009, the EU adopted Regulation 443/2009/EC which established a CO_2 emission target per manufacturer of 130 grams per kilometre (g/km) for the fleet weighted average of new cars sold by 2015. This regulation was amended in March 2014 and established a stricter emission target of 95 g/km by 2021.Based on the EU`s 2050 target, it is also expected that CO_2 regulation will get tighter in the next twenty years [10]. The pressure is therefore on the automotive sector to develop increasingly fuel efficient and environmentally friendly technologies which have lower or even zero direct CO_2 emissions.

1.2 Technological Options to Reduce Emissions from Cars

The automotive industry is dominated by the internal combustion engine vehicles (ICEVs) which use petroleum gasoline or diesel fuel with two types of engine: spark-ignition for gasoline, liquid petroleum gas (LPG) and natural gas, and compression-ignition for diesel fuel. Diesel engines are thought to be approximately 25-30% more energy efficient [4]. However, it is acknowledged that ICEVs are largely inefficient since 14-30% of the energy contained in a litre of fuel is used to drive an ICEV depending on different driving conditions. The rest of the energy is lost to internal combustion engine (ICE) and driveline inefficiencies or used to power accessories [11].

Thus, a significant potential exists for increasing the efficiency of ICEVs with overall vehicle improvements such as weight reduction, aerodynamics improvement, rolling resistance reduction and air conditioning system improvement, and ICE improvements such as downsizing the engine, improving the combustion and the transmission etc. Nevertheless, it is assumed that the lowest CO_2 rates that can be achieved with fossil fuelled ICE powertrains is 80-90 gCO_2/km for the best diesel ICEVs. To increase the efficiency above this limit necessitates electrification and/or biofuels [12]. As there are several concerns with regards to the environmental impact of biofuels such as overall increase in the GHG emissions owing to the production of biofuels and land use changes [13], most authors now express that electric propulsion or electric mobility represents the most viable short-term solution for the sustainability needs of automotive industry [14-20].

In principle, electric propulsion is a technological alternative to the ICE. Vehicles that use the electric propulsion technologies are described as electric vehicles (EVs). Different types of EVs including hybrid vehicles (HEVs), plug-in hybrid vehicles (PHEVs), range-extended electric vehicles (REEVs), battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) have been recently designed with the aim of solving pollution problems caused by the emission of ICEV. The prefixes to "EV" recognise the differences in the primary propulsion, primary energy storage units and drive train configurations which will be discussed in more detail in Chapter 2.

Two main possible technology pathways therefore exist for carmakers in order to reduce the GHG emissions of vehicles: (i) improving the ICEV efficiency and (ii) a transition from conventional ICEVs to EVs. Each pathway also comprises a portfolio of technologies. Regarding strategies of carmakers, it is observed that the main technology strategy implemented by carmakers is the improvement of the ICEV efficiency [21-28]. Yet, owing to the increased stringency of the GHG regulations and established long term GHG goals which, in return, increase expectations that environmental regulations will be even tighter in the future, automobile manufacturers are also electrifying the powertrain. On average, around 80% of the industry's patents are thought to be awarded to ICEV related technology, against only about 20% for technologies associated with BEVs, PHEVs and HEVs [24].

When the EU`s GHG emission targets are compared with the industry`s ICEV focussed strategy, it might be said that the numbers indicate that 130 g target for 2015 were already overachieved (2013: 126.8 g/km and 2014: 123.4 g/km) across the new car fleet as a whole [29], especially with the increasing number of diesel powered cars in the European Automotive Market [30]. However, the Volkswagen emission crisis, which Volkswagen admitted in 2015 that certain diesel cars produced by the company emit more pollution on the road than in regulatory tests [31], demonstrate that the numbers given by the automobile manufacturers might not truly represent the actual numbers. This also raises questions whether the 2015 target has actually been overachieved. Concerning the 95 g target for 2021, it is argued that the target might be met by carmakers by increasing the efficiency of ICEVs plus a small number of EV models in car fleets [32-34]. This implies that ICEV focussed strategy implemented by the industry might still be viable to achieve the target.

However, the EU`s 2050 target implies 95% decarbonisation of the road transport sector compared to 1990 levels [9]. According to a recent study, this target also translates into a CO_2 emission target of 10 gCO_2/km for the average of new cars sold by 2050 [10]. This means that it is not possible to achieve such target by improving the ICEV efficiency as it is technically unfeasible to reduce transport emissions below 80-90 gCO_2/km with the best diesel ICEVs. Even with the best diesel hybrid vehicles, it is not possible to reduce emissions below 60 gCO_2/km [12]. Thus, the aforementioned study argues that a gradual shift from ICEVs to BEVs and FCEVs with HEVs, PHEVs and REEVs as bridging technologies need to occur in the EU. It is also claimed that FCEVs will be used for larger vehicles in road transportation (trucks and heavy vehicles) while BEVs will be the main technological option for the automotive industry in 2050 to comply with the EU`s 2050 target [10].

1.3 Electrification of the Powertrain and Related Challenges

According to the innovation literature, electric propulsion technologies are radical technologies which have substantial impacts on carmakers and suppliers, infrastructure providers (such as oil, gas and utility companies/suppliers) and consumers etc. [35-39]. Owing to the multi-dimensional impacts of BEV technologies, several studies in literature highlight that a successful technology change involves overcoming barriers that go far beyond purely technological innovation; and that economic, business, infrastructural, institutional and societal innovations are just as important [33, 40-48]. In this regard, a transition from ICEVs to BEVs represents more than a technological challenge [33, 49, 50]. It is recognised as a “socio-technical” challenge in innovation literature [33, 40-48] which requires co-evolution between multiple developments in the whole automotive value chain [33, 49, 51].

To achieve the 2050 GHG emission reduction target, all technologies have to be engineered today and challenges facing such transition need to be mastered with carefully developed strategies. Aligned with such perspective, European industry roadmap for electrification of road transport [52] was published in 2009 and updated in 2012. The roadmap identifies when and what actions are necessary to master the different challenges of deploying BEVs on a large scale in order to comply with the 2050 GHG target. According to the roadmap, achieving the EU`s 2050 target represents a challenging set of timelines and entails urgent actions such as mass production of dedicated EVs (BEVs and PHEVs) need to be established, customer adaptation for BEVs need to be increased significantly and a great deal of charging infrastructure need to be rolled out by 2020. Yet, achieving these radical transformations in the automotive value chain cannot be accomplished without significant changes to the existing industry structure and policy framework [12].

1.4 Statement of the Problems for Achieving Electrification in the Automotive Sector

The automotive sector needs to gradually shift from ICEVs to BEVs with HEVs, PHEVs and REEVs as bridging technologies to meet the EU`s 2050 GHG emission reduction target [10]. However, this requires transformation in the whole automotive value chain which will not be possible without changes in the industrial architecture and policy framework [12] as explained below.

1.4.1 Changes in the Industrial Structure

To achieve the 2050 target, mass production of BEVs is required [52]. Nonetheless, this requires new technologies and new competences which, in return, decreases the previous significance of old technologies and competences. An illustrative example is that BEVs need new generations of batteries, electric motors and inverters while they do not require some of the vital technologies of ICEVs such as ICE and gearboxes. Besides, new forms of thermo-management need to be developed since there is no longer a combustion process generating heat which can be used for heating or cooling. Thus, a significant part of the automotive architecture needs to be redesigned. Some new design concepts include motors that are placed in the wheels, and vehicle bodies made from carbon fibre instead of steel [32].

The move to new technologies and automotive architectures also entails new competences which, in return, creates opportunities for newcomers whereas the replacement of old competences threatens established companies. Thus, value-added is reallocated between the existing industrial players and newcomers. In this respect, carmakers need to re-evaluate their make-or-buy decisions, especially with regards to powertrain technologies and batteries [32].

Therefore, there needs to be changes in the existing industrial structure to deal with the GHG emission reduction challenge in the automotive industry. Theoretically, the socio-technical transition literature also explains that a technical transition in the automotive industry requires industrial restructuring [33, 42, 46, 51, 53-55]. Similarly, another well-known theoretical model focusing on technical change in literature, Product Life Cycle (PLC) approach, describes that a radical technology change in an industry is accompanied by substantial changes in the industrial architecture [56, 57].

The industrial reorganisation has already started with the experimentation and production of EV models by the existing industrial players and newcomers. In 2015, the number of cars sold worldwide reached approximately 89 million units. Total global EV sales including BEVs, REEVs, HEVs and PHEVs in 2015 were also close to 2 million as can be seen in Table 1.1. However, these numbers still represent a small percentage of total vehicle sales.

Table 1.1: Global EV sales in 2014 and 2015 Compiled from [58]

Year	PHEV and BEV sales	HEV and REEV sales	Total
2014	320,713	1,566,184	1,886,897
2015	548,210	1,362,429	1,910,639

For example, in 2016 (January-May period), worldwide plug-in car sales (PHEVs and BEVs) hit around 240,000. It is expected that the total number of plug-in car sales will reach approximately 800,000 units until the end of 2016. In the models ranking, the best seller was Nissan Leaf followed by Tesla Model S. Another new entrant`s (BYD) three models also appeared in the world`s top 10 selling plug-in cars as can be seen in Figure 1.1.

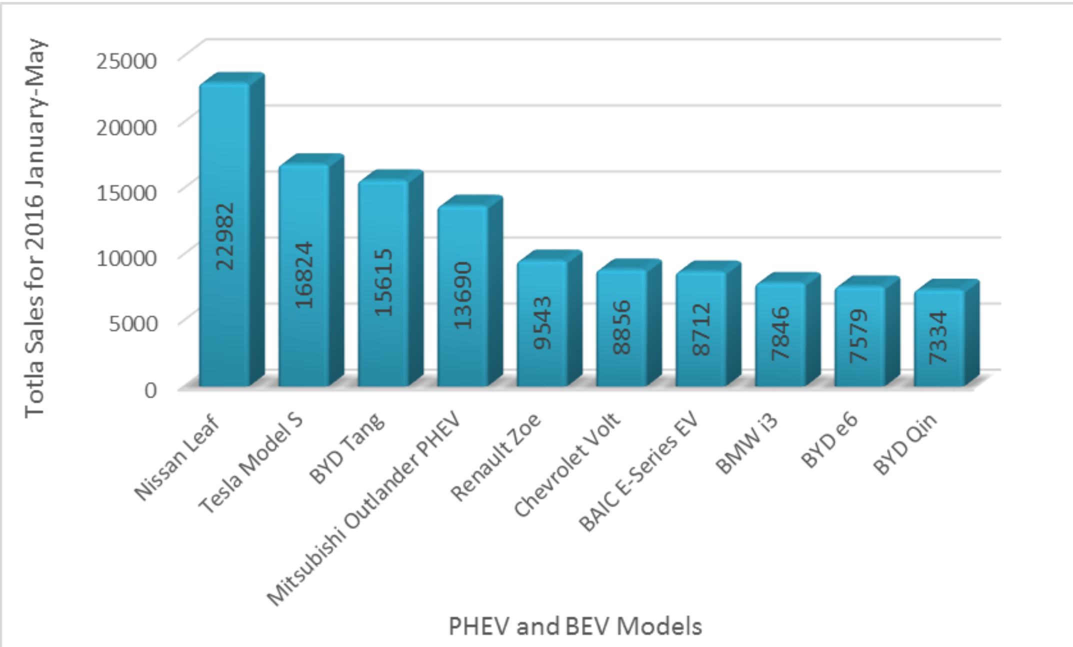


Figure 1.1: World`s Top 10 Selling Plug-in Cars 2016 January-May [59]

In terms of automobile manufacturers, BYD is the largest plug-in automobile manufacturer with over 33,000 deliveries in the first five months of 2016 as depicted in Figure 1.2. Since BYD`s PHEVs and BEVs are available only in China, this new entrant`s success is even more interesting. Nissan with global presence of LEAF is second at nearly 24,500 with Tesla on the tail, approaching 22,000. Other largest plug-in automobile manufacturers are BMW, Mitsubishi, Volkswagen, Renault, BAIC, Chevrolet and Ford respectively.

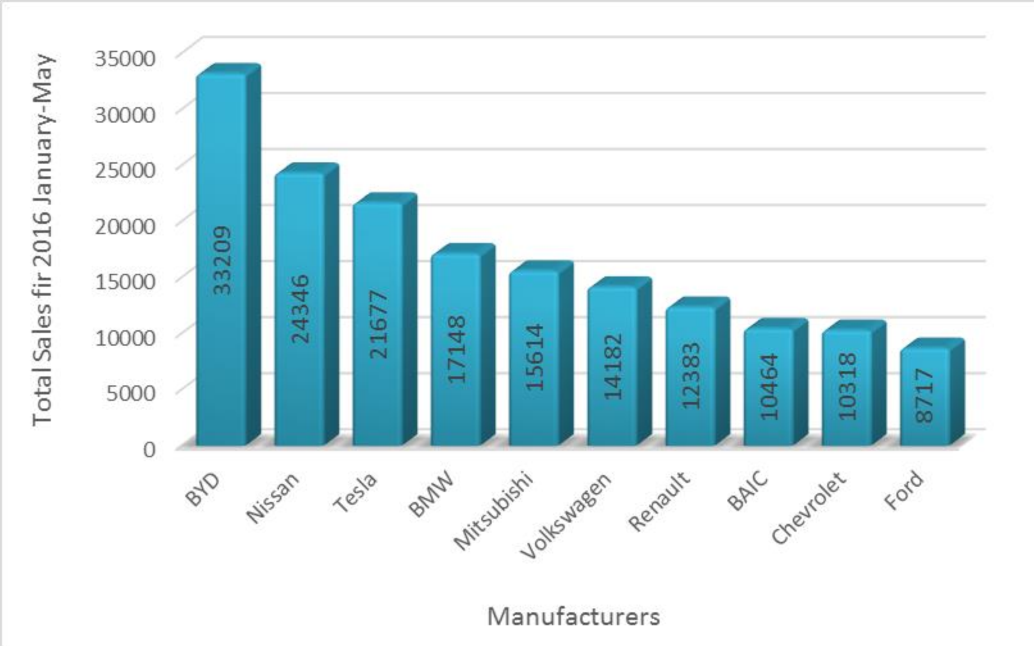


Figure 1.2: World`s Top 10 Plug-in Automobile Manufacturers 2016 January-May [59]

Even though the sale numbers of BEVs are increasing with the contribution of new entrants and traditional automobile manufacturers, the share of PHEVs and BEVs still represent a very small percentage of total vehicle sales. For example, in 2015, there were 1,26 million BEVs and PHEVs on the roads globally. This represents approximately a 100% increase compared to 2014. In 2005, the numbers of BEVs and PHEVs were still measured in hundreds. However, to achieve the Kyoto Protocol`s 2050 CO_2 reduction aim, there needs to be 150 million BEVs and PHEVs on the roads by 2030 [60]. Meeting these targets entails substantial market growth to develop further the current 1.26 million EV stock and represents a huge challenge for the automotive industry.

Achieving 150 million BEVs and PHEVs on the roads by 2030 also requires a strong battery industry. In the past, "*lead-acid, nickel-metal hydride (NiMH) or sodium-nickel-chloride (ZEBRA) batteries"* were used for the on-board energy supply of BEVs [61]. However, nowadays, BEVs generally use lithium ion (li-ion) batteries as they offer high energy as well as power density compared to other types of batteries [61, 62]. Several firms from very diverse sectors have also started to invest in li-ion batteries which are the most expensive part of a BEV. For example, in addition to the established battery companies, such as Bosch, Varta and Johnson Controls, chemical companies, carmakers (often in joint ventures with prominent battery producers from Japan and Korea), automotive parts manufacturers as well as plant engineering and construction firms are increasingly entering into the battery value chain.

This trend can be recognised by examining the production numbers. For example, production grew around 72% in 2015 compared to 2014 as displayed in Table 1.2. Panasonic was the leader in terms of battery production with 38% of market share in 2015. A significant part of Panasonic batteries have been used in Tesla Model S. The growth of Panasonic in 2015 was high (approximately 67%). However, the Chinese company BYD which was the second in the top 10 battery makers list grew even faster (around 258). The South Korean manufacturer LG Chem was the third in the list and did not lose any share. However, AESC (Automotive Energy Supply Corporation) which is the joint venture between NEC and Nissan lost 12% market share in 2015 compared to 2014. Although Lithium Energy Japan`s (GS Yuasa / Mitsubishi) sales increased, the company lost 1% market share. Samsung which has a partnership with BMW and FIAT also increased the battery production. Overall, although the numbers indicate that battery production is increasing, it is still extremely low to achieve 150 million BEVs and PHEVs on the roads by 2030.

Table 1.2: **World`s Top 10 Battery Makers Ranked by MWh Produced in 2015 [63]**

Battery Makers	**2015 (MWh)**	**2014 (MWh)**	**%` 2015**	**%` 2014**
Panasonic	4552	2726	38	38
BYD	1652	461	14	6
LG Chem	1432	886	12	12
AESC	1272	1620	11	23
Mitsubishi/GS Yuasa	600	451	5	6
Samsung	504	314	4	4
Epower	489	N/A	4	N/A
Beijing Pride Power (BPP)	397	121	3	2
Air Lithium (Lyoyang)	283	N/A	2	N/A
Wanxiang	268	N/A	2	N/A
TOTAL	**12289**	**7167**		

The industrial reorganisation also extends beyond battery production. For example, battery producers have started manufacturing cars such as BYD in China and Bolloré in France;; tyre manufacturers such as Continental and Michelin produce entire concept cars; chemical companies such as Evonik increase their auto parts portfolio; and carmakers and energy utilities venture into new mobility services, such as car-sharing. However, to achieve the 2050 target, transformation in the automotive industry structure need to be accelerated and the existing industry structure need to be shifted to a compatible future structure for BEVs.

1.4.2 Integration of Newcomers to the Future BEV based Industrial Structure

In literature, it is recognised that a large share of radical innovations emerge from new entrants. This is because the introduction of a radical technology in an industry lowers entry barriers and creates windows of opportunity for new entrants to enter the market [28, 64-71]. This is a different situation compared to an established technology where it is difficult for a new firm to enter the market [72]. The socio-technical transition literature also highlights the significance of new entrants for the development and diffusion of radical technologies [33, 40, 41, 73-75]. According to these studies, established companies have vested interests and they are inclined to defend their current positions and business models with incremental innovations rather than fully adopting radical innovations. Such situation also explains the ICEV focussed strategy of automobile manufacturers. On the contrary, new entrants are much less constrained by dominant institutions and the status quo [47]. Thus, new entrants are recognised as more capable of developing radical technologies in literature, especially when technologies are still in the "niche" status. New entrants include both micro, small and medium sized enterprises (SMEs) and diversifying established firms moving into emerging BEV markets [65]. Yet, recent studies found that SMEs compose the majority of those companies in BEV niches [25, 76]. Although it is difficult to confirm that SMEs compose the majority of companies in BEV niches by looking at the sales figures which were discussed previously, indeed, new entrants such as Tesla and BYD are contributing strongly to the development and dissemination of BEVs.

According to Dodourava and Bevis [77], *"in the automotive industry, innovations are driven and executed by OEMs. Although Tier 1 suppliers appear to be very significant to the innovation generation, the role of OEMs might be explained as powerhouses assessing the innovative solutions offered by suppliers, selecting the most suitable solution and eventually controlling the paths to the market".* Therefore, OEMs and Tier 1 suppliers compared to smaller suppliers have more opportunities in terms of choosing technologies and products in order to achieve mass commercialisation owing to the high capital intensity of the automobile industry. In this regard, smaller suppliers and SMEs have marginal roles

However, it appears that various opportunities are opening up for SMEs with a transition from ICEVs to BEVs. Although OEMs and Tier 1 suppliers are increasingly developing and implementing BEV innovations, they are also looking outside the organisational boundaries in search for deep specialized knowledge and expertise owing to the specialisation and the speed of new technical developments. In this regard, with the transition, SMEs are having more opportunities to capitalise on their innovations [77]. Altenburg [32] claims that there are five key areas where new opportunities are emerging: a) to reduce the total cost of ownership (TCO) of BEVs by developing battery technologies and new business models b) to overcome the range problem by improving battery performance, developing range extenders and systemic solutions such as battery swapping and inductive charging c) to ensure energy supply and optimise energy usage by developing software solutions d) for recycling and e) for new niche market BEVs.

SMEs are also very significant for the economic growth. There are more than 20 million SMEs representing 99% of businesses in the EU. SMEs are the “back-bone” of the European economy and a significant driver for economic growth, employment and social integration in addition to their crucial role in innovation and research and development (R&D). Thus, the European Commission aims growth by promoting successful entrepreneurship and improving the business environment for SMEs with policies designed for assisting SMEs at all stages of development. The Small Business Act for Europe expresses the EU's commitment to SMEs and entrepreneurship.

In conclusion, as there needs to be changes in the industrial structure with the transition from ICEV to BEV (which has started), SMEs that are recognised as more capable of developing radical technologies [28, 37, 78] are having significant opportunities to become a part of the developing BEV value chain. Maximising SME engagement and benefit from the transition to BEV is significant owing to their potential in triggering economic development and innovation via the exploitation of emerging BEV business opportunities. Yet, there are motivators [28, 37] and barriers [79] for SME involvement that are either preventing or stimulating growth and innovation. In this regard, understanding and supporting the development of SMEs in emerging BEV supply chains is very significant for achieving GHG emission reduction targets as well as improving the economy of the EU.

1.4.3 Changes in the Policy Framework

As described before, achieving the 2050 GHG emission target of the EU is not possible without significant changes in the industrial structure [32]. Nevertheless, such transformation is very unlikely to happen on its own within an acceptable period of time which ensures the EU`s 2050 road transport decarbonisation pathway. This is because opposition power (ICEV based value chain) is strongly invested. Vehicle manufacturers are still investing mostly to improve the ICEV efficiency [21-28]. The present market structure also benefits continuation of ICEVs and consumers are not yet familiar with BEVs. Most of the consumers have never driven a BEV, let alone have thought buying one. Besides, BEVs necessitate a considerable investment by consumers owing to the high sales price of BEVs compared to those of similar ICEVs [80]. This is mostly because of the additional cost of batteries that is also one of the key reasons for the slow uptake of BEVs [32, 34]. Additionally, BEVs create uncertainty for drivers owing to the limited range and long charging intervals. Thus, charging stations need to be established, battery performance need to be improved and range extenders or other related technologies need to be developed [32, 80]. Lastly, even though charging stations are established, issues such as interoperability, maintenance and the required time to charge need to be solved [80].

Target instruments therefore need to be used by governments to accelerate the development of new BEV value chain and industrial structure. In literature, it is also recognised that environmental innovations such as BEV technologies have a so called “double-externality problem”, where the costs of development, deployment and use are borne by the innovator alone, although the society benefits from it as well [81-83]. This means that the “benefits” of BEV use accrue mainly to society and to the environment in the form of reduced pollution and carbon emissions, whereas the performance penalty (reduced range, long recharging time, inadequate facilities for recharging, higher purchase cost and uncertain rates of depreciation) accrue mainly to the owner or purchaser of the vehicle. This problem decreases incentives for consumers and businesses alike to invest in environmental innovations. To resolve this, considerable policy effort needs to be directed at solving these externalities. The transition literature also recognises that a transition from ICEV to BEV only takes place if there is a policy intervention which destabilises current practices and creates opportunities for BEV technologies [41, 47, 55, 84, 85].

It is therefore increasingly recognised that prescriptive policy interventions are necessary in order to stimulate the development of BEV technologies, resulting in a concern for fiscal and other incentives, learning from socio-technical experimentation, consensus building, R&D support, infrastructure development, regulatory frameworks and other features. Aligned with such perspective, most of the EU's largest countries have established supportive policies for the accelerated introduction of BEVs.

An illustrative example of supportive policies is the 2009 National Development Plan for Electromobility in Germany set a target of 1 million BEVs in the national fleet by 2020 and provided €500m in funding support. German government aims to reduce the dependence on oil and decrease CO_2 emissions, and strengthen Germany as an industrial and technological location [86]. Although environmental targets exist too, industrial goals play a more significant role for German policies since Germany`s economy is highly dependent on its automotive industry and this is endangered by a global transition from ICEVs towards BEVs [55].

In France, the development of BEVs is seen as a twofold opportunity in order to fight against climate change, while at the same time restructuring the automotive sector to ensure the future viability of the domestic automotive industry and to safeguard jobs [87]. The 2009 "carbon-free vehicles" plan offered an ambitious target of 2 million BEVs on the road by 2020 and €1,5bn in total funding including infrastructure up to 2015. Additional measures include a €5,000 cash rebate on EV purchases, free registration, reduced overnight parking charges in public spaces, and a 2010 law that requires new residential and commercial premises with parking facilities to include recharging points. There is a commitment to deploy up to 75,000 public and 900,000 private charging stations by 2015, and 4, 4 million by 2020, while also using public purchasing of vehicles to stimulate demand. Meanwhile, the French "bonus-malus" system of penalising heavy CO_2 emission vehicles in taxation while rewarding low- CO_2 emission vehicles also acts to shift the balance of the overall mix of sales. The French automotive industry has been at the forefront of BEV production, notably with Renault producing the Twizy, Zoe, Fluence and Kangoo BEVs and making strong corporate statements regarding the expected future share of EVs in total sales with the industrialists acting in tandem with the policy-makers [88]. The Paris Velib scheme has attracted much attention [89] while the EV Autolib scheme has equally prospered.

Norway also implemented several supportive policies to reduce the carbon emissions in the road transport sector. For example, the country has specified a higher CO_2 emissions target for new vehicles which is 85 g/km by 2020 compared to the EU-wide target of 95 g/km by 2020. However, since Norway has no car manufacturing industry (although Norwegian car company "Think Global", which was founded in 1991, had developed and produced a total number of approximately 2,500 units of EVs, it filed for bankruptcy in 2011), the country`s policies focus primarily on "user behaviour, raising awareness, and charging infrastructure". For example, Transnova (now Enova) received 50-100m Kroner (~€6-12m) between 2009 and 2010 to support the introduction of EV technologies and to finance charging infrastructure for EVs. In 2013, another 6m Kroner (~€720,000) were made available by Transnova to support the fast charging infrastructure. Transnova also funded "Grønn Bil" (green car), which aims to accelerate the uptake of EVs by publishing statistics on EV registrations and charging points [90]. Besides, BEV users have preferential access to a significant part of public infrastructure, including "free access to toll roads (since 1997), reduced fares on ferries (since 2009), free parking (since 1999), access to bus lanes (since 2003), and free charging at public charging stations (it is often bundled with free parking)" [91]. It is claimed that BEV owners save around 16,000 Kroner (~€1,915) every year owing to these incentives. PHEV users are also allowed to charge for free at public charging stations in some cities. However, they must pay the standard parking fee. To facilitate the enforcement and increase the visibility of those measures, EVs have also received special "registration plates" using the prefix "EL" since 1999. In terms of financial incentives, BEVs are exempted from the registration tax (until 2020). Although PHEVs are not exempted from the registration tax, they still gain lower registration taxes compared to ICEVs owing to lower CO_2 emission values. Secondly, BEVs have been exempted from the VAT since 2001. The VAT usually adds 25% of a vehicle's list price to the total cost in Norway. The VAT exemption for BEVs is aimed to be continued until the end of 2017. For BEVs, the list price is decreased by 50% in the calculation of the company car tax. This incentive is aimed to be continued until 2018 [90]. As a result of these supportive policies, at the end of 2015, there were approximately 75,000 BEVs and about 12,000 PHEVs registered in Norway. This represents a 17% market share for BEVs and 5% market share for PHEVs [92].

China, which has the world biggest electric bike market with over 200 million electric bikes running on the road [93], also implemented numerous policies to accelerate the development and production of EVs. In 2009, the Chinese government acknowledged that although domestic automobile manufacturers probably could not catch up with their global competitors’ ICE technology in the near future, they could catch and surpass the developed automotive countries in the emerging EV fields owing to country`s advantages of enormous market capacity and lower costs. The government predicted that this strategy, which is also known as “corner overtaking” strategy, could succeed if Chinese companies quickly brought BEVs to mass production and consolidated technological developments in “batteries, traction motors, and power electronics” [94]. Therefore, the government adopted “development plan for fuel-efficient and new energy vehicles” in 2010 to support the development of EV industry. With this plan, the government aimed to invest approximately 100 billion Chinese Yuan or CNY (€13,51bn) for the development of the whole industrial chain of EVs including “support for R&D, support for the related industry, and support for private and public consumption” between 2011 and 2020. The aforementioned plan involves two stages. In stage one (2011-2015), the government aimed to develop BEVs and PHEVs with a total production reaching 500,000 cars. It was also aimed that the market volume should reach at least 1 million by 2015 for HEVs [95]. Nevertheless, according to statistics made by China Association of Automobile Manufacturers, the production of EVs and PHEVs in China in 2014 reached 78,499 units [96] which is much lower than government`s predictions. However, in stage two (2016-2020) the Chinese government aims to increase its efforts for developing BEVs and PHEVs and intends to reach an accumulated market volume of 5 million EVs. To support this aim, new fuel consumption standards for passenger vehicles were released in December 2014 and came into force on 1 January 2016. With these standards, the government expects a fleet average target of 5 L/100km for new vehicles sold in 2020 [97]. Besides, in September 2015, the government created a guideline to build the necessary charging infrastructure to achieve the power demand of 5 million EVs by 2020. This guideline aims at least one public charging station for every 2000 EVs. Lastly, in April 2016, “the Traffic Management Bureau under the Ministry of Public Security” declared the introduction of green license plates to identify and increase the visibility of EVs as against the country's standard blue plates.

Therefore, there is an increasing policy emphasis globally on supporting the technical transition from ICEVs to BEVs. The above mentioned different policies adopted by national governments are clear examples that different approaches are required by different countries in order to reach specific transition goals. Previous research studies also found that public policies aimed at promoting electrification of road transport have taken different forms in different countries [55, 83, 98-100]. The reason for observed differences in national policies is that, as discussed in the previous section, a transition in the automotive industry will induce significant changes to the existing structure of the automotive industry and such situation makes it for some national governments a question of industrial policy as well as of energy and environmental policy. Industrial goals especially play an important role for determining the paths and policies adopted by national governments. A recent study [55] supports this finding by claiming that "*although the energy and environmental policy goals are largely similar across countries, industrial policy goals vary more significantly for determining EV policies as it reflects the particular structure and strategy of national industries".*

In summary, across the EU and elsewhere in the world there is a burgeoning array of policy measures both to support technological development and to stimulate the market with respect to BEVs based on national governments` specific BEV transition targets, but given this diversity of interventions there is a need for a systematic framework to evaluate policy effectiveness. Such a framework might have the potential to support national governments in: identifying and improving the dynamics of BEV innovation instruments more effectively, validating results and impacts of instruments on development of BEV technologies and selecting the most appropriate instruments for their country based on their transition goals.

1.5 Research Aim and Objectives

The overall aim of this research is understanding and challenging the factors limiting the technical transition from ICEV to BEV in the automotive sector in Europe to support the sector responding the 2050 GHG emission reduction challenge. As described in the previous section, a transition from ICEV to BEV might be achieved by (i) an industrial structure which enables the mass production of BEVs (ii) understanding and supporting the development of newcomers which are in the majority of SMEs in emerging BEV supply chains and (iii) use of target instruments by governments to accelerate the development of BEV value chain and industrial structure. In this respect, the specific objectives of this research are to:

- Review the existing GHG regulations, available technologies to reduce GHG emissions from cars and carmakers` technology strategies to reach those targets, and explore the automotive industry`s technological transition pathway to respond the challenge of long term (2050) GHG emission reduction target.

- Explore the present industry structure and compatible future structure, identify the challenges associated with such architectural change in the automotive industry and develop a set of strategies aiming to overcome such challenges in order to support the development of a commercially strong BEV sector in Europe.
- Explore the approach of SMEs to the emerging BEV sector to understand SMEs and identify support areas they need to have a role in the possible BEV based automotive value chain re-shaping in order to stimulate the BEV technology and business in Europe.
- Develop and trial a novel framework that can be used to predict the technology development of EVs based on national governments` different technology strategies in order to support national governments in making informed decisions regarding the use of target instruments for the development of EV value chain and industry structure.

Research aim and objectives are also displayed in Figure 1.3.

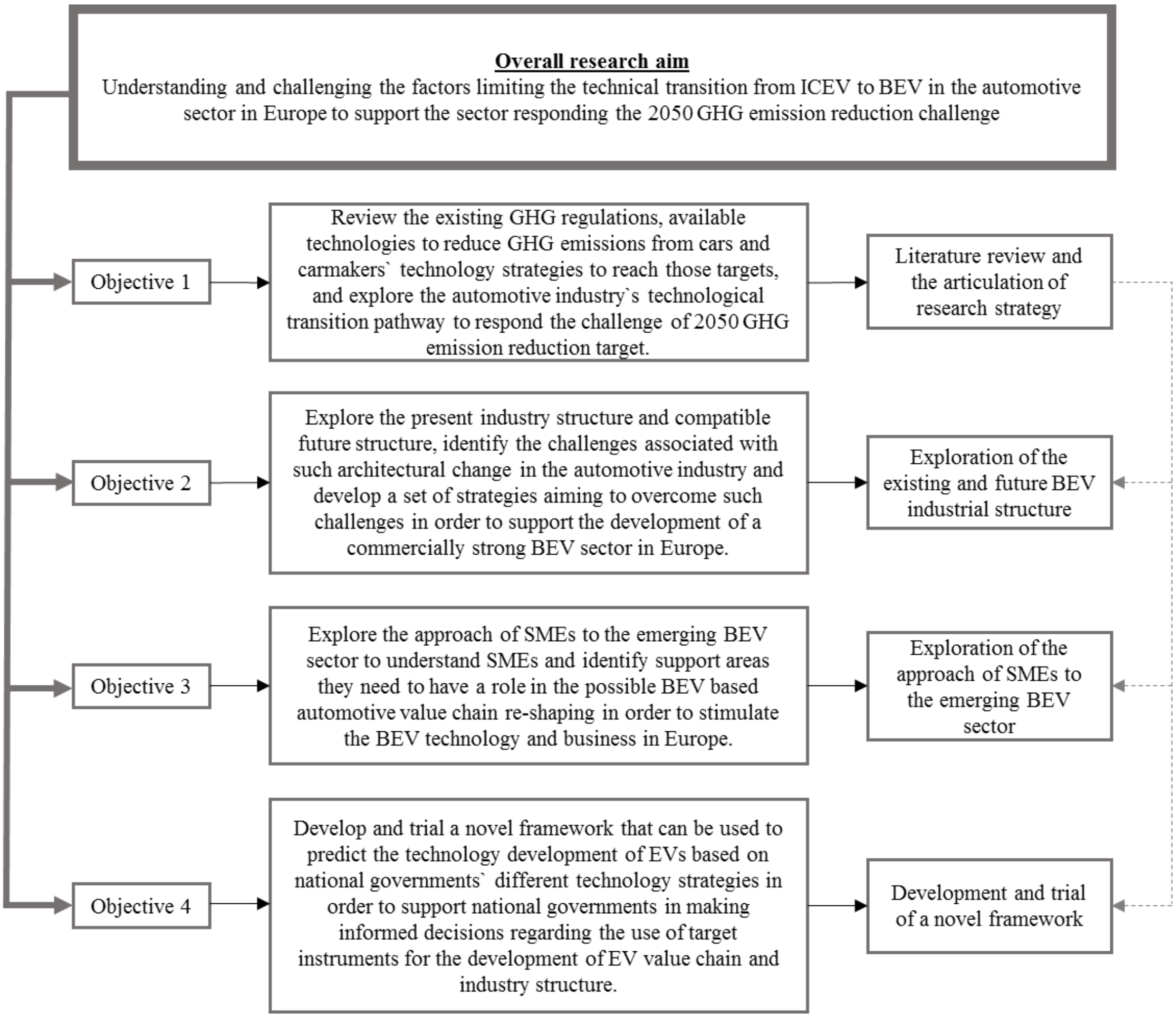


Figure 1.3: Research aim and objectives

1.6 Contributions of the Present Work

The major achievements and contributions of this research investigation will be i) exploration of the existing and future BEV industrial structure ii) exploration of the approach of SMEs to the emerging BEV sector and iii) development and trial of a novel framework for the use of target instruments. More specifically:

Exploration of the existing and future BEV industrial structure: This research will investigate the implications of BEVs on the automotive supply chains and explore what competences and capacities might be needed for mass production of BEVs in Europe to develop a strong BEV sector. In this regard, automotive sector in North-West Europe (NWE) will be analysed by conducting production structure analysis, make or buy analysis, value-add analysis, white spot analysis and competitor analysis. Whereas production structure analysis will explore the existing relationships in the BEV supply chain in NWE and examine how it evolve in the future, make or buy analysis will provide an insight on the future task sharing regarding the components of electric drivetrain. Besides, value-add analysis will determine the value added difference between ICEV and BEV. With white spot analysis, the competencies and capacity of the automotive sector regarding BEVs will be defined. Lastly, competitor analysis will establish the position of European Automotive Industry in comparison with American counterpart. Based on those analyses results, this study will offer some strategies to support the development of a commercially strong BEV sector in Europe.

Exploration of the approach of SMEs to the emerging BEV sector: This research will explore the change in the automotive supply chain with the transition from ICEV to BEV, examine roles of SMEs in the existing automotive supply chain and scrutinise how SMEs composing the majority of new entrants in the European BEV market might have a role in the possible BEV based automotive value chain re-shaping. Besides, this research will propose that economic growth and emission reduction targets established in the existing economic strategy of the EU (Europe 2020 strategy) might be achieved, and a significant contribution to achieve the 2050 emission reduction target might be made by supporting SME development. However, since there are motivators [28, 37, 78] and barriers [79] for SME involvement that are either preventing or stimulating growth and innovation, the approach of SMEs to the BEV based automotive value chain re-shaping in Europe will be explored to understand SMEs and investigate support areas they need to have a role in the BEV based automotive value chain re-shaping by conducting a series of interviews with SMEs throughout NWE. Additionally, as policy has a very significant role for supporting SME development by providing and sustaining ideal conditions [76], SME responses will then be linked with EU`s two recent framework programmes (EU`s main instruments for implementing its common scientific and innovation policy) to discriminate policy and delivery of EU`s framework programmes for SMEs on the basis of their perception on motivators and barriers for BEV business. In so doing it is recognised that improving the link between policy and delivery for SMEs might stimulate the BEV technology and business in Europe.

Development and trial of a novel framework: To support national governments in making informed decisions, a framework providing an ex-ante impact of various innovation decisions will be developed. This framework will be based on "adaptive neuro-fuzzy inference system" (ANFIS) which is a hybrid scheme that uses the learning capability of the artificial neural network to derive the fuzzy if-then rules with suitable membership functions worked out from the training pairs, which in turn leads to the inference [101]. During the discussion of input parameters of the ANFIS framework, an extensive review of published literature concerning theories about the drivers of the innovation and their implications on the government policies for inducing technical change, technology-push and demand-pull instruments national governments might use to promote the development of EV technologies, and the relative performance of these instruments on EV technology development will be provided. During the discussion of output parameter of the aforementioned framework, patent analysis as a way to measure the technology development of electric propulsion technologies will be reviewed.

The necessary data for the model will be gathered by analysing EV innovation policies (technology-push and demand-pull policies) of United States of America (USA), Japan, EU, Germany, France and United Kingdom (UK), and comparing them with the actual technology development that will be measured by patent filings in those regions. Thus, another contribution of this research study will be the examination of EV innovation policies and EV technology development rates (in terms of patent filings) of above-mentioned regions. The reason for choosing these regions is that this study aimed intentionally to study the three most developed regions in the world, EU, USA and Japan, and inside the EU, three biggest economies, Germany, UK and France. When developing the ANFIS model, EV policies and EV technology development rates rather than BEV policies and BEV technology development rates will be examined since technology-neutral strategies are encouraged by several studies in literature [76, 82, 102, 103]. European Automobile Manufacturers' Association (ACEA), the main industry association for European automakers, is also in favour of technology-neutral policies [103]. Owing to ANFIS`s ability of learning and predictive characteristic, the developed model will be able to predict the technology development of EVs (in terms of patent filings) based on national governments` different technology push and pull strategies.

The developed ANFIS model will also be trialled by applying it to Austrian innovation instruments with the support of Austrian Research Promotion Agency (FFG). The FFG is the main public body to support industrial research, development and innovation in Austria and it is the biggest Austrian funding agency for applied research. Austria was examined in this study as a comparative case to trial the developed framework since the automobile industry is one of the leading industrial sectors in Austria and this industry is significantly affected by the technical transition owing to the significant number of employees working in this sector (more than 175,000 people), mainly in the production and development of drive trains [104].

Austria is also recognised as an R&D centre for international companies such as Magna (develops EVs and plans to start mass production), Samsung SDI (manufactures battery systems for EVs and Bosch (produces electrical drives, starter motors and generators, automotive electronics etc.). Besides, Austrian company AVL employing more than 8000 people worldwide is the world's largest privately owned company for development, simulation and testing technology of powertrains (hybrid, combustion engines, transmission, electric drive, batteries and software) [105]. The Austrian Federal Government also aims to *"further develop and direct policy instruments for the preparation of the market for EVs in the sense of an intelligent incentives system, so that the transition from the market preparation phase to that of launching electric mobility on the market is accelerated"* [106]. This research will support this objective by making suggestions about the country`s future innovation policies by using the ANFIS framework.

1.7 Contributions to the Present Work

This research study was supported by the "European Network on Electric Vehicles and Transferring Expertise" (ENEVATE) partnership [107]. ENEVATE partnership was funded by the INTERREG IVB NWE Programme which is a programme of the EU to promote the economic, environmental, social and territorial future of the NWE area. The NWE Cooperation Area consists of eight countries: Belgium, France, Germany, Ireland, Luxembourg, Netherlands, UK and Switzerland. It covers around 20% of the total EU27 land area and almost 40% of the EU27 population [108]. Besides, this area also covers a significant proportion of car manufacturing in the EU since top EU passenger car producers were: Germany, Spain, UK, France, Czech Republic, Slovakia, Belgium, Hungary, Italy and Poland respectively in 2014 [109].

INTERREG IVB NWE funds projects supporting transnational cooperation. The aim is to find innovative ways to make the most of territorial assets and tackle shared problems of Member States, regions and other authorities [108]. In that respect, in 2012, INTERREG IVB NWE funded the ENEVATE partnership in order to facilitate and accelerate the introduction of electric mobility in NWE region. The ENEVATE partnership involving partners from NWE (Table 1.3) is an initiative of European Automotive Strategy Network, which is a platform for European Automotive regions, clusters, companies and institutes. The partnership aims to boost innovation and competitiveness of the developing BEV sector through structured transnational cooperation between public authorities and business representatives. The contributions of the partnership to this research study can be summarised as follows:

- To support the transition from ICEV to BEV, mass production of BEVs need to be established. However, this requires strong supply chains. Competencies need to be found and connected to develop strong supply chains. As part of the ENEVATE project a database was developed in order to capture the competencies within the existing ICEV and nascent electric mobility sectors across NWE. The partnership then conducted production structure analysis, make or buy analysis, value-add analysis, white spot analysis and competitor analysis (with interviews). The author of this study contributed to the interpretation of the results of those analyses and explained the changes in the industrial structure in Chapter 3 by using those results as a basis.
- One of the aims of the ENEVATE project was identifying opportunities for SME competitiveness and collaboration, and encouraging SMEs to use support instruments. This activity was initiated and directed by the author of this research. The ENEVATE network was only used to support this activity by identifying SMEs and interviewing them.

Table 1.3 ENEVATE Partners

Country	*ENEVATE Partners*
Belgium	Campus Automobile Spa-Francorchamps Flemish Institute for Technical Research
France	Pôle Véhicle du Futur
Germany	Agiplan GmbH Bayern Innovativ GmbH Forschungszentrum Jülich ETN Inno AG Regional management Nordhessen GmbH
Ireland	Electricity Supply Board
Netherlands	AutomotiveNL
United Kingdom	Cardiff University Future Transport Systems European Automotive Strategy Network

1.8 Thesis Structure

This thesis is divided into a number of chapters, which are as follows:

Chapter 2 Response of Automobile Manufacturers to the Challenge of Reducing Transport Emissions

This chapter provided an extensive review of GHG regulations and strategies of vehicle manufacturers to respond the regulations. It started with discussion on environmental pressure, Kyoto Protocol and emerging GHG regulations in different regions in the world. Next, available technologies to reduce GHG emissions from automobiles were discussed and technology strategies of carmakers in different regions were examined. After that, strategies of carmakers and GHG targets imposed by the regulations including the EU`s 2050 GHG reduction target were compared to assess the automotive industry`s technological transition pathway. By doing so, the need for electrification in the automotive industry was clarified. Finally, challenges regarding electrification of vehicles in Europe to achieve 2050 GHG emission reduction target were analysed and this research`s strategy to overcome these challenges were described.

Chapter 3 BEV Sector of Today and the Future

In this chapter, the implications of BEVs on the industrial structure were analysed and competences and capacities needed for mass production of BEVs in Europe were explored. A production structure analysis, make or buy analysis, value-add analysis, white spot analysis and competitor analysis were conducted. The results of analyses were then used to develop a set of strategies for a commercially strong BEV sector in Europe.

Chapter 4 BEV Technology Value Chain and SMEs

This chapter explored the approach of SMEs to the emerging BEV sector to understand SMEs and identify support areas they need to have a role in the possible BEV based automotive value chain re-shaping by conducting a series of interviews with SMEs in NWE. In this respect, adopted interview methodology was discussed. Then, interview results were presented. Next, the results of interviews were linked with EU`s two recent framework programmes (Seventh Framework Programme and Horizon 2020) to improve the link between policy and delivery. In so doing, it was recognised that improving the link between policy and delivery for SMEs might stimulate the EV technology and business in Europe.

Chapter 5 Development of a Policy Intervention Evaluation Framework for EV Technology Development

This chapter proposed an ANFIS based policy intervention evaluation framework for EV technology development which provides an ex-ante impact of various innovation decisions to support national governments in making informed decisions. In this regard, firstly, input parameters (technology-push and technology-pull instruments) and output parameter (patent filings) for the aforementioned framework were discussed. Next, a dataset was generated by analysing EV innovation policies of USA, Japan, EU, Germany, France and UK and comparing them with the actual EV technology development that was measured by patent filings in those regions. Subsequently, an ANFIS model was constructed by specifying an equation and transforming the generated dataset into input-output data pairs. Lastly, the data pairs were used for training and validating the ANFIS framework by using the MATLAB software.

Chapter 6 Trial of the Policy Intervention Evaluation Framework for EV Technology Development

This chapter explained how the ANFIS framework was applied to Austrian instruments to make suggestions about Austrian future innovation policies for supporting EV technology development. In this respect, firstly, data for Austria which was obtained from the FFG were checked with the ANFIS model to test the validity of the model. Secondly, three different innovation policies were developed. Two of these scenarios were developed by FFG in cooperation with the Austrian Ministry for Transport, Innovation and Technology. The last scenario was developed theoretically based on the results of Chapter 4 which investigated support areas they need to have a role in the possible BEV based automotive value chain re-shaping. Those scenarios were then used as inputs for the ANFIS model to calculate the effect of those scenarios on the innovation output. Finally, qualitative cost-benefit analysis (CBA) was used to understand the wider impacts of policy scenarios on a range of cost and benefit components.

Chapter 7 Conclusions

This chapter presented research conclusions providing a summary of the key findings obtained with this project, limitations and further work outlining some recommendations for future investigation.

The next chapter reviews the existing GHG regulations and carmakers` strategies to reach those targets, explores the automotive industry`s technological transition pathway to respond the challenge of long term (2050) GHG emission reduction target of the EU and discusses challenges regarding aforementioned transition pathway in order to substantiate this research`s strategy to overcome the GHG emission reduction challenge in the automotive industry.

CHAPTER 2 - RESPONSE OF AUTOMOBILE MANUFACTURERS TO THE CHALLENGE OF REDUCING TRANSPORT EMISSIONS

2.1 Introduction

Triggered by the environmental pressure, several governments have been introducing fuel economy and emission regulations to decrease greenhouse gas (GHG) emissions from the automotive industry. Among those regulations, one of the strictest regulation was adopted by the European Union (EU). The EU adopted a regulation which established a carbon dioxide (CO_2) emission target of 130 grams per kilometre (g/km) for the average of new cars sold by 2015. The regulation was later amended and established a stricter emission target of 95 g/km by 2021. Besides, the EU set a long term target of achieving overall at least 80% CO_2 reduction by 2050 compared to 1990 levels [7].

To respond these regulations and GHG targets, a portfolio of technologies have been developed by automobile manufacturers. Although some of those technologies are already available and have some market penetration but could be used more extensively, other technologies are new or presently very costly to be broadly used. These technologies might be classified under two headings: technologies for improving the efficiency of conventional internal combustion engine vehicle (ICEV) and electric vehicle (EV) technologies. Both options are recognised to have significance on different timescales between now and 2050 [12].

This chapter reviews GHG regulations adopted by different governments and analyses available ICEV and EV technologies to reduce GHG emissions from automobiles. Strategies of carmakers in different regions concerning aforementioned technology options are also examined. Next, strategies of carmakers in the EU and the EU`s GHG targets imposed by the regulations including the long term (2050) GHG reduction target are compared to examine the automotive industry`s technological transition pathway. By scrutinising such technology transition pathway, the need for electrification in the automotive industry to achieve 2050 target is clarified. Next, challenges concerning electrification of vehicles are discussed and this research`s strategy to respond such challenges is described.

2.2 Environmental Pressure and Emission Regulations for Cars

Although the Earth has experienced a changing climate since the beginning of time, human activity has caused significant climate change during the last century. In literature, global warming describing the observed increase in the Earth's average temperature is broadly acknowledged. The reason for global warming is the build-up of key GHG in the atmosphere accumulated from continual use of fossil fuels and land-use changes over the 20^{th} century [1].

As a response, numerous governments have signed the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) that was held in Rio de Janeiro from 3 to 14 June 1992 [2] and they have agreed that global warming has to be limited to below 2°C (degrees Celsius) compared to the average temperature in pre-industrial times to prevent the most severe impacts of climate change and possibly catastrophic changes in the global environment [110]. To achieve UNFCCC`s 2°C Scenario (2DS) requires significant and urgent efforts that need to be implemented by 2050. According to International Energy Agency (IEA), energy use more than doubles and total GHG emissions escalate significantly by 2050 without efforts to stabilise atmospheric concentrations of GHGs. Thus, average global temperature rise is projected to be at least 6°C in the long term (the 6°C Scenario (6DS)) [111]. To prevent such situation, the countries that signed the Kyoto Protocol committed themselves to decrease GHG emissions. The treaty set no binding limits on GHG emissions for individual countries and contained no enforcement mechanisms.

However, on 11 December 1997, the Kyoto Protocol establishing legally binding obligations was adopted in Kyoto, Japan, and entered into force on 16 February 2005. The protocol implemented the objective of the UNFCCC to fight global warming by reducing GHG emissions. During its first commitment period, from 2008 to 2012, thirty seven industrialized countries and the European Community (now the EU) committed to take a prominent role in climate action by decreasing their GHG emissions by at least 5% below 1990 levels [2]. The year 1990 was chosen as a reference year since that was the year when the United Nations first launched negotiations on climate change.

In 2012, a second commitment period for the Kyoto Protocol was decided. It was designed to reduce emissions of participating Parties by at least 18% below 1990 levels between 2013 and 2020 to achieve 2050 GHG emission target [2]. Currently, governments are ratifying these new targets. Recognised as the Doha Amendment, it is expected to enter into force after three quarters of the Parties to the Protocol submit their instruments of acceptance to the Depositary [112]. For 2020, the EU has made a unilateral commitment to reduce overall GHG emissions from its twenty eight Member States by

20% compared to 1990 levels. Such commitment is also now one of the key targets of the EU 2020 strategy [3].

Since oil is the dominant fuel source for transportation, transport is a key contributor to GHG emissions [1], as displayed in Figure 2.1. It is significant to mention that the copyright of the figures used in this chapter including Figure 2.1 is not with the author of this study, but resides elsewhere. The related references for the figures are given throughout this chapter.

Figure 2.1 shows that, in 2009, transport used nearly 100 exajoules (EJ) accounting for more than 50% of the global oil use. Road vehicles including cars, trucks, buses and two-wheelers also accounted for almost 75% of transportation fuel use worldwide, with most of the rest used by ships and aircraft. Light-duty vehicles or LDVs (cars and "passenger light trucks" including sports utility vehicles (SUVs), minivans and personal pick-up trucks) accounted for more than 50% of road usage [4].

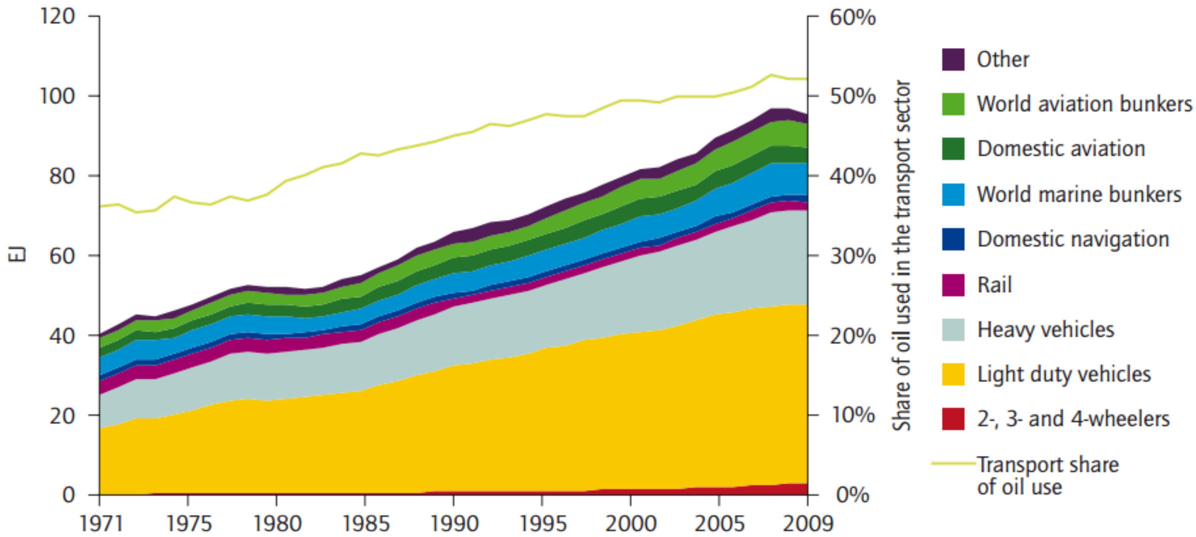


Figure 2.1 World transport energy use by mode, 1971-2009 [4]

Road transport therefore plays a key role for decreasing GHG emissions and achieving UNFCCC`s 2DS. However, achieving 2DS requires significant cuts in CO_2 emissions, which is the main GHG, from road transport by 2050 and this necessitates strong measures. Indeed, according to IEA [111], without significant efforts (6DS), fuel use in all road modes will increase significantly with total fuel use doubling between 2010 and 2050 as illustrated in Figure 2.2. As oil is the dominant fuel source for road transport [1], CO_2 emissions rise at a similar rate. In 2010, cars emitted more than 2 gigatonnes of CO_2

($GtCO_2$) emissions globally on a well-to-wheel (W2W) basis (about 85% from the fuel combustion in the vehicle and 15% from fuel production and distribution) in comparison to just over 1 $GtCO_2$ for passenger light trucks and nearly 1.8 $GtCO_2$ for freight trucks. Buses and two-wheelers emitted much lower CO_2 emissions: approximately 0.5 $GtCO_2$ and 0.2 $GtCO_2$ respectively. These numbers indicate that automobiles are the highest level of CO_2 emitters in the road transport.

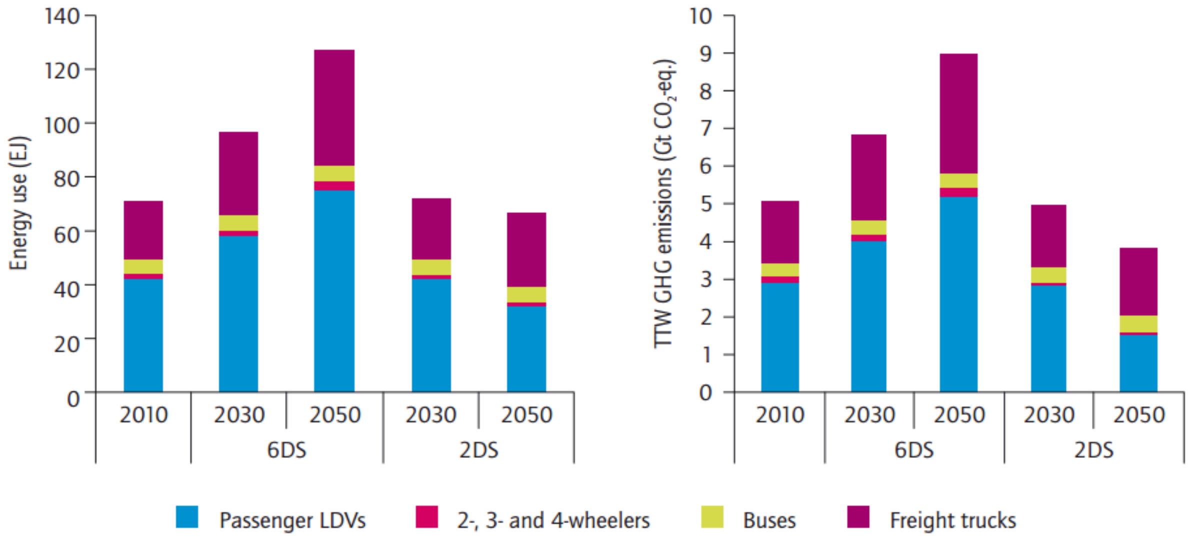


Figure 2.2 Road fuel use and CO_2 by vehicle type in 2DS and 6DS scenarios [111]

To achieve 2DS, energy use and CO_2 emissions of automobiles therefore need to be reduced substantially by 2050. Aligned with such perspective, transport was one of the key sectors highlighted to be tackled by the 1997 Kyoto protocol. In this respect, transport has featured heavily in the political agendas of the 38 parties who signed the agreement since 1997 [1]. To reduce energy use and CO_2 emissions, governments have introduced increasingly stringent fuel economy and emission standards. Different countries and regions have adopted different fuel economy or GHG standards owing to numerous historic, cultural, and political reasons [113].

The differences between standards arise from the level of stringency, the standards` forms and structures and testing methods which explain how the vehicle fuel economy or GHG emission levels are evaluated [113]. For example, vehicle fuel economy standards may be in the form of numeric standards on the basis of vehicle fuel consumption such as litres of gasoline per hundred kilometres of travel (L/100-km) or fuel economy such as miles per gallon (mpg) or kilometres per litre (km/L). GHG emission standards might also be expressed as grams per kilometre (gCO_2/km) or grams per mile (gCO_2/mile). Testing methods might be different across regions. Three well-known examples are the United States of America (USA) city and highway cycles, the new European drive cycle (NEDC) and Japan`s JC08 cycle tests [113]. Three different standards in three different regions, EU, USA and Japan, are discussed below.

2.2.1 EU Standards

Fuel consumption was firstly considered from the perspective of fuel by the EU. However, owing to its commitments under the Kyoto Protocol of the UNFCCC, the strategy was later changed to regulate CO_2 emissions from vehicles [113]. When labelling vehicles on the market, different member states still have diverse reporting units including gCO_2/km and L/100-km. However, NEDC tests are based on gCO_2/km [113].

For regulating CO_2 emissions, the EU first established a set of voluntary emission reduction targets agreed with the European Automobile Manufacturers' Association (ACEA) in 1998. These targets were designed in a way that the average emissions of all new cars sold in the EU would be equal or less than 140 gCO_2/km by 2008 through technological measures and it would be no more than 120 gCO_2/km by 2012 through non-technological measures (taxation/labelling) [76]. However, the average for the whole car fleet for 2008 was approximately 153.7 g/km [29]. Thus, the 2008 CO_2 emissions target was not attained.

To further strengthen its measures to automakers and reach its commitments under the Kyoto Protocol, a legislative framework was introduced in order to provide drivers for the EU automotive sector towards a set of specific CO_2 reduction targets, thus in April 2009, the EU adopted Regulation 443/2009/EC which established a CO_2 emission target of 130 g/km for the average of new cars sold by 2015. This regulation was amended in March 2014. The amended regulation established a stricter emission target of 95 gCO_2/km by 2021 [29]. The EU also aims to cut its overall CO_2 emissions substantially by at least 80% by 2050 compared to 1990 levels to comply with UNFCCC`s 2° C global warming target although a legislative framework has not been introduced yet for this target [7].

2.2.2 USA Standards

After the 1973 oil crisis, the USA Congress passed the "Energy Policy and Conservation Act of 1975" which set the Corporate Average Fuel Economy (CAFE) standards for cars and light trucks [113]. For cars specifically, the standards aimed to double the fuel economy from 13.6 mpg in 1974 to 27.5 mpg by 1985. Different standards for light trucks were also introduced by the “National Highway Traffic Safety Administration” (NHTSA). The standards` main aim was to decrease the USA`s dependence on foreign oil rather than addressing environmental or public health concerns. To further increase fuel efficiency, the “Energy Tax Act of 1978” introduced a tax on “gas-guzzler” cars. At the beginning of 1980s, cars which were not able to reach a minimum fuel economy requirement of 15 mpg qualified for the gas-guzzler tax. In 1991, the minimum fuel economy requirement was increased to 22.5 mpg [114].

In May 2009, after the declaration by President Obama, USA aimed to significantly reduce GHG emissions. In USA`s history, it was the first time that regulation both established GHG emissions and CAFE standards owing to the judgement of the USA Supreme Court which ruled that CO_2 is considered a "pollutant" under the Clean Air Act (CAA). It was also the first time that, GHG emissions were regulated at the federal level. “Environmental Protection Agency” (EPA) was authorised to regulate GHG emissions. NHTSA also retained control over CAFE standards [114]. The average light duty vehicle GHG emission rate is reduced to 36.2 mpg (equivalent to 152 gCO_2/km under NEDC cycle) threshold for model year (MY) 2016 [34].

After the successful adoption of a National Programme for GHG and fuel economy standards for MYs 2012-2016 vehicles, President Obama invited the agencies to continue their efforts to develop a second phase of the National Programme, with standards for MYs 2017-2025 light-duty vehicles. In August 2012, EPA and NHTSA jointly issued GHG emissions and fuel economy standards to cover model years 2017 to 2025 [114]. The average light-duty vehicle GHG emission rate is decreased from the MY 2016 level of 36.2 mpg to 59.1 mpg (equivalent to 93 gCO_2/km under NEDC cycle) for MY in 2025 [34].

2.2.3 Japan Standards

The Law regarding the rational use of energy (“Energy Conservation Law”) which was approved in 1979 established the basis for Japan’s fuel economy regulations. The law authorised the “Ministry of International Trade and Industry” (MITI) to set fuel economy standards for passenger vehicles. The first fuel economy standards were set at the same year and applied to MY 1985 vehicles. Next targets were established in 1993 and applied to MY 2000 vehicles. In 1999, revisions to “Section 6 of the Energy Conservation Law” introduced the “Top Runner Programme” [114].

The programme can be described as an energy efficiency system applicable to automobiles and specific kinds of machinery under the authority of the "Ministry of Economy, Trade and Industry" (METI). The Top Runner Programme for passenger vehicles (classified as cars with a riding capacity of 10 people or less) determines the most fuel-efficient automobile in each weight class and entitles it the "top runner." Next, fuel consumption targets are set at the level of the top runner. All other vehicles are required to meet or exceed the new target values for their weight class within three to ten years. The 1999 Top Runner Programme established a fleet average target of approximately 15.1 L/km for 2010, and in 2007 a target of 16.8 L/km (under the Japanese JC08 driving test cycle (equivalent to 125 gCO_2/km under NEDC cycle) was set for 2015. Recently, the Japanese government issued 2020 standards that would set the fuel economy target at 20.3 km/L (equivalent to 105 gCO_2/km under NEDC cycle) [114].

To reduce GHG emissions substantially by 2050 and comply with UNFCCC`s 2° C global warming target, other countries are also introducing stringer GHG emission standards, as displayed in Figure 2.3. The pressure is therefore on the automotive sector to develop more and more fuel efficient and environmentally friendly technologies which have lower or even zero direct CO_2 emissions. In the following section, car technologies to increase fuel economy and decrease CO_2 emissions will be discussed.

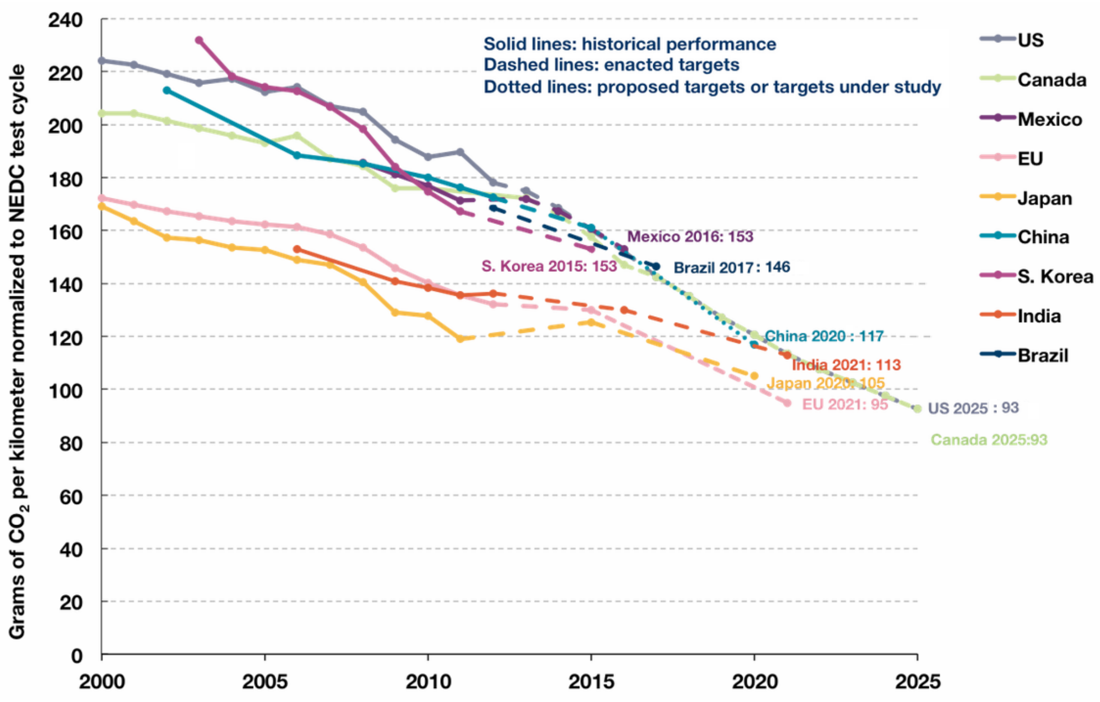


Figure 2.3 Global comparison of passenger vehicle GHG emission standards normalised to NEDC gCO_2/km [114]

2.3 Technologies to Reduce Emissions from Cars

There are several technological options for automobile manufacturers to improve the fuel efficiency and reduce the GHG emissions of vehicles. While the majority of these technologies are currently available and have some market penetration but might be used more extensively, other technologies are new or presently very costly to be extensively used. Nevertheless, the overall potential for applying these technologies is considered to be high. Alternative fuels including biofuels, hydrogen and electricity are also available [4]. In this study, the focus remains on the technological options for automobile manufacturers although alternative fuels are mentioned with respect to discussed technologies.

For automobile manufacturers, there are two main possible technology pathways for reducing emissions: (i) improving fuel efficiency and reducing GHG emissions from conventional ICEVs and (ii) a transition from ICEVs to low carbon vehicles. Both options are recognised to be significant for automobile manufacturers on different time periods between now and 2050 [12]. In the following sub-sections, both of these pathways will be discussed.

2.3.1 Reducing Emissions from ICEVs

The ICEV is widely available, highly developed and relatively low-priced [12]. However, it is assumed that approximately 14-30% of the energy contained in a litre of fuel is used to drive an ICEV. The rest of the energy is lost to engine and driveline inefficiencies or used to power accessories [11]. Thus, CO_2 emissions per vehicle-km for cars are thought to be normally in the region of 100-225 gCO_2/km. The poor energy conversion efficiency of ICEVs has been accepted owing to the ready availability and low cost of fossil fuels in most of the 20th century [12]. However, owing to the stringent fuel economy and GHG standards, there is a need to improve the energy conversion efficiency of ICEVs, which might be possible to some extent with advanced technologies.

Figure 2.4 displays the breakdown of energy conversion in a typical ICEV. In reality, diverse engine configurations and sizes result in the variations depicted in the figure [11]. As can be seen, most of the available energy in the fuel is transformed to heat rather than work as a consequence of combustion inefficiencies, heat transfer from the engine block, wasted high temperature exhaust gases, friction, pumping, drivetrain losses etc. Most losses are from the powertrain which means that vehicle efficiency might be increased significantly by improving the powertrain. Apart from the powertrain, a broad array of vehicle technologies might also help improve vehicle efficiency by lowering the energy demands on the drive train [12]. In this respect, the technologies available to improve the fuel economy and reduce GHG emissions of cars include powertrain and overall vehicle improvements such as weight, aerodynamics, tyres and auxiliary power systems (lights, heating, air conditioning, etc.), as discussed below [4].

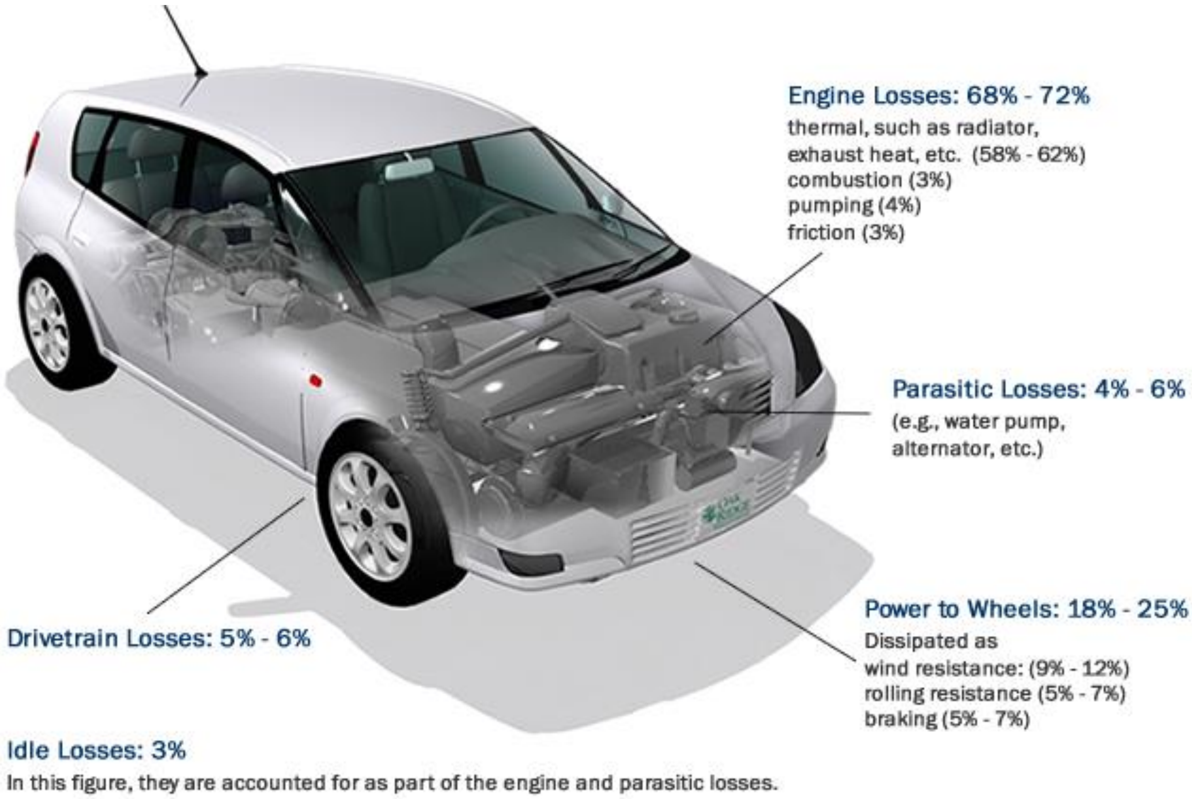


Figure 2.4 Losses of energy for a typical passenger vehicle [11]

2.3.1.1 Overall Vehicle Improvements

The powertrain transforms energy in the fuel into the useful motive or tractive energy at the wheels to propel the vehicle. This energy is used to overcome the vehicle's inertia, wind resistance and rolling resistance. Besides, it powers the auxiliaries such as heating, ventilation, air-conditioning, pumps and power steering. Decreasing inertia, wind resistance and rolling resistance and using auxiliaries demanding less energy might therefore result in efficiency gains regardless of the fuel source or powertrain type [12]. Technologies for overall vehicle improvements are described below and summarised in Table 2.1. Nevertheless, it is significant to explain that all numbers in terms of costs discussed in this section and the next section are approximate only, and these numbers are only given to compare different technologies. There are different numbers discussed in the literature. For example, some costs mentioned in Table 2.1 and Table 2.2 are different than the costs discussed by Hill et al. [115]. However, although the costs for technologies for improving the fuel efficiency of ICEVs vary in literature, it does not change the fact that these costs are very low compared to costs required for adopting electric propulsion technologies as adoption of EV technologies require the creation of very high new capital intensive systems. This will be discussed more in depth in section 2.4.1.

Firstly, the tractive energy is used to overcome the vehicle's inertia when accelerating. Nevertheless, when brakes are used, energy which is initially used to overcome inertia and propel the vehicle is lost as heat through friction at the brakes. Since less energy is needed to move a lighter vehicle, less energy is also wasted from braking a lighter vehicle [11]. Thus, weight reduction decreases the energy required and increase the fuel efficiency resulting in less GHG emissions. Weight reduction can be achieved in a number of ways: (i) reducing vehicle size (ii) reducing chassis weight by re-designing the vehicle and using lightweight materials such as aluminium and composite materials and (iii) reducing powertrain weight. It is argued that 0.7% efficiency improvement might be achieved for each 1% weight reduction [12].

Table 2.1 Overall vehicle improvements (all numbers are approximate only) compiled from [4, 11, 12].

Overall Vehicle Efficiency Improvements				
Improvements	*Losses Affected*	*Relevance*	*Improvement Potential*	*Costs*
Weight Reduction (Inertia)	Power to Wheels	Relevant in stop-start driving, for example in cities (urban and suburban driving)	0.7 % efficiency improvement for each 1% weight lost; up to 10% savings possible	£250-1500 (€355-2130) for 10% weight reduction
Aerodynamics (drag)	Power to Wheels	Relevant at higher speeds (greater than 40 miles per hour (mph) or 65 kilometres per hour (km/h), e.g. intercity motorway driving.	3-7% improvement in fuel consumption	Low; part of vehicle design phase
Rolling resistance	Power to Wheels	Relevant for all types of driving	5–7% reduction in rolling resistance increases fuel efficiency by 1%; up to 5% savings possible	$40-70 (€36-64)
Head lamps (halogen, xenon, LEDs)	Parasitic Losses	Relevant for all types of driving	0.2-0.5%	$300-500 (€272-453)
Air Conditioning Systems	Parasitic Losses	Relevant for all types of driving	2-4% (more in hot regions)	$100-200 (€91-181)

Secondly, the tractive energy is used to overcome the wind resistance. Less energy is required at lower speeds and more energy is needed when the speed increases. Wind resistance is directly related to the vehicle's shape and frontal area. Thus, another way of increasing fuel efficiency and reducing CO_2 emissions is reducing the vehicle`s frontal area and streamlining the vehicle [11]. Aerodynamic streamlining does not usually require additional materials, although it may need new types of material. Aerodynamic streamlining for new models such as with spoilers, front air dams, side skirts and under-body panels requires investment in design and styling. However, such investment is unlikely to be high with regards to costs per vehicle [4]. Although smoother vehicle shapes have already reduced drag significantly, further reductions are still possible. It is argued that 3-7% improvement in fuel consumption might be achieved by reducing aerodynamic drag [12].

Thirdly, the tractive energy is used to overcome the rolling resistance which is related to flattening and friction of the tyre as it rolls. New tyre designs and materials might decrease rolling resistance. It is claimed that a 5-7% reduction in rolling resistance increases fuel efficiency by 1%. Still, these improvements must be balanced against traction, durability, and noise [11]. According to one of IEA`s recent reports [4], up to 5% savings in fuel efficiency might be possible. Low rolling resistance tyres (LRR) are already increasingly used by automobile manufacturers as they are not expensive. LRRs are thought to come with a cost of approximately $40 (€36) per vehicle, which is expected to decrease to $20 (€18) per vehicle in the medium to long term. Tyre pressure monitoring systems are also being introduced at a cost of around $20-30 (€18-27) per vehicle to guarantee that tyre pressure is optimal for driving. The only change they require is the introduction of an additional sensor per wheel or the integration of the information collected from other sensors [4].

Lastly, the energy is used to power the auxiliaries. According to the IEA`s report [4], using more efficient head lamps and air conditioning systems might increase the fuel efficiency of the vehicle. It is claimed that most vehicles are equipped with halogen headlamps which are comparatively inefficient. Light-emitting diode (LED) and xenon lamps are thought to be more efficient although they might be costly. Xenon lights might reach halogen performance with less than half the energy use. However, they are more expensive. LED lamps still currently cost more than xenon lights but their potential for cost reduction appears to be greater. For use as daytime running lights, LEDs offer significant near-term energy savings at modest cost. Improved mobile air conditioning (MAC) systems could also save 2-4% of vehicle fuel use in areas where air conditioning is used a significant percentage of the time. The additional cost of a high efficiency MAC system is thought to be around $100-200 (€91-181) [4].

2.3.1.2 Powertrain Improvements

The second option for increasing the fuel efficiency and reducing GHG emissions is using advanced technologies for internal combustion engine (ICE) powertrain. It is claimed that approximately 15% improvement in ICE efficiency is possible. There are several technologies to reduce powertrain losses. Table 2.2 summarises these technologies. These technologies might also be used together to some extent. Lots of these technologies are already used in today`s cars and they are diversely branded by carmakers such as Volkswagen Bluemotion, BMW efficient dynamics or Renault Eco. Typically, these cars emit approximately 18% less CO_2 emissions compared to a similarly sized vehicle with the same sized engine. Powertrain savings may be increased if the ICE engine can be downsized as smaller engines exhibit lower engine (friction and pumping) losses. Performance of the engine might still be maintained by turbocharging the downsized engine [12].

Table 2.2 Improvements to ICE powertrains adapted from [12]

ICE Powertrain Improvements				
Improvements	*Losses affected*	*Description*	*Improvement potential*	*Costs*
Engine downsizing	Engine loss (friction and pumping losses) Idle loss Power to wheels	Engine downsizing without performance penalty through enhanced boost (turbo-charged; supercharged-mechanical or electrical). Applicable to all ICEs.	Modest downsize with turbocharging gives a 5-7.5% fuel economy benefit. Large $C0_2$ reduction (30-40%) might be possible with extreme downsizing.	Modest downsizing using turbocharging costs $120-690 (€109-625). Diesels are more expensive than gasoline.
Exhaust gas energy recovery	Engine loss (exhaust loss)	Thermo-electric devices, secondary cycles or turbo-generators recover some of the energy lost as heat in the exhaust stream. With a turbine, it is possible to make better use of the exhaust energy by tuning the device to recover unsteady flow energy.	6-10 % efficiency increase using turbo generator	unidentified
Improved combustion	Engine loss (combustion loss)	Direct injection, increased compression ratios and wider lean burn power ranges give some improvement. Higher improvement with advanced combustion processes such as homogeneous charge compression ignition (HCCI).	HCCI could give 50% improvement in engine efficiency at part load compared to spark ignition engines and 30% compared to compression ignition engines	HCCI costs $263-685 (€238-621) for cars. Yet, technical challenges remain in controlling HCCI over varying operating conditions. Direct injection: $122-525 (€111-476)
Variable valve timing (VVT)	Engine loss	A control improvement. Camless (actuator driven valves) engine is still a possibility for the future.	0.5-7%	$169-322 (€153-292)

ICE Powertrain Improvements				
Improvements	*Losses affected*	*Description*	*Improvement potential*	*Costs*
Auto stop/start with improved alternator controls	Idle loss Parasitic loss Power to wheels	Engine turned off if vehicle stopped for more than a few seconds. It requires driver interaction such as gearbox in neutral position. Alternator is engaged (loaded) during braking, coasting or decelerating only.	3-7%	$600 (€544)
Kinetic energy recovery system (KERS)	Power to wheels: significant in urban driving.	Every time a car brakes, kinetic energy is wasted. A hydraulic system or a flywheel (about 70% round trip efficiency) or electric system (about 50% round trip efficiency) can recover some of this.	About 20% CO_2 saving using flywheel system	Car-based flywheel KERS cost $1500 (€1359) in mass production
Transmission improvements	Drivetrain loss	Some improvement for manual gearboxes such as dual clutch. Higher improvements for automatic	4-5%	£400-600 (€568-852)

Regarding ICEs and fuels, most of today's ICEVs use petroleum gasoline or diesel fuel with two types of engine: spark-ignition for gasoline, liquid petroleum gas (LPG) and natural gas, and compression-ignition for diesel fuel. These engines operate differently with different efficiencies. Diesel engines are assumed to be on average 25-30% more energy efficient for a similar vehicle. However, they are more expensive and they require exhaust after-treatment systems for pollutant emissions [4].

Overall, emissions from ICEVs might be reduced by applying several technological improvements which might be summarised under two headings: overall vehicle improvements and ICE powertrain improvements. It is argued that the lowest CO_2 emission level that might be achieved with best diesel ICEVs is 80-90 gCO_2/km. To surpass this limit using ICE requires electrification and/or biofuels. Regarding biofuels, it is claimed that owing to possible supply limitations, their optimal transport use in the long term might be for long haul trucks/buses and aircrafts rather than cars, where alternatives to liquid fuels are not presently viable [12]. Besides, there are serious concerns regarding the environmental impact of biofuels. According to a recent study [13], to achieve an 8.8% of the total energy with biofuels in transport by 2020 (which is aligned with the EU`s renewable energy target: 10% of transport fuel to be from renewable sources by 2020) will emit between 81-167% more GHG than fossil fuels and necessitate an area twice the size of Belgium in new land to grow biofuel crops. In that context, most authors now converge on the idea that electric propulsion represents the most viable short-term solution [14-20] for reducing the emissions of cars below 80-90 gCO_2/km. In the following section, electrification of powertrain will be discussed.

2.3.2 Reducing Emissions with Electric Mobility

The second option for reducing GHG emissions for automobile manufacturers is electric mobility referring to the electrification of the automotive drivetrain. EVs may either augment the ICE (hybridise) or eliminate the need for it altogether. Hybrid and electric vehicle system components may include a battery for energy storage, an electric motor for propulsion, a generator, a mechanical transmission and a power control system. These components are brought together in different ways by different systems to partially or fully electrify the vehicle drivetrain as demonstrated in Figure 2.5. These powertrain technologies are discussed below.

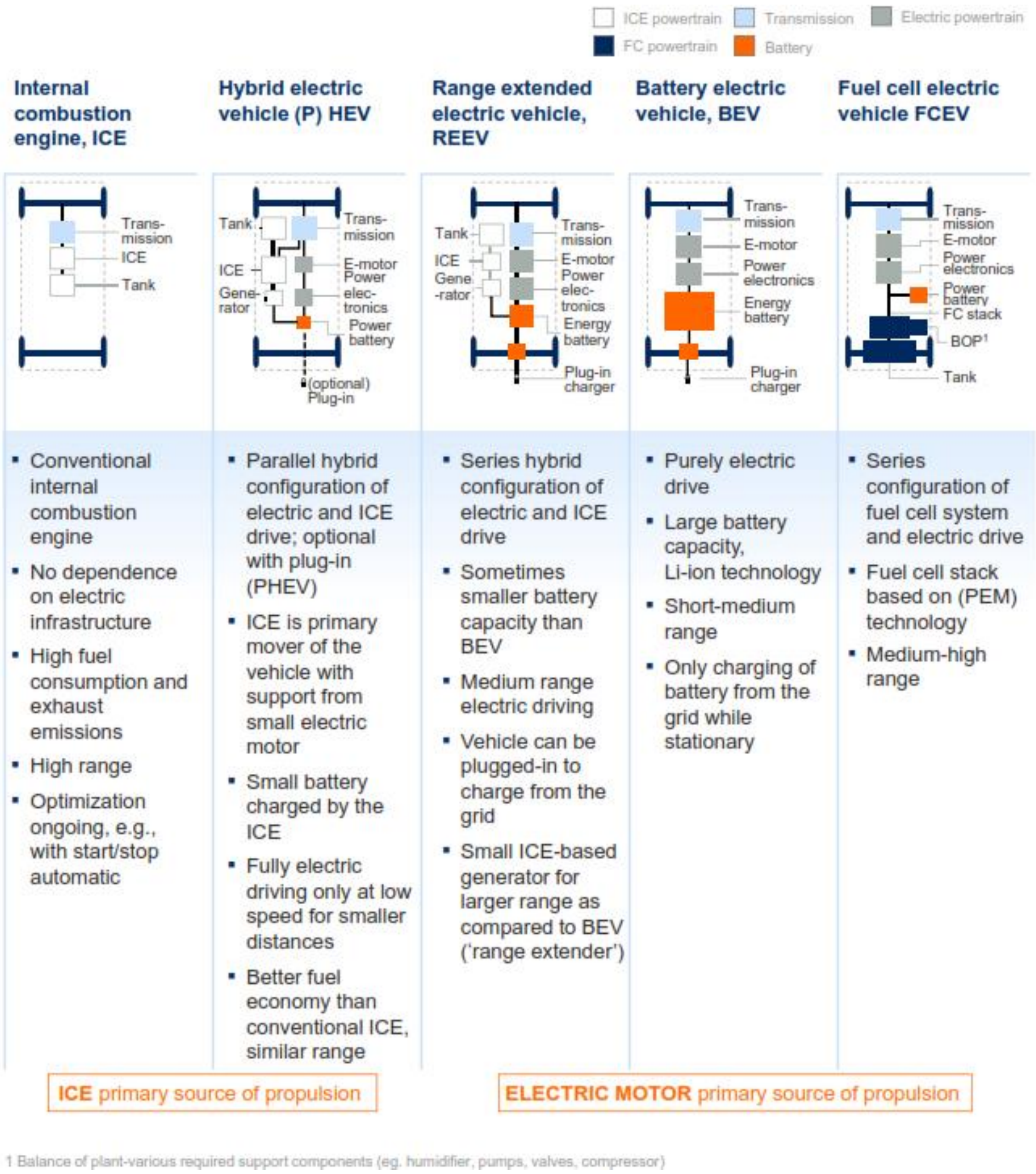


Figure 2.5 Different powertrain technologies in detail [34]

2.3.2.1 Hybrid vehicle (HEV)

As can be seen in Figure 2.5, a HEV uses a battery-powered electric motor to supplement its traditional ICE [6, 116]. There are two types of HEVs: parallel and serial hybrids. In a parallel hybrid vehicle, the ICE and electric motor operate on the same drive shaft; either or both might power the vehicle whereas in a series hybrid the motor drives the vehicle using electricity from either the batteries and/or a small ICE, which operates as a secondary power unit driving a generator as displayed in Figure 2.6. A "combined" hybrid allows operation in either mode [12].

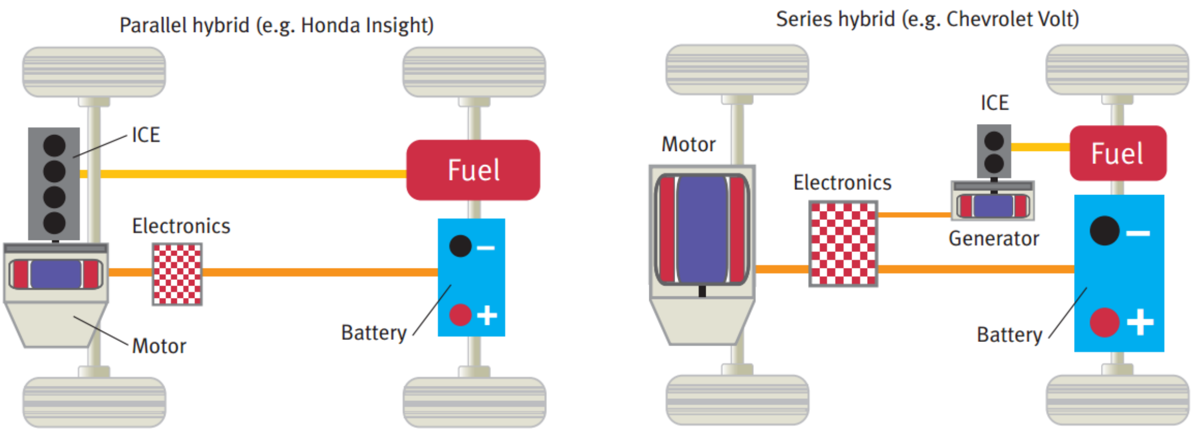


Figure 2.6 Parallel and series hybrid [12].

The addition of the electric motor reduces idling and enables the vehicle to operate with zero emissions at low speeds (typically below 95km/h). Thus, HEVs offer better fuel efficiency and create less emissions compared to traditional ICEVs [117, 118]. It is assumed that significant fuel economy benefits of 40-60% in urban (stop-start) driving can be gained with HEVs [12]. At higher speeds, the combustion engine drives the vehicle [118, 119] and it is believed that HEVs perform similarly to conventional, efficient diesels at highway speeds. Combined urban and motorway driving is assumed to provide approximately 15-30% fuel savings [12].

From a mechanical and control perspective, the extra complexity of HEVs compared to ICEVs increases the energy required (and therefore the amount of CO_2 emitted) during production. Still, the impacts of this are significantly surpassed by the CO_2 emissions savings achieved during use resulting in overall lower lifecycle CO_2 emissions compared with conventional vehicles. Nevertheless, a hybrid requires an ICE and one or two powerful electric motors/generators. Motors are thought to cost approximately the same per kilowatt as ICEs. This implies a large capital cost increase. Batteries and power electronics are also a substantial cost [12].

2.3.2.2 Plug-in hybrid vehicle (PHEV)

As demonstrated in Figure 2.5, a PHEV is similar to a standard HEV since it combines an electric motor with a traditional ICE. Yet, the main difference between these vehicles is that a PHEV can be recharged by plugging the vehicle into an electrical outlet [117, 119, 120]. Besides, a PHEV can be driven in purely electric drive mode within the maximum range of the energy storage. The naming convention for PHEVs explains how far each PHEV can be driven on electricity alone. For instance, a $PHEV_{40}$ can be driven for 40 kilometres [12].

The calculation of the CO_2 emissions emitted by the vehicle is contingent upon the amount of fuel versus electricity used in addition to the carbon intensity of the grid. A variety of PHEV operating modes in different combinations are possible as explained below [12].

- *Charge depleting mode:* All-electric operation with ICE turned off
- *Charge sustaining mode*: Battery state of charge stays within a narrow band. This is the same operating mode used in HEVs.
- *Blended mode*: Charge-depleting mode with ICE contributing at high speeds or high loads.

Based on aforementioned modes, potentially very low or even zero CO_2 emissions are possible in all-electric mode if the electricity is supplied from a low- or zero-carbon source [12, 121, 122].

The idea of using a small ICE as a range extender offers a large amount of flexibility and bridge the gap between conventional ICEVs and EVs [12]. Thus, PHEVs also mitigate many of the challenges that face EVs such as “range anxiety”, which describes the fear of getting stranded with a discharged battery, and, to some extent, cost as a comparatively small battery pack is needed [32]. Yet, charging infrastructure needs to be established (as for battery electric vehicles). Still, there is significant potential for home and workplace charging [12].

2.3.2.3 Battery electric vehicle (BEV)

Unlike HEVs and PHEVs, BEVs are 100% electric. They do not include ICE and consist only of batteries, power electronics and motors as illustrated in Figure 2.5. They rely solely on their electric motors for propulsion and, hence, they create zero tailpipe emissions [121, 123].

In the past, the on-board energy supply of BEVs was based on “*lead-acid, nickel-metal hydride (NiMH) or sodium-nickel-chloride (ZEBRA) batteries*” [48]. However, nowadays, BEVs generally use lithium ion (li-ion) batteries as lithium is the lightest of all metals and li-ion batteries offer high energy as well as power density [48, 49]. Besides, li-ion batteries require little maintenance compared to other batteries, and li-ion battery chemistries and cell construction are developing fast. For example, the frequently used, but costly, cobalt is being replaced by chemistries using "iron phosphate or manganese" [48].

However, there are concerns regarding the contribution of li-ion batteries to the environmental impact of BEVs. According to Notter et al. [48], who compiled a detailed lifecycle inventory of a li-ion battery and a life cycle analysis of BEV based mobility, the environmental impact of li-ion batteries used in BEVs for transport service is relatively small. This is because the lithium content in a li-ion battery is very low. It accounts for only 0.007 kg per kg li-ion battery. Besides, the processes that are used to extract lithium from brines are very simple and, thus, require low energy. Notter et al. [48] also argue that:

"Although lithium occurs in average concentrations lower than 0.01% in the Earth's crust and hence can be considered to be a geochemically scarce metal, assessment with abiotic depletion potential does not result in a high impact for the lithium components. Lithium carbonate (Li2CO3), the base material for the cathode active material and the lithium salt have an impact of only 1.9%. Compared to other components, for example, Mn2O3 (4.4%), copper (5.3%) or aluminium (15.1%), the abiotic depletion of lithium resources does not seem to be critical. However, these results are valid only as long as Li2CO3 is produced from brines. If the lithium components were based on spodumene, a silicate of lithium and aluminium, the extraction of the lithium would require a considerable amount of process energy."

Therefore, the environmental impact of li-ion batteries used in BEVs is small as long as the lithium is extracted from brines. On the contrary, the operation phase contributes significantly to the environmental burden caused by transport service as long as the electricity for the BEV is not produced by renewable sources [48]. Other studies in literature also found that the impact of operation dominates in transport service and "infrastructure, maintenance, and service" have minor contributions to the environmental burden of BEVs [50, 51]. In that context, to reduce GHG emissions and achieve sustainability in the automotive industry, electricity required for powering BEVs also needs to be produced from a low- or (ideally) zero-carbon source.

From a mechanical and control perspective, BEVs are typically simpler than hybrids. These vehicles also offer high powertrain efficiency and regenerative braking. However, the primary barrier for BEVs is capital cost. Current battery cell prices are very restrictive. Even though it is technically possible to achieve a range of more than 300 km, currently, high costs make such vehicles very expensive for the mass market. Other challenges for BEVs include battery energy density and durability, charging times and infrastructure. High power, high current fast charging might reduce charging times to less than 20 minutes. Yet, fast chargers are costly and necessitate sufficient local grid capacity. Degradation of battery life through fast charging is also a concern [12].

2.3.2.4 Range-extended electric vehicle (REEV)

A REEV might be said to be a cross between a PHEV and a BEV. Like PHEVs, REEVs use both ICEs and electric motors. Nevertheless, like BEVs, only electric motors are used for propulsion. The ICE in an REEV is used to power a generator. The generator charges the battery that powers the motor [119]. The "engine/generator" system enables the vehicle produce electricity when “battery-only range” or more is driven. Hence, those types of vehicles boost the driving range by adding hundreds of miles compared to BEVs.

2.3.2.5 Fuel cell electric vehicle (FCEV)

A FCEV uses a fuel cell to power its on-board electric motor. Fuel cells convert chemical fuel such as hydrogen, methanol or natural gas into electricity through a chemical reaction (generally by using oxygen from the air and hydrogen). FCEVs emit only water and heat, but no tailpipe pollutants. Thus, they are considered as zero emission vehicles although the well-to-wheel emissions are based on the fuel feedstock and processing route. Owing to the high energy density of hydrogen, longer distances might be travelled with those vehicles between fill-ups of hydrogen. Refuelling time for hydrogen tanks is also very short (a few minutes) [19]. However, the cost of FCEVs are presently much higher than ICEVs [12]. Moreover, they require hydrogen infrastructure which is currently extremely limited even compared with the BEV infrastructure [34].

In brief, electrification of powertrain is required for reducing transport emissions below 80-90 gCO_2/km [4]. However, there is a portfolio of technological options for automobile manufacturers regarding the electrification of the powertrain and each technological option comes with varying degrees of additional costs and other powertrain specific challenges such as related infrastructure, as summarised in Figure 2.7. In the following section, automobile manufacturers` strategies regarding above mentioned technological options to reduce GHG emissions from cars and reach the targets imposed by the regulations will be discussed.

	PHEV	REEV	BEV	FCEV
Environment	▪ Emission reduction because of battery and e-motor, but ICE still primary source of propulsion	▪ Substantial emission reduction compared to ICE – emission only when range extender is used	▪ Zero emission cars[2], far more efficient well-to-wheel than ICE	▪ Zero emission cars[2], far more efficient well-to-wheel than ICE
Benefits	▪ Use of existing fuel infrastructure ▪ Similar range as ICE	▪ Extender provides higher range than BEV ▪ Real electric car, less range anxiety	▪ Pure electric, zero emission car ▪ Charging possible at home / office etc.; infrastructure growing	▪ Range is high ▪ Refueling takes only a few minutes
Hurdles	▪ Low range on just e-motor ▪ ICE is still the primary source of propulsion - substantial emissions on longer trips	▪ Additional complexity and cost compared to a BEV ▪ Extender offers limited additional range	▪ Refueling takes long, even with fast charge at least 20-30 minutes ▪ Relatively low current range ▪ Infrastructure required, availability limited but growing	▪ Energy-intensive to produce hydrogen ▪ Hydrogen infrastructure required – currently very limited

1 Indicative comparison of typical models of xEV powertrains - differences exist by car model and by country. Conclusions also depend on (and might change as a result of) multiple assumptions (for example regarding power mix)
2 Excluding electricity generation for charging the vehicle

Figure 2.7 EV powertrains-key benefits and challenges [34]

2.4 Technology Strategies of Automobile Manufacturers to Meet the Regulations

As discussed in the previous section, technological innovation is required to respond the challenge of reducing GHG emissions. Regarding technologies, automobile manufacturers might follow two main technology pathways: (i) improving ICEV efficiency and (ii) a transition from existing ICEVs to EVs including HEVs, PHEVs, BEVs, REEVs and FCEVs [12]. Before discussing technology strategies of automobile manufacturers regarding these options, it is worthwhile to understand the differences between two technology pathways by examining innovation literature.

2.4.1 Technological Innovation: Incremental and Radical

Technological innovation means the commercialisation of invention [124, 125]. However, in innovation literature, many definitions for innovation types have been developed, resulting in a vagueness in the term "innovation" [124, 126]. For example, whereas McDermott and O'Connor [127] define innovation as a novel technology or combination of technologies offering significant benefits, Rogers [128] describes innovation as an idea or a technology which is perceived as new. Yet, Garcia and Calantone [126] explain that innovation is an iterative process triggered by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention. They further claim that an invention only becomes an innovation when it progresses through production and marketing tasks and it is diffused into the marketplace.

Although there are several similar definitions regarding technological innovation exist in literature, many researchers agree that those definitions do not describe the degree of departure from existing technology and practices [124, 127, 129-131]. This is because, although some innovations entail new skills, levels of market understanding, big changes in new processing abilities, and systems throughout the organization, others do not require such skills and abilities. Besides, some products might be very different from current activities within the firm that those products require very different processes to bring them to market [57].

To describe the degree of departure from existing technology and practices, researchers have therefore used "newness" as a measure. Owing to innovations` degree of newness, two different classes are frequently used in literature: minor adaptation or a totally new idea [124]. Although these classes are examined under different headings by different scholars such as evolutionary/revolutionary [132], sustaining/disruptive [71], incremental/really new [133, 134], incremental/breakthrough [135], continuous/discontinuous [56, 136], instrumental/ultimate [137], reformulated/original [138], routine/radical [139], they are more commonly described as incremental and radical in innovation literature [71, 129, 130, 140-148].

Since the degree of newness is used as a measure to distinguish radical innovations from incremental innovations, the question then arises as to how to measure the degree of novelty introduced by an innovation? Therefore, there have been several studies in literature to understand and develop a consistent and reliable multidimensional measure of radical innovations [127]. In general, these studies are in tendency to distinguish "radicalness" either by describing the major technological changes brought by an innovation or its profound impacts on firms, industries and markets [149].

From a technology standpoint, radical innovations have been usually defined as *"innovations which could not have evolved through improvements to, and adjustments of, the existing technology"* [149]. Radical innovations are based on a different set of science and engineering principles [70] and incorporate considerably different core technology [127, 150]. On the other hand, incremental innovations improve upon and extend existing technology [127]. Radical innovations are also frequently described as innovations serving as the basis for various succeeding incremental technological developments [151].

Radical innovations have also been distinguished as *"representing a significant leap forward in the technological frontier or adding significant new value to the marketplace"* [149]. For example, Dosi [152] argues that while incremental innovations relate to normal technical progress (continuity), radical innovations result in emerging new paradigms (discontinuity). Tushman and Anderson [64] expresses a technological discontinuity as *"an order-of-magnitude enhancement in the maximum achievable price-versus-performance frontier of an industry"*. Similarly, Leifer [153] claims that radical innovations create a new set of performance features or develop the existing performance features of five times or greater and reduce costs significantly (30% or more).

Finally, radical innovations have been described in terms of the profound impacts they have on firms, industries and markets [149]. Schumpeter [125] argues that "creative gales of destruction" destroy the foundation of large, incumbent firms' competitive advantage by rendering their technology and earlier investments obsolete. Utterback [132] also claims that whereas radical innovations discard a significant part of firm's past investments in "technical skills and knowledge, designs, production technique, plant and equipment", incremental innovations give way to standardization and status quo within the firm or industry. Besides, Garcia and Calantone [126] claim that radical innovations result in discontinuities in both the existing market structure and the existing technology structure. From their perspective, radical innovations present both macro level innovativeness characteristics as the product is new to the world, the market and the industry, and micro level characteristics, since it is novel to the firm and to the consumers [126]. Correspondingly, after reviewing seven historical case studies of successful disruptive (radical) technologies (digital cameras, mass produced automobile, hydraulic excavators, quartz watches, steam ships, eReaders and iPod), Hardman et al. [35] suggests that launch of a radical innovation should cause a disruption (discontinuity) to the established system involving in at least two of the following areas: market leading companies, customers and infrastructure.

Despite the above mentioned differences in definitions of radical technology, previous research studies stress that radical innovations involve significantly different core technology and they have profound impacts on firms, industries and markets while incremental innovations are associated with recognised technology, small change and status quo. Thus, radical technologies are distinguished with technological, industrial and societal change in literature. These changes result in discontinuities in the existing systems and create huge challenges for established companies.

When electric propulsion technologies are examined with this phenomena, previous research studies state that these technologies are radical innovations since they replace ICE technology and they have significant impacts on vehicle manufacturers and suppliers, infrastructure providers (such as oil, gas and utility companies/suppliers) and consumers etc. [35-39]. Thus, they create discontinuities and, therefore, several challenges for the automobile manufacturers. Although challenges regarding electrification will be discussed more in depth in the later sections, one major challenge for automobile manufacturers, which is high adaptation costs owing to the high volume production concept in the automotive industry, is discussed below to understand the impacts of electrification to carmakers.

In the automotive industry, high volume production concept is applied to upsurge scale, decrease production costs, offer cheaper cars to customers (in comparison to, for instance, handmade cars) and, ultimately, achieve profits [154]. For example, the ICE is usually produced in a separate factory in high volumes so as to reach economic break-even points [155]. The average production capacity at British engine plants was said to be approximately 500,000 engines per year in 2005 [156]. Similarly, approximately at least 250,000 units per car model are aimed to be produced by original equipment manufacturers (OEMs) to reach break-even points [50].

However, high volume production is very sensitive to capacity utilisation at the vehicle assembly plants, which are affected by consumer demands. A typical profitability zone is accepted as above 80% capacity utilisation. Thus, such production system makes the industry susceptible to changes in consumer demand for cars [156]. Besides, this system requires very high investments in production equipment at the vehicle assembly plants [156, 157]. According to Andrews et al. [157], the cost of a modern vehicle assembly plant including “a press shop, a welding plant, a painting shop and an assembly shop” is between 390 and 665 million pounds (approximately between 536 and 914 million euros).

Such features of the high volume production makes the automotive industry a highly capital intensive sector. The major problem faced by the established automotive sector therefore deals with the high adaptation costs [158]. Thus, if a technology requires either the creation of very high new capital intensive systems, or the early abandonment of current high capital intensive systems, it creates substantial challenges for OEMs and, thus, it is likely to meet considerable resistance from the car industry. Capital investments are here described in a broader way referring to investment in skills and expertise in research and development (R&D), product development and production areas [158].

In the established automotive sector, the main expertise of automobile manufacturers is the low-cost design and production of combustion technology and transmissions. Hence, integrated OEMs have dedicated entire manufacturing plants to the production of ICEs and transmissions [18]. However, most OEMs have limited expertise and intellectual property in the key technology components of EVs such as electrochemistry and power electronics [18]. Electric drivetrains also replace the current ICE technology and transmission, thus rendering existing sunk investments in ICE technology obsolete and requiring new investments into a different manufacturing system for electric drivetrain technologies. Additionally, EV technologies require hiring or training engineers with expertise in these new technologies, whilst making that expertise in the ICE abandoned [158]. Since EV technologies also carry the risk of low consumer acceptance [159], a shift to EVs imply tremendous challenges for carmakers.

Owing to such radical characteristic of electric propulsion technologies, it might therefore be expected that a typical OEM`s main strategy for reaching GHG emission reduction targets is improving the ICEV efficiency rather than fully electrifying the power train as far as GHG reductions enforced by regulations are met. As discussed previously, this translates into 80-90 gCO_2/km [12]. However, above this limit, the main strategy has to be the electrification of the powertrain. The innovation literature also suggests that technological progress is cumulative, building on specific local initial circumstances and developing from there through incremental changes. Thus, most R&D efforts target enhancements of the established technologies rather than testing radically different pathways and, thus, support initial technology choices [32].

However, there are several technological options for carmakers regarding both the improvement of the ICEV efficiency and the electrification of the powertrain. Besides, different countries have adopted different GHG regulations which have different levels of stringencies. A question then emerges as to how these differences affect OEMs` strategies in different countries? According to the innovation literature, the evolution of technologies is reinforced by specific institutional arrangements such as regulations, R&D programmes and business networks which are useful for the evolving technologies, but not necessarily for possible alternatives. Hence, technologies and institutions "co-evolve" [160] in particular, self-reinforcing ways leading to technological "trajectories" or "pathways".

According to Altenburg [32], "*each time technologies evolve in parallel in diverse places and institutional environments, the way one thing leads to another essentially reflects local specificities. Therefore, technological pathways may be very different across countries, particularly when initial circumstances such as regulations, consumer habits, purchasing power etc. are very diverse*". In this regard, it might be expected that although the main strategy implemented by the OEMs is improving the ICEV powertrain, different technological options might be adopted by OEMs in different regions. It might also be expected that automobile manufacturers in countries with more stringent GHG emissions standards shift faster to EV technologies.

Against this background, the following section will examine the OEMs` strategies in different regions.

2.4.2 Technology Strategies of Automobile Manufacturers in Different Regions

In previous sections, it was explained that automobile manufacturers have two main technology pathways to reduce GHG emissions: (i) improving ICEV efficiency and (ii) a transition from ICEVs to EVs. With regards to these options, innovation literature suggests that a typical OEM`s main strategy for meeting GHG regulations is improving the ICEV efficiency rather than fully electrifying the power train as far as GHG reductions enforced by regulations are met (80-90 gCO_2/km [12]). However, technology choices might vary across the regions owing to the context-specific technological trajectories. Against this background, technology strategies of OEMs in three largest developed regions, EU, USA and Japan, are examined below.

2.4.2.1 EU

As discussed before, EU initially implemented voluntary GHG emission reduction target policies [161]. Owing to these targets and higher fuel prices in the EU (for example compared to those in USA), carmakers developed and offered a mix of models with smaller engines and more efficient diesel engines in the European market [30]. Nevertheless, voluntary GHG emission reduction target of 140 gCO_2/km by 2008 were not attained. According to Schipper and Fulton [162], there had only been marginal energy and CO_2 emission savings as a result of this large shift to diesel engines. This is because diesel vehicles tend to be heavier and they tend to be driven more than gasoline vehicles because of lower diesel prices and better fuel economy.

Owing to the failure of voluntary GHG emission reduction target, the EU adopted a regulation which established CO_2 emission targets of 130 g/km by 2015 and 95 gCO_2/km by 2021. Due to the increased stringency and the shift from voluntary to mandatory targets, achieving sustainable mobility has become the primary objective of R&D activities within the EU. Thus, a large share of the European automotive industry R&D expenditures, which is thought to be approximately €20 billion, is directed towards environment-related innovations. Yet, most of the R&D expenditures are directed to improve the ICEV efficiency through a range of mechanical and electronic innovations discussed in the previous sections such as "stop-start", engine downsizing, gasoline direct injection, turbo-charging, and dual-clutch transmission. Electrification of the powertrain has also been pursued although it is usually accepted as a long-term strategy. Thus, carmakers in the EU follow three main tracks for reducing GHG emissions from cars: (i) fuel efficiency (ICE optimisation) (ii) biofuels and (iii) electrification of the powertrain [30].

One significant example is Volkswagen Group. To achieve 2020 target, the Volkswagen Group has been following a strategy which has three main pillars: (i) developing the efficiency of ICEVs (ii) developing vehicles that can be fuelled by compressed natural gas (CNG) and iii) electrifying the powertrain including HEV, PHEV and BEV technologies. The priority is given to maximising the ICEV efficiency although electrification of vehicle models is also pursued, as demonstrated in Figure 2.8 [163].

Figure 2.8 Volkswagen Group has started electrifying the vehicle models [163]

BMW also follows a similar strategy to decrease GHG emissions. The strategy is called “Efficient Dynamics” which is based on four main "pillars". The first pillar is focusing on the optimisation of ICEV to achieve better fuel consumption. This pillar also includes steps to optimise lightweight construction, aerodynamics and energy management. The other pillars are developing HEVs (BMW ActiveHybrid 7, BMW ActiveHybrid 5 and BMW ActiveHybrid 3), PHEVs (BMW i8, BMW X5 xDrive40e, BMW 330e, BMW 740e, BMW 2 Series Active Tourer PHEV), BEVs (BMW i3, for BMW i3 a range extender option is also available) as well as FCEVs (BMW Hydrogen 7).[164].

Daimler also improves the fuel economy and reduces the GHG emissions by implementing numerous technological options which are summarised under the “BlueEFFICIENCY” concept. By implementing several measures, Daimler reduced the CO_2 emissions of its fleet of vehicles sold in Europe to 129 g/km in 2014. The strategy implemented by the Daimler is explained below [165]:

- *Optimising ICEVs:* This package involves incremental innovations for increasing the efficiency of ICEVs including ICE and overall vehicle improvements. For example, the new downsized engines (BlueDIRECT V6 and V8 petrol engines) which feature in several model series deliver a much higher power output while reducing fuel consumption by up to 24%. This is the main strategy followed by the Daimler.
- *Hybridisation*: By combining ICEs with electric motors, Daimler has achieved significant CO_2 reductions. E 300 BlueTEC HYBRID and S 500 PLUG-IN-

HYBRID were launched in 2013 and 2014 respectively. Daimler aims to launch 10 new plug-in hybrid models by 2017.

- *Emission free-drive systems*: 60 Mercedes B-Class F-Cell (a FCEV developed by Daimler) were leased to customers in USA, Europe, Singapore and Japan in 2011. Daimler also launched the Smart Fortwo (a BEV) in 2012.

2.4.2.2 USA

USA aims to achieve 36.2 mpg (equivalent to 152 gCO_2/km under NEDC cycle) for MY 2016 and 59.1 mpg (equivalent to 93 gCO_2/km under NEDC cycle) for MY in 2025 [34]. Figure 2.9 displays the fuel efficiency of vehicle fleet in USA in 2009 and best case scenario for 2015. As can be seen, incremental ICE innovations may allow carmakers in USA to meet the CAFE mandate by the year 2016 without electrifying the powertrain. With diesel engines, it is even possible to meet the 2025 target. In this respect, although carmakers in USA are developing EV technologies and electrifying the powertrain, they are mainly implementing incremental innovations to meet the CAFE mandate [30].

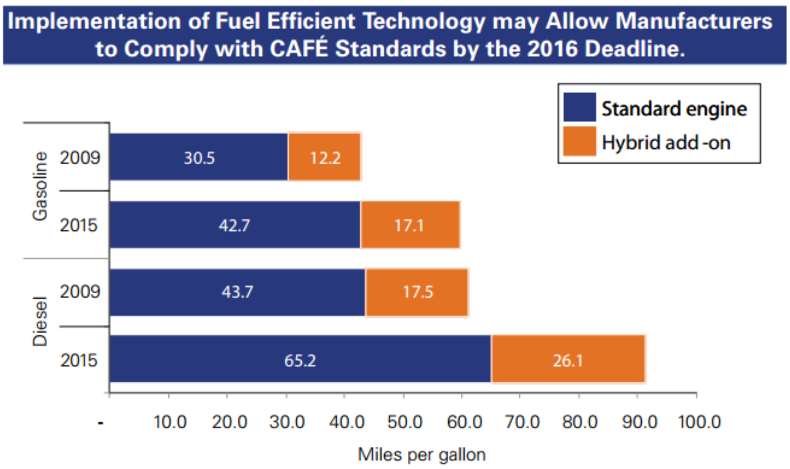


Figure 2.9 Fuel efficiency of USA vehicle fleet in 2009 and the best case scenario for 2015 [30]

For example, Ford has improved the fuel economy and reduced the GHG emissions by implementing several technological options [30] as explained below:

- *Six-speed automatic transmissions:* Ford has announced that it will seek to improve fuel economy by moving to six-speed transmission across its entire fleet to improve the fuel economy.
- *Eco-boost gasoline turbo-charged direct injection technology:* According to Ford, such technology provides 20% better fuel economy and emits 15% less CO_2

emissions. Ford expects to increase the penetration of this technology in its models from 20% to 90%.

- *Improved aerodynamics and weight reduction:* Ford has improved the aerodynamics of the vehicle and reduced the weight which has resulted in better fuel economy.
- *Electric power assist steering:* Powering the steering with an electric motor rather than a hydraulic pump results in approximately 3% improvement in fuel economy of Ford vehicles.
- *Electrification:* Ford has also pursued an electrification strategy which is called "power of choice". In this respect, Ford has been electrifying global vehicle lines rather than limiting development to a single, special EV model. According to Ford, this strategy allows customers to choose from a variety of EV powertrains including HEVs (Ford Fusion Hybrid, the Lincoln MKZ Hybrid and Ford C-MAX Hybrid), PHEVs (Ford C-MAX Energi and Ford Fusion Energi), and a BEV (Ford Focus Electric which has a driving range of 76 miles on a single charge) [166].

Other carmakers in USA are also mainly relying on the improvement of ICE technology although, at the same time, they are making investments for electrifying the powertrain [30]. For example, the strategy of General Motors (GM) for meeting the CAFE mandate involves: (i) extensive technology improvements to conventional ICE powertrains (ii) alternative fuel vehicles and (iii) vehicle electrification, as depicted in Figure 2.10. GM believes that alternative fuels offer the highest near-term potential to improve the fuel economy and reduce GHG emissions. Thus, they develop flexible fuel vehicles ("FlexFuel") that can run on gasoline-ethanol blend fuels as well as vehicles that run on CNG and LPG. GM offers 13 FlexFuel vehicles in USA for the MY 2015. GM also believes that EVs are the long term solution for reducing CO_2 emissions. Thus, the majority of the investments are made for incremental technological solutions. Currently, GM offers seven models in the USA featuring some form of electrification [167]. These are:

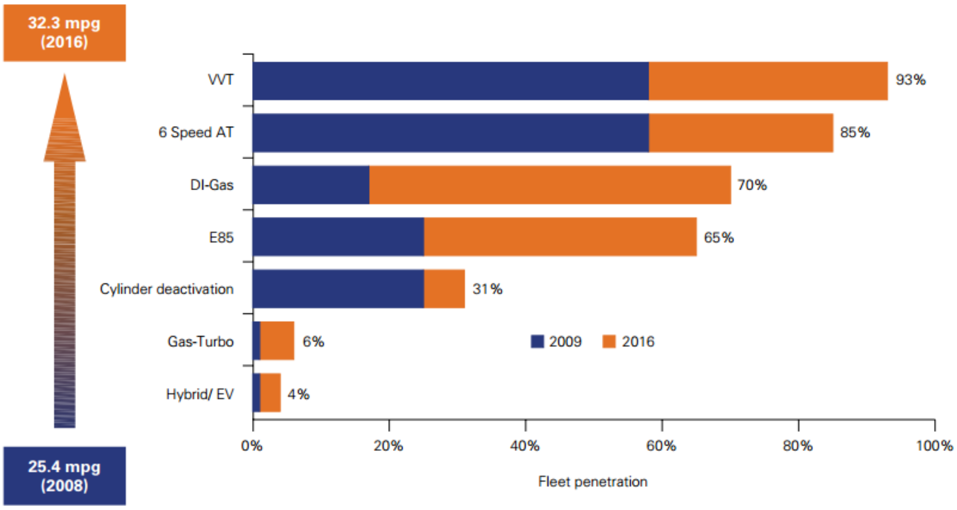


Figure 2.10 Roadmap of General Motors for fuel efficiency improvement [30]

- *eAssist technology:* It is a light electrification solution enhancing fuel efficiency up to 25%. Featured on the 2014 Buick LaCrosse and Regal (both with an EPA estimated mpg 25 in city and 36 on motorways) and 2014 Chevrolet Malibu Eco (EPA estimated mpg 25 in city and 36 on motorways), the electric motor recaptures energy and shuts off fuel during braking. To further increase efficiency, it stops and restarts the engine in urban (stop-and-go) driving. An on-board lithium-ion battery also provides an electric boost in certain conditions to improve the fuel efficiency.
- *REEVs:* Chevrolet Volt and Opel Ampera which offer 35 miles (56 km) of electric driving and another 340 miles (547 km) ICE driving. Cadillac ELR also offers more than 300 miles (483 km) of combined driving range.
- *BEV:* The Chevrolet Spark EV offers 82 miles (132 km) of range. It is the first EV which offers its users to recharge their batteries up to 80 percent in less than 20 minutes.
- *FCEV:* As part of their long-term strategy, GM develops hydrogen fuel cell technology. In this regard, Chevrolet Equinox FCEV demonstration programmes such as Project Driveway have accumulated more than 4.8 million kilometres of driving by consumers, celebrities, business partners and government agencies. GM and Honda have also established a long-term agreement to jointly develop fuel cell system and hydrogen storage technologies aiming for the 2020 timeframe. The collaboration involves sharing expertise, economies of scale and common sourcing strategies.

2.4.2.3 Japan

Japanese automakers have been dealing with many new GHG regulations including both domestic and foreign regulations. This is because approximately half of Japanese cars sold worldwide are produced in Japan. Besides, a large share of vehicles produced in Japan is exported to other countries. For example, of the 11.6 million vehicles produced domestically in 2008, 6.7 million vehicles were exported to other countries. Owing to the reliance on overseas demand, Japanese carmakers have become more attentive towards regulations in other countries. Consequently, to comply with different regulations and survive in different markets, Japanese OEMs have been following an energy diversification strategy which addresses conventional gasoline, diesel and alternative fuel engines as well as electric powertrains [30].

One significant example is Toyota Motor Company. Toyota has been developing a wide portfolio of technologies and has aimed to use its hybrid systems for further improvement of these technologies, as illustrated in Figure 2.11 [168]. Indeed, hybridisation has become a very significant strategy for Toyota. Owing to such strategy, Toyota has become a global leader in hybrid vehicles. By 2015, approximately 9 million hybrid vehicles have been sold worldwide, led by Toyota with more than 7 million Lexus and Toyota hybrids sold [169]. Honda also follows a similar strategy. Honda has developed efficient gasoline and diesel engines as well as BEVs, HEVs, and FCEVs. Hybrid technology is also used to improve these systems [30]. It is also significant to mention that personal mobility vehicle market displayed in Figure 2.11 offers significant opportunities for new comers.

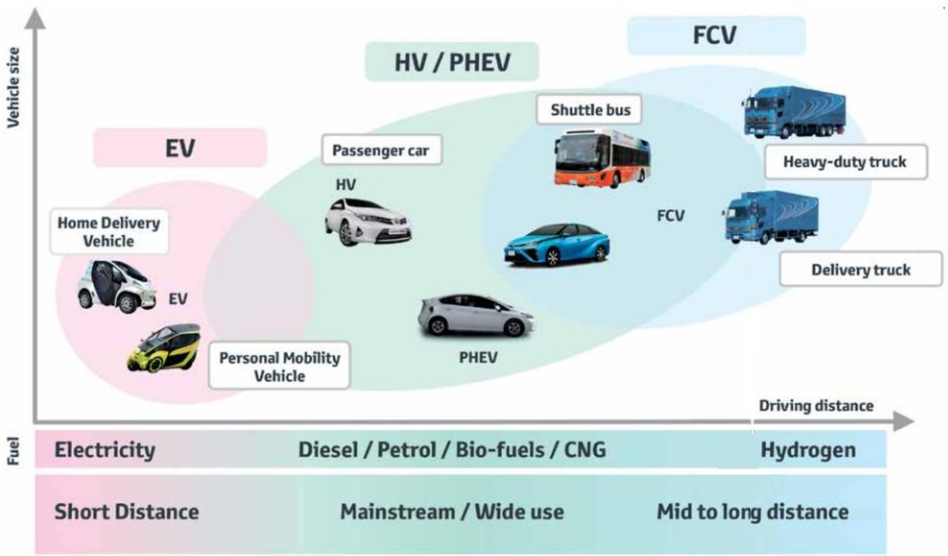


Figure 2.11 Toyota Motor Company`s powertrain roadmap [168]

However, it seems that Suzuki aims to innovate incrementally by focusing on ICE innovations to dominate the "Kei" niche or minicar segment accounting for one third of Japanese car market. Suzuki believes that they are better off improving and continuing to provide cheap "Kei" cars providing above-average fuel efficiency rather than developing a high-cost hybrid or electric car [30].

2.4.3 Technology Strategies of Automobile Manufacturers: Global Overview

Previously, it was discussed that automobile manufacturers have two main technology pathways to reduce GHG emissions: (i) improving ICEV efficiency and (ii) a transition from ICEVs to EVs. As suggested by the innovation literature [32] and clarified in previous sections by examining OEM strategies in EU, USA and Japan, although technology choices vary between regions and even between OEMs in the same regions (such as different technologies adopted by GM and Ford in USA), the main technology strategy implemented by OEMs is the improvement of the ICEV efficiency [21-28]. Averagely, around 80% of the industry's patents are thought to be awarded to ICEV related technology, against only about 20% for technologies associated with BEVs, PHEVs and HEVs [24]. Aberdeen Group`s recent study which examined 218 companies globally to understand the automotive industry`s strategies to achieve fuel efficiency and emission standards disclose such ICEV driven technology strategy of the industry, as displayed in Figure 2.12.

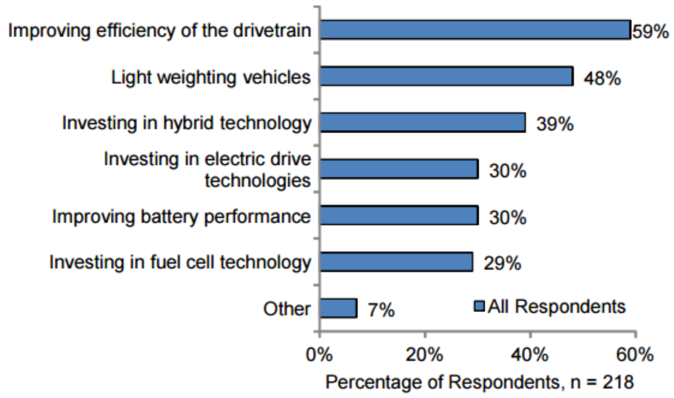


Figure 2.12 Strategies to achieve fuel efficiency and emission standards [170]

However, owing to the increased stringency of the GHG regulations and established long term GHG goals which, in return, upsurge expectations that environmental regulations will be tighter in the future, automobile manufacturers are also electrifying the powertrain. Figure 2.13 demonstrates such trend. As can be seen, the number of EV models, especially HEVs and PHEVs, offered by the carmakers are increasing [34]. The high number of hybrid models produced by OEMs compared to other EV models might also be seen as an attempt by OEMs to innovate without having to move away from their core competencies [159].

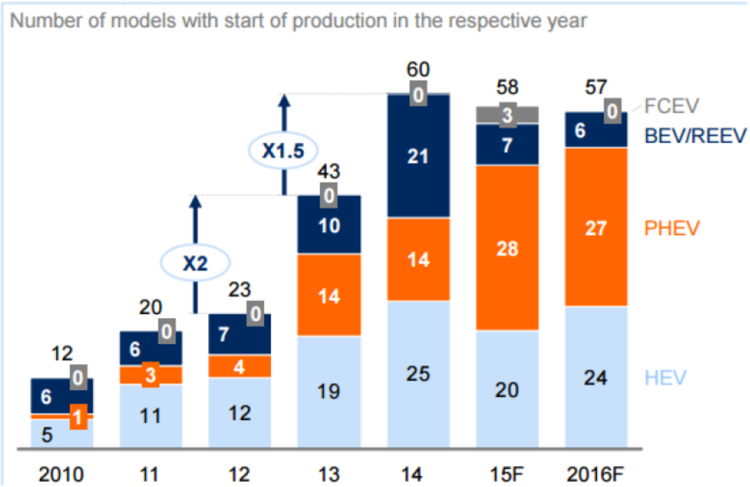


Figure 2.13 Global EV model launches 2010-2016 forecasted [34]

In the following section, the EU`s technological transition pathway with regards to long term (2050) target will be examined to understand if the automotive industry`s existing technology strategy is viable to comply with such target.

2.5 EU`s Technological Transition Pathway

In previous sections, it was clarified that tightening regulations are pressuring automobile manufacturers to reduce their fleet emissions. As a response, OEMs are developing a portfolio of technologies. Although technology choices vary between regions and even between OEMs in the same regions, across the EU and elsewhere in the world, the most attention and resources are geared toward improving ICEV efficiency [21-28]. In this section, this technology strategy of the car industry will be compared with established EU GHG emission reduction targets to assess if such strategy is viable to achieve the established targets.

The EU established CO_2 emission targets of 130 g/km by 2015 (approximately equivalent to 5.6 l/100km for petrol or 4.9l/100km for diesel), around 18% below the average in 2007, and 95 gCO_2/km by 2021 (equivalent to 4.1 l/100km for petrol or 3.6 l/100km for diesel), or about 40% reduction from 2007 [29]. Besides, the EU aims to cut its overall CO_2 emissions by at least 80% by 2050 compared to 1990 levels to comply with UNFCCC`s 2° C global warming target although a legislative framework has not been introduced yet for this target [7].

With regards to these targets, OEMs pool the emissions across their brands to generate a sales-weighted average emissions figure. Different OEMs have differentiated targets. An automaker producing heavier and higher-emitting cars obtain a higher target. For example, if an OEM's cars by 2015 are 100 kg heavier than the industry average, the OEM is allowed having a 4.57 g/km higher CO_2 target (134.57 instead of 130 g/km CO_2 on average). In contrast, if the OEM`s cars are lighter than industry average, the OEM gets a lower target. Enforcement is made by means of a system of fines. For every g/km by which an OEM surpasses its target, the OEM has to pay a €95 fine for each vehicle sold [29].

Figure 2.14 depicts the historical CO_2 development progress of the industry and future targets as established by the EU's regulations on CO_2 from cars. As can be seen, the average CO_2 emissions of the industry were declined to 123.4 g/km in 2014 from 126.8 g/km in 2013 representing a rate of progress of 2.6% which is less than the previous year that recorded progress of 4.1%. Overall progress over the year 2007 (158 g/km) to the year 2014 (123 g/km) period also accounted for 22% reduction (or approximately 3.6% per year) [29].

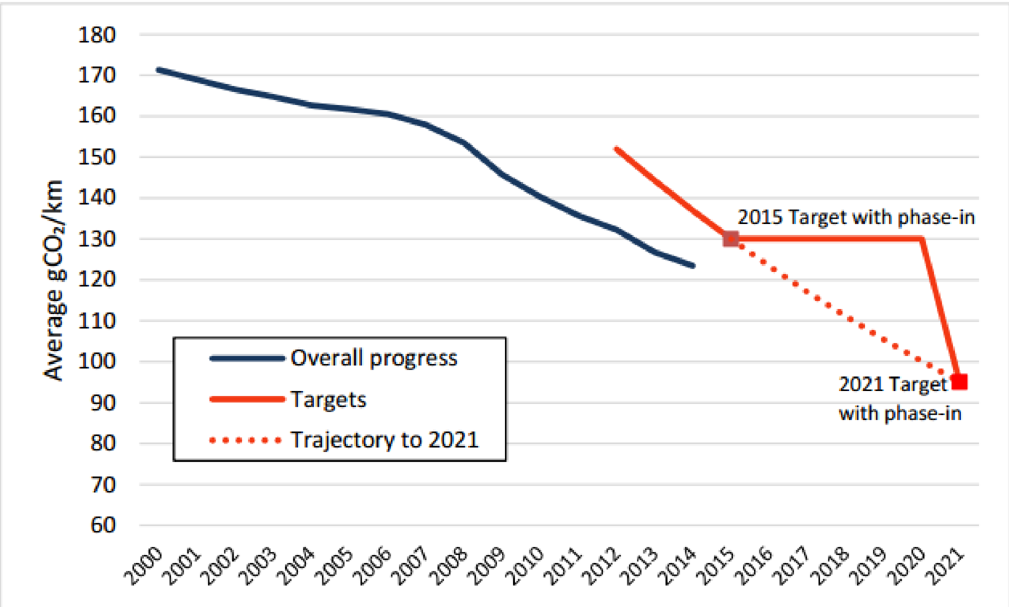
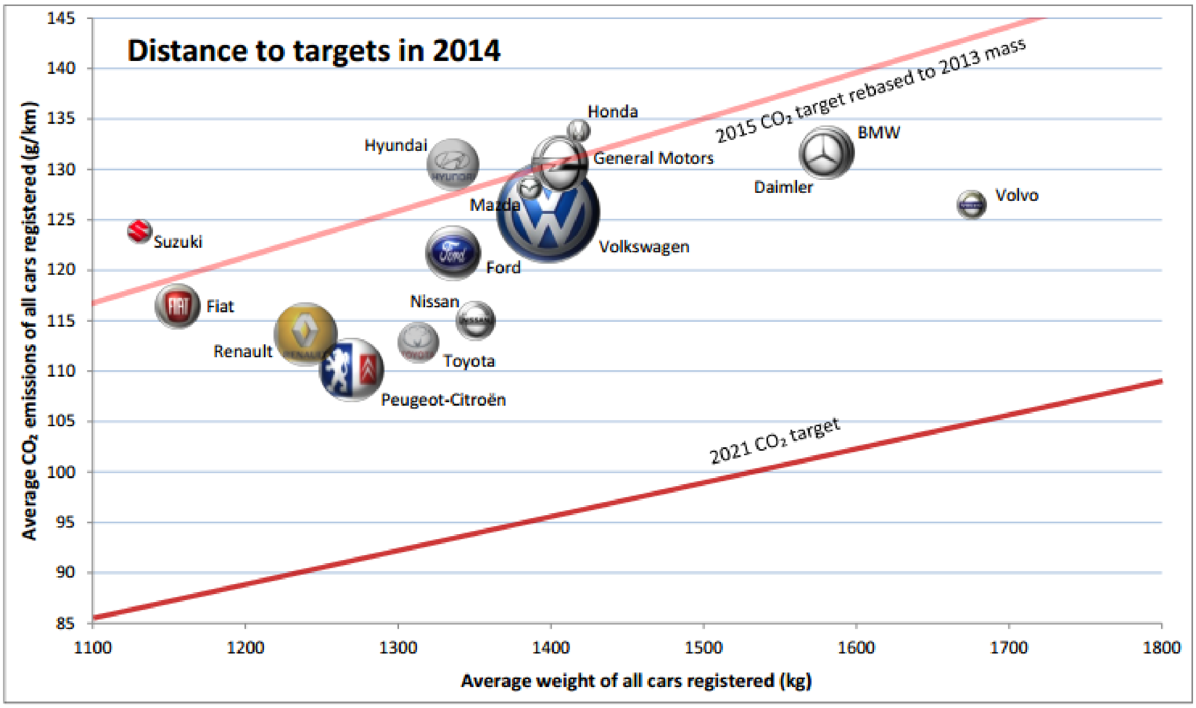


Figure 2.14 Progress of fleet average CO_2 emissions of new cars in the EU against regulatory targets [29]

These numbers also infer that the 130 g target for 2015 were already overachieved across the new car fleet as a whole. In terms of the individual automobile manufacturers and their respective 2015 targets, Figure 2.15 demonstrates that only Suzuki, Hyundai and

Honda have not achieved the set targets among the fifteen largest carmaker in the EU. Nevertheless, Volkswagen emission crisis in 2015 showed that these numbers may not necessarily represent the actual numbers and, therefore, it is possible that there might be other automobile manufacturers which have not achieved their targets.

The figure also displays that 130 g/km average target does not apply to individual OEMs directly since OEM targets are determined on the basis of the weight of the vehicles they produce compared to the average weight of the vehicles the entire industry will produce over a specified period. Hence, it does not necessarily mean that OEMs with the lowest emissions are the closest to their targets.



Note: size of bubble reflects the size of the CO_2 'footprint' of the total cars sold

Figure 2.15 Sales-average CO_2 emissions by OEM against targets [29]

Figure 2.15 also demonstrates that some OEMs are making good progress such as Peugeot-Citroen to comply with the 2021 target whereas the majority of the car makers need to increase their efforts to comply with the required target. Figure 2.16 displays the past and future progress of the largest fifteen OEMs in the EU based on the ranking of their CO_2 emissions to meet the 2021 target. As can be seen, across future overall EU car sales, the rate of progress required for the 2014-2021 period is only slightly higher (3.7%) than the rate that has been achieved during the 2008-2014 period (3.6%). Nevertheless, nine manufactures among the fifteen largest in the EU need to increase their efforts and six of them need to increase their efforts significantly [29]. In that context, it is argued that 2021 target might be met by OEMs by improving the efficiency of ICEVs plus a small number of EV models in the fleet [32-34]. Although the number and type of EV models in the fleet would be different for each manufacturer, this implies that strategies implemented by the OEMs which are discussed in the previous section is still viable to achieve the 2021 target.

		Progress as % year on year		
	Ranking	2000-2008	2008-2014	2014-2021
1	Peugeot-Citroën	1.9%	3.8%	2.7%
2	Volvo	n/a	5.1%	2.7%
3	Toyota	1.8%	4.3%	2.8%
4	Nissan	1.0%	5.5%	2.9%
5	Renault	1.5%	3.8%	3.3%
6	Daimler	1.5%	4.7%	3.7%
7	BMW	3.6%	2.6%	3.7%
8	Ford	2.4%	3.6%	3.7%
9	Volkswagen	0.6%	3.8%	3.9%
10	Fiat	1.6%	2.8%	4.0%
11	Mazda	2.1%	3.5%	4.2%
12	General Motors	0.8%	2.6%	4.4%
13	Honda	3.0%	2.3%	4.6%
14	Hyundai	2.8%	2.2%	4.7%
15	Suzuki	1.3%	3.8%	5.0%
	All Manufacturers	1.4%	3.6%	3.7%

Figure 2.16 Comparison of past and future progress of OEMs to meet the 2021 target [29]

Nevertheless, for the year 2050, the EU aims to cut its overall CO_2 emissions by at least 80% compared to 1990 levels [7]. For transport, this involves at least 60% reduction target for 2050 compared to 1990 levels [8]. According to a recent study [9], achieving 80% decarbonisation overall by 2050 also translates into a 95% decarbonisation of the road transport sector compared to 1990 levels, as shown in Figure 2.17. In this respect, achieving the 2050 target will not be possible with the existing strategy implemented by the industry (improving ICEV efficiency) and will require a transition from ICEVs to EVs.

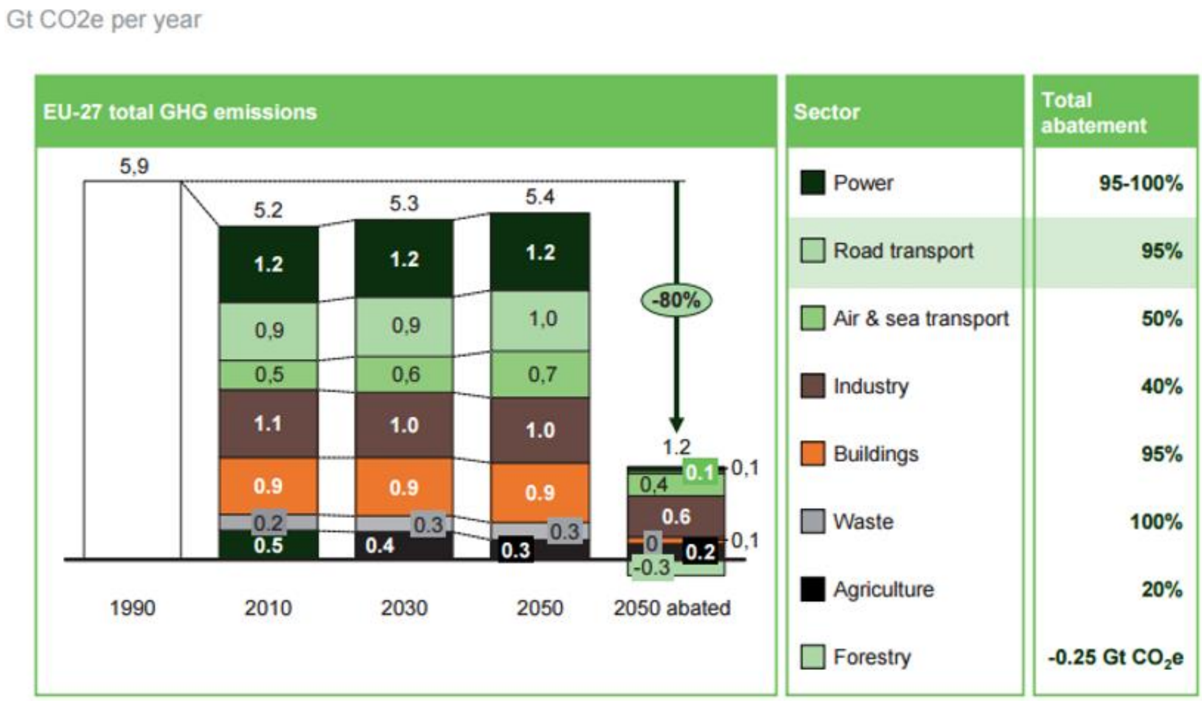


Figure 2.17 Road transport must achieve 95% decarbonisation in order to comply with the EU`s CO_2 reduction goal of 80% by 2050 [9]

One of McKinsey`s recent studies [10] reveal the required change in the technologies developed by the industry. To demonstrate the change in technologies, which are eventually linked to the EU`s GHG regulations and imposed targets, the study developed three scenarios for European automotive sector. All scenarios considered CO_2 emissions from W2W, whereas today often only the emissions from tank-to-wheel (T2W) are considered. These scenarios are:

- "Below 100": Moderate CO_2 emission reduction to 95 gCO_2/km in 2050. This means that regulation as of 2021 will not get tighter. Yet, the T2W standard will change to a W2W standard.
- "Below 40": Strong CO_2 emission reduction to 40 gCO_2/km in 2050. This scenario anticipates a continuation of increasingly restrictive emission standards.
- "Below 10": Very strict CO_2 emission reduction to 10 gCO_2/km in 2050 representing the EU`s 2050 target to comply with UNFCCC`s 2° C global warming target. This means that the EU`s CO_2 regulation will get tighter in the next two decades to support the 2050 target.

Each of these scenarios and required technologies to achieve these scenarios are displayed in Figure 2.18. As can be seen, vehicle technologies are expected to change drastically as it is not possible to reduce transport emissions below 80-90 gCO_2/km with the best diesel ICEVs. Even with the best diesel hybrid vehicles, it is not possible to reduce emissions below 60 gCO_2/km. Besides, the number of cars on the roads will be significantly higher than today in 2050 [12]. Thus, the figure demonstrates that electrification of vehicles will need to be a reality even in the short term: 20-35% of cars will need to have an electric motor by 2020. In the medium term, combinations of ICE and electric motors (especially HEVs) will need to capture market shares of 40-60%. Finally by 2050, the electric powertrain either as an only solution or as a hybrid will need to dominate in all scenarios [10]. Such change in the vehicle technologies is also aligned with the IEA`s scenario which predicts that approximately 75% of all vehicle sales by 2050 would need to be plug-in electric of some type to achieve UNFCCC`s 2° C global warming target [171].

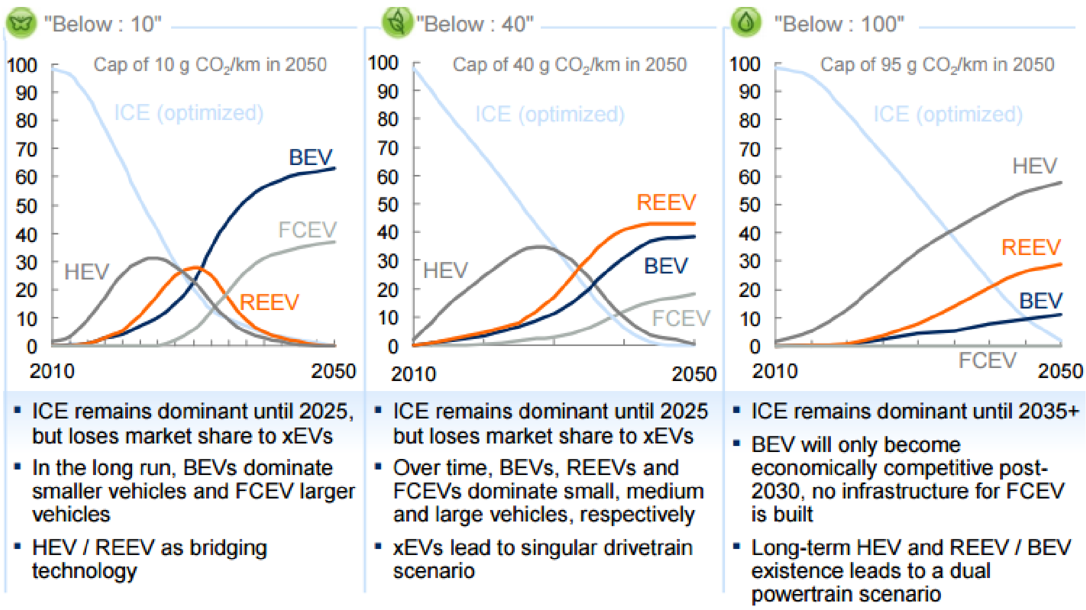


Figure 2.18 Future of global powertrain market [10]

Overall, although the automotive industry's main strategy (improving ICEV efficiency) [21-28] might be viable to achieve the EU`s 2021 GHG emission target [32-34], it will not be possible to achieve the EU`s 2050 target [4, 10]. Besides, as described above, even though the CO_2 regulation does not change until the year 2050, the ICE technology will progressively phase out. However, to achieve the 2050 target, which is expected that the CO_2 regulation will get tighter and will possibly establish a CO_2 emission target of 10 g/km for the average of new cars sold by 2050, the ICE technology needs to be phased out quicker and a gradual shift from ICEVs to BEVs and FCEVs with HEVs, PHEVs and REEVs as bridging technologies need to be achieved. The rest of this chapter will therefore focus on BEVs as it is expected that FCEVs will be used for larger vehicles in road transportation (trucks and heavy vehicles) while BEVs will be the main technological option for cars in 2050 to comply with the EU`s 2050 target [10].

The following section will discuss challenges with regards to such radical technology change in the automotive sector in Europe.

2.6 Challenges to Achieve 2050 GHG Emission Reduction Target (Electrification Challenges)

A gradual shift from ICEVs to a diverse portfolio of electric and partially electric powertrains will need to take place in the EU (and elsewhere in the world) by 2050 even with the existing regulation. However, based on the Kyoto Protocol`s 2° C global warming target and the EU`s respective 95% decarbonisation of road transport aim for the year 2050 representing 10 gCO_2/km target for cars [10], the transition from ICEVs to BEVs needs to be accelerated. To achieve that all technologies have to be engineered today and challenges facing such transition need to be mastered with carefully developed strategies. In that context, the following sub-sections will discuss challenges facing the transition from ICEVs to BEVs by scrutinising the innovation literature and the EU`s plan to overcome these challenges by examining the European industry roadmap for electrification of road transport.

2.6.1 Socio-Technical Transitions and Transition Challenges for BEVs

Previously, it was explained that electric propulsion technologies are radical innovations which have significant impacts on vehicle manufacturers and suppliers, infrastructure providers (such as oil, gas and utility companies/suppliers) and consumers etc. [35-39]. Due to the multi-dimensional impacts of BEV technologies, there is a substantial innovation literature which emphasises that a successful technical change involves overcoming barriers that go far beyond purely technological innovation; and that economic, business, infrastructural, institutional and societal innovations are also very important [33, 40-48]. Accordingly, Mazur et al.[55] explain that "*innovation theory has evolved significantly from the one concentrating on technological innovation on its own to the one examining innovation processes from a system perspective. This has brought more complexity into innovation theory, signifying that the societal and institutional* *system in which an innovation is happening and spreading also need to be considered, leading to research on transitions of socio-technical systems".*

Recent studies in literature therefore frequently explain technical change with socio-technical transitions theory. This theory explains that technology cannot be disconnected from its social context as a "seamless web" interconnects technology and society [172]. Based on this perspective, societal systems such as the road transport system are described as a configuration of elements including technology, policy, markets, consumer practices, infrastructure, cultural meaning and scientific knowledge in literature. These systems are called "socio-technical" systems and major changes are described as socio-technical transitions. Transitions are understood to be co-evolutionary long-term processes comprising numerous actors and social groups [33, 49, 51]. A shift from ICEVs to BEVs would represent a transition, as it requires changes in multiple elements of the road transport system. This perspective highlights that a technical transition in the automotive industry poses more than a technological challenge for the automotive sector [33, 49, 50]. It requires changes in the multiple dimensions of the road transport system [33, 49, 51].

The transition to the current ICEV based road transport system in the late 19th century provides some insights into the transition challenges for EVs. A transition from horse carriages to the first automobiles generated a lot of discussion and press attention. At the beginning, public opinion was often antagonistic and people were underlining high costs, noise, danger, and low speeds. Experimentation with cars were conducted by a few "outsiders" and wealthy early adopters [173]. It is also significant to mention that the installed base contained mostly steam powered vehicles and BEVs. Steam technology was developed and dependable, and water and coal were widely available. Although electric propulsion was newer, BEVs became attractive in cities since taxis were quiet and started immediately. Battery performance was also developing. Owing to such developments, the future for BEVs looked bright [174].

The ICE was a late entrant. The first ICEV was produced in 1885 by Karl Benz in Germany [175], fifty one years after the first BEV that was introduced by Thomas Davenport [176]. However, despite first-mover advantage, electric and steam vehicles were soon surpassed by ICEVs. In 1912 registered BEVs reached at 30.000, while the ICEV installed base was already thirty times greater [173]. Nonetheless, what were the reasons that BEVs failed, in spite of early success and first-mover advantage? Based on the socio-technical transition theory, changes in the multiple dimensions of the road transport system played roles as explained below.

Firstly, infrastructure developments and changes in customer preferences played a role. The people wanted to drive into the countryside where the advantages of BEVs in cities were of little value. Power to recharge the batteries was also rarely available. Hence, few BEVs were driven into the countryside. However, because few BEVs were driven into the countryside, there was not much incentive for businesses to develop recharging stations outside major cities, further restricting the attractiveness of BEVs. While ICEVs also faced a similar situation at the beginning of their market entry, *"fuel distribution through small retail establishments assisted by the ICEVs enabled the gasoline distribution network to grow fast*" [177].

Several towns also had bicycle shops and mechanics which were experienced in the mechanical linkages and chain drives used in first ICEVs while experience with batteries and electric motors was less widely distributed [177]. Besides, although ICEVs had some certain shortcomings such as being complicated, noisy, dirty, using inflammable fuel which was resulting in malodorous exhaust and requiring a hazardous hand crack to transfer the power from the engine to the drive train, they were offering outstanding power, speed, and range potential [175]. Charles Kettering also invented the electric ignition and the electric self-starter that removed the hand-crank for the Cadillac Motor Company in 1910–1911. With this technological development, ICEVs became simpler to start, more secure and accessible [178, 179].

Henry Ford also overcame the challenges posed by ICEVs (noise, vibration, and odour) and began assembly-line production of low-priced, lightweight ICEVs [178]. Accordingly, ICEVs began its large diffusion with Ford T by benefiting from economy of scale [179]. In contrast, BEVs did not benefit from any economy of scale. For example, in contrast to 180,000 Ford T, only 6000 BEVs were produced in USA in 1913 [179].

Network effects also played an important role in the upsurge of ICEVs. Network effect is caused by a system being dependant on the high number of users within the network. Positive feedback mechanisms are created leading to more users [42]. For ICEVs, "word of mouth" among non-drivers played an important role. The first ICEVs were feared owing to their speed and perceived risks of explosion. Yet, they were also exciting innovations attracting attention of people who had not yet purchased a car. These non-drivers representing the great majority at that time would then tell others about what they had seen, rapidly spreading awareness about each type of vehicle. Together with newspapers and journals dedicated to ICEVs, “word of mouth” among non-drivers stimulated awareness regarding ICEVs [173].

In short, customer preferences, growing scale, production skills, manufacturing expertise, installed base and infrastructure, network effects and technological developments all interacted in a co-evolutionary way to the emergence of ICEV as a dominant design in the automotive industry [173]. With the emergence of ICEV as a dominant design, the number of automobile manufacturers producing BEVs reduced to zero during the 1920s [179] and BEV production and development came to a halt as a personal way of transportation after ICEVs took over in 1935 [178, 180].

Today, driven by environmental pressures and government regulations [159, 178, 181], another transition from ICEVs to BEVs in the automotive industry is needed to achieve the EU`s 2050 target [10]. However, BEVs are not able to successfully compete with ICEVs in terms of price and performance since key technologies such as battery and electric motors need to be further developed and mass produced [6, 173, 178]. Besides, the above mentioned close interdependencies between social context and the evolution of technology still exist. According to Struben and Sterman [173], *“the diffusion challenge for BEVs today is also very different from the 19th century, when little awareness, the huge potential for growth of the total installed base, undeveloped infrastructure, and lack of standards allowed ICEVs to surpass steam powered vehicles and BEVs regardless of their first-mover advantages and initial greater performances. Approximately, a century later, BEVs confront with a highly developed industry and infrastructure, powerful vested interests, and a society, economy, and culture firmly connected to ICEVs”.* This means that achieving a transition from ICEV to BEV would not be possible without substantial changes in the whole transport value chain and to achieve such changes would require carefully designed and implemented strategies. The EU`s integrated industry plan for electrification is examined in the following section.

2.6.2 European Industry Roadmap for Electrification of Road Transport

Since a transition from ICEV to BEV is more than a technological challenge [33, 49, 50] and it involves other challenges such as mass production, infrastructure development, customer adoption etc., it is very likely that evolutionary technological development and dissemination of EVs will not be fast enough to ensure compliance with the 2050 GHG emission target of the EU. To support and accelerate the transition from ICEVs to BEVs, "European roadmap: electrification of road transport" was published in 2009 and updated in 2012 [52] by the European Technology Platforms which are "European Road Transport Research Advisory Council (ERTRAC), European Technology Platform on Smart Systems Integration (EPoSS), and the European Technology Platform for Electricity Networks of the Future (Smart Grids)". The roadmap was the result of a "Task Force Electrification" which was formed at the beginning of 2009 to assist the "Public Private Partnership (PPP) European Green Cars Initiative (EGVI)" that was established in 2008 to encourage and facilitate pre-competitive research on road transport systems within the European Research Area.

The roadmap identifies when and what actions are required to overcome the different challenges of deploying EVs on a large scale until 2025 in order to achieve 2050 GHG target, as displayed in Figure 2.19. As can be seen, whereas the lower black curve depicts the evolutionary development of accumulated number of EVs, upper black curve shows the estimated growth under assumption of accomplishing the key technological breakthroughs and overcoming other related challenges as explained in four milestones. Milestones and required actions are summarised below:

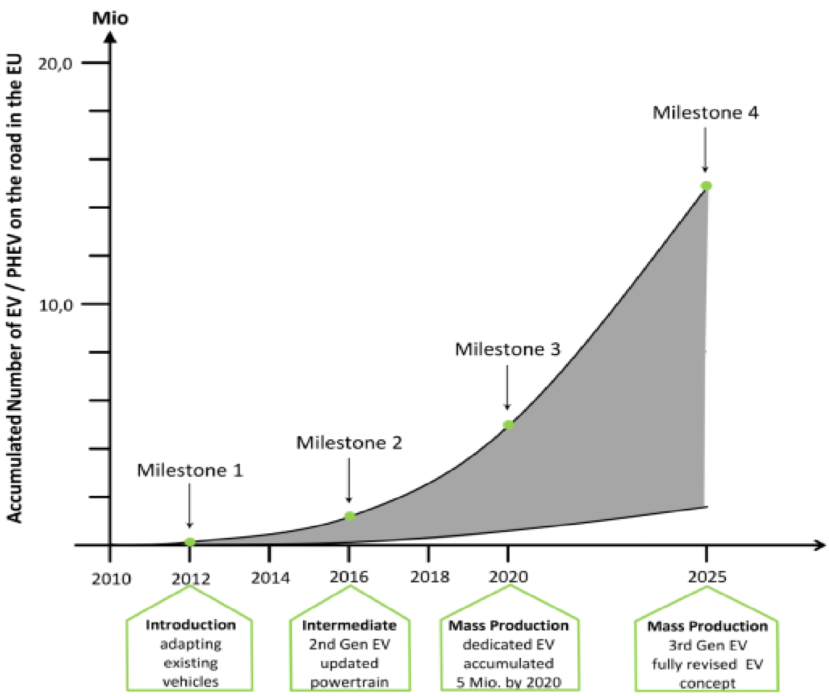


Figure 2.19 Milestones of the European industry roadmap for electrification of road transport [52]

- **Current Situation-Milestone 1 (Introduction-2012)**: According to the roadmap, to accelerate the development of EV technologies and reach the 2050 target, firstly, existing ICEVs need to be converted into EVs. Besides, demonstration and field operational tests need to be initiated and first fleets need to be evolved for niche applications such as taxis, car sharing systems and delivery services as EVs are expensive for the private customers. Moreover, standards for safety, data communication and billing need to be developed together with testing activities and actions in order to increase public acceptance for EVs.
- **Milestone 2 (Intermediate-2016):** During this period, the fundamental technologies for second generation EV providing efficiency gains of all consumers, advanced system integration and high performance energy storage systems need to be developed. Concurrently, an enlarged charging infrastructure allowing dissemination over many cities and regions need to be developed.
- **Milestone 3 (Mass Production-2020):** Mass production of dedicated PHEVs and BEVs need to be established. Batteries providing nearly twice the life time and energy density compared to 2009 lithium-ion technology status at approximately 30% of 2009 cost should be achieved. Highly integrated and cheap electrical motors and power electronics, highly efficient and cheap thermal solutions and particularly batteries which is accepted as the most critical component for EVs should be on the market in big quantities to make EVs sellable without government subsidies. This also means that significant amount of subsidies for EVs need to be provided by governments until mass production of EVs are established. Furthermore, the infrastructure for grid integration may be required to be developed to provide advanced levels of convenience.
- **Milestone 4 (Fully Revised Electric Vehicle Concept-2025):** Lastly, the automobile concept needs to be revised to increase energy efficiency and enable synergies of improvements in various technology fields (such as batteries, vehicle weight etc.) which again lead to incremental changes in energy efficiency and cost. This means that the third generation EV needs to be based on dedicated integrated platforms including a revised information and communications technology reference architecture and middleware. To achieve this, innovative zero-emission drive train systems enabled by highly improved energy recovery and batteries with enhanced vehicle to grid and fast charging capabilities need to be available. Contactless charging may also be required to be widely available and

widely standardised alternative for more comfort and, charging while driving may be required to be available in specific areas. Vehicles also need to be fully integrated into the multi-modal transport.

Based on the above mentioned EU`s electrification plan, it is therefore clear that achieving the EU`s 2050 target scenario represents a challenging set of timelines and requires urgent actions such as mass production of dedicated EVs need to be established, customer adaptation for EVs need to be increased significantly and a great deal of charging infrastructure need to be rolled out by 2020. Besides, new automotive architectures dedicated for BEVs need to be designed and mass produced and new solutions for infrastructure such as contactless charging need to be developed by 2025. It therefore seems unlikely that achieving these radical transformations in the automotive value chain can be attained without significant changes to the existing industry structure and policy framework [12].

2.7 Required Changes in the Automotive Value Chain to Achieve 2050 GHG Emission Reduction Target

Achieving the 2050 GHG emission target of the EU requires a transition from ICEVs to BEVs with HEVs, PHEVs and REEVs as bridging technologies [10]. However, as discussed in the previous section, such technology transition is more than a technological challenge [33, 49, 50] and it involves substantial changes in the whole automotive value chain which are not possible without significant changes to the existing industry structure and policy framework [12]. In this regard, the required changes in the industry structure and policy framework are discussed below.

2.7.1 Changes in the Industrial Structure

As described by the European industry roadmap for electrification of road transport (milestone 3 and 4) [52], achieving 2050 target requires mass production of BEVs. However, this indicates major changes in the automotive and related industries and, thus, requires new supply chains. This is because BEVs require a range of new components including *"electric engines with integrated powertrains, magnets, powerful traction batteries, inverters, charging devices and different power electronics"*. Suppliers of thermo management solutions and new materials, such as carbon fibre-reinforced polymers, would also benefit from this change. Conversely, demand will be reduced for ICEs and related parts, including *"pistons and crank shafts, alternators, exhaust systems* *and fuel tanks"*. Besides, a BEV requires less complex transmissions with just one or two gears [32].

Lithium-ion batteries which are the most expensive part of a BEV is thought to be accounted for about 30% of the total cost of the vehicle. Batteries for PHEVs and REEVs can be smaller and less costly. Yet, they still constitute an important part of the value added. Producers of battery chemicals (cathode and anode materials) and components such as separators, battery cell manufacturers and providers of battery management systems will thus capture an increasing part of the value added as the electrification of powertrains advances [32].

As explained by the European industry roadmap (milestone 4) [52], the shift to electric powertrains also has implications for the architecture of cars. For example, there are several alternatives for the positioning of the electric engine. It can be centrally placed like an ICE. However, there may also be two motors attached to the front and rear axles respectively or four small motors placed in the wheels. Similarly, batteries might be positioned as one detachable pack to exchange them when they are discharged or automobile manufacturers may choose to build several modules built into various parts of the vehicle body so as to enhance weight distribution which improves driving performance. Furthermore, modular designs might be used. EVs and ICEVs might be designed in a similar way to exploit economies of scale in production or new designs for EVs might be chosen such as using carbon fibre or other lightweight materials instead of a steel-based chassis [32].

New components and new automotive architectures also necessitate new technological competencies. Demand for competences in mechanical engineering and mechatronics in the automotive industries is expected to decrease while competences in "chemistry, electronics, electrical engineering and new materials" are expected to increase significantly. With changing requirements, the question also emerges as to who will occupy these new fields of technological specialisation in the automotive supply chain. In this respect, automobile manufacturers are reconsidering their make-or-buy decisions, especially with regards to powertrain technologies and batteries. Thus, value added is reallocated between vehicle manufacturers and suppliers. Especially in battery technology, different firms from very diverse sectors have started to invest. According to Altenburg [32], *"in addition to established battery companies such as Bosch, Varta and Johnson Controls, chemical companies, vehicle manufacturers, automotive parts* *manufacturers and plant engineering and construction firms are being increasingly active in different parts of the battery value chain”* .

However, the industrial reorganisation also extends beyond battery production. Around the world, battery producers have started manufacturing cars such as BYD in China and Bolloré in France. Other suppliers in the traditional automotive supply chain have also demonstrated significant efforts for developing EV technologies. For example, Continental which is traditionally a tyre company has invested substantial resources for EV technologies. Continental manufactures electric motors fully integrated in the powertrain as well as hybrid transmissions together with another supplier, ZF Friedrichshafen AG. The company also offers lithium-ion batteries and integrated powertrain management systems. Continental even built a concept BEV (conversion of Renault Megane) combining a range of its patented EV technologies to demonstrate its know-how to automobile manufacturers. French competitor Michelin also built concept BEVs (Venturi Volage and Heuliez Will). Another example is Evonik. Although it is traditionally a chemical company, it developed an electric sports car with a light weight auto body using auto parts based on structural foam and carbon fibres patented by Evonik, a battery using its patented ceramic-coated separator, and specific tyres developed by the company. Lastly, vehicle manufacturers and energy utilities venture into new mobility services such as car-sharing to develop new solutions for the electric mobility [32].

In addition to system integration, the ICE has been a core competency for nearly all large automobile manufacturers and its specific design was a critical determinant of the corresponding brand identity. Battery management systems were designed based on the particular automotive architecture and engine. Thus, they also contributed to the distinctiveness of each model. With the shift to lithium-ion batteries and electric or hybrid engines, automobile manufacturers need to decide whether to develop the respective competencies in-house or to source them from associated suppliers. If they do not develop the corresponding capabilities, their share of value added will decrease significantly [32].

Therefore, automobile manufacturers are using different strategies to assess the desirable path with regards to value add. Concerning batteries, Daimler is manufacturing the battery cells in a joint venture with Evonik. Other German OEMs consider battery cells as a commodity. Nevertheless, they create joint ventures with battery specialists to develop expertise in battery packaging and battery management. Conversely, Ford sources entire batteries externally. Regarding electric motors, Daimler produces electric motors for

HEVs in-house on a large scale and sources electric motors for BEV from a joint venture with Bosch. Volkswagen aims to manufacture the majority of electric motors in-house. Yet, Renault is procuring electric motors from Continental. BMW took equity participation in significant suppliers for its carbon fibre-based BMWi series so as to retain control of a new core technology [32].

To sum up, achieving 2050 GHG emission target of the EU is not possible without significant changes in the industrial structure. The transformation in the industrial structure has already started with the experimentation of EVs by the existing industrial players and newcomers. Nevertheless, achieving the aforementioned target requires the mass production of BEVs as explained by the European roadmap of the electrification of the road transport (milestone 3 and 4) [52]. To mass produce BEVs, transformation in the automotive value chain need to be accelerated and the existing industry structure need to be shifted to a compatible future structure.

2.7.2 Integration of Newcomers to the Future EV based Industrial Structure

Since the transition to BEVs demands a variety of new products and services, it creates numerous business opportunities outside of, but complementary to, the automotive production chain. Some of them address main challenges of BEV deployment and are therefore likely to become significant drivers of the technology transition. Established companies and especially new entrants are trying to capture these opportunities along the BEV value chain that did not exist with ICEV. However, such situation also affects the industrial structure. According to Altenburg [32], there are five key areas where new business opportunities and models are currently emerging:

- To reduce the total cost of ownership (TCO) of EVs;
- To overcome the range problem;
- To ensure energy supply and optimise energy usage;
- For recycling
- For new niche market cars.

These areas are briefly discussed below:

(*1) New Business Opportunities to Reduce the TCO of EVs:* The TCO comprises a car's purchase price and its running cost as illustrated in Figure 2.20. Currently, estimates for difference in the TCO of EVs compared to ICEVs differ significantly, from about €5,000-20,000 per vehicle, based on powertrain type, model, and country, as well as fuel price and other variables [34]. This high price is mostly because of the additional cost of lithium-ion batteries which is also one of the key reasons for the slow uptake of EVs [32, 34].

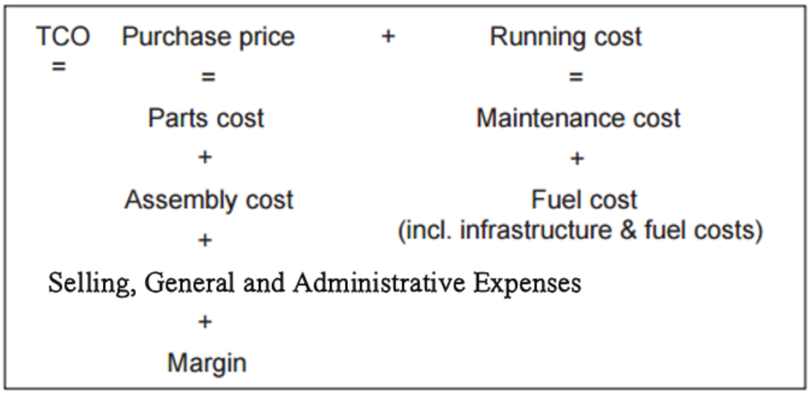


Figure 2.20 TCO Calculation [9]

Owing to the high cost of batteries, the short-term adoption of BEVs relies on government intervention with demand incentives (subsidies, tax breaks) and consumer willingness to pay extra money to bridge the gap. For longer-term mass market adoption, lower battery prices will be an important driver. Large-format battery pack prices are expected to drop due to growing economies of scale. However, the main long-term decrease is expected to come from technological developments [34].

Because of the significance of such critical component, new entrants such as Tesla and Continental are developing batteries. In fact, Tesla recently announced the establishment of Gigafactory that is expected to produce batteries in 2017 and reach full capacity in 2020, and produce more lithium-ion batteries annually than were produced worldwide in 2013. With Gigafactory, Tesla expects to reduce the cost of their battery pack by more than 30% owing to economies of scale, technology improvements, innovative manufacturing, reduction of waste, and establishing most of the manufacturing processes in the same factory [182].

Additionally, to reduce the TCO of cars, battery leasing has become an accepted ownership model for many different brands of BEVs across Europe. For example, customers who are willing to own a Renault Zoe, they need to buy the car and lease the battery. Nissan LEAF, the Volkswagen e-Golf and e-Up! and the Smart ForTwo ED also offer battery leasing arrangements similar to the one offered by Renault. However, customers of these cars can also opt to buy the car's battery pack alongside the car if they wish [183].

A new business model, car-sharing, is also emerging. It is being broadly discussed as an alternative way to accelerate the diffusion of BEVs, especially in cities [184]. Such model also opens up opportunities, especially for newcomers who do not have established distribution systems to compete with the large carmakers. For example, the French company Bolloré has developed a BEV which is called "Bluecar". Such vehicle can only be rented through a regional car rental in Ile de France which runs more than 2,000 Bluecars in the region. Bolloré is currently expanding into other French cities by employing the same business model [181].

(2) New Business Opportunities to Overcome the Range Problem: After the TCO of BEV, limited range and long charging intervals are recognised as the second biggest challenge for BEV deployment. Consumers have range anxiety and several hours are also required to fully recharge a battery. Such situation further restricts the adoption of BEVs [32]. In order to accelerate the transition, charging stations therefore need to be developed and "range anxiety" need to be overcome.

Different electric powertrains require different types of charging or refuelling infrastructure as shown in Figure 2.21. BEVs and FCEVs are totally rely on the new infrastructure to be deployed [34]. For charging the batteries, the public sector via initiatives at city, regional, or country level has established public wired charging infrastructure. More than 20,000 public charging stations have been installed throughout Europe with more than 1,000 public fast-charging stations. However, the wired charging infrastructure density still remains uneven across Europe. Besides, current deployment is mostly focused on cities. Thus, existing charging infrastructure is not suitable for intercity travels [34].

Energy source	GASOLINE/DIESEL	HYDROGEN	BATTERY		
	Fueling gasoline or diesel at a petrol station	**Fueling hydrogen at a hydrogen refueling station**	**"Wired" charging using a plug**	**Battery swapping**	**Induction charging**
Description	Conventional gasoline or diesel refueling	Hydrogen refueling (similar to natural gas refueling)	Plugging in to a charging station using a cable and plug	Replacing a battery for a fully charged one at a special swapping station	Battery in the car is charged by wireless induction charging
Time needed[1]	5 min	5 min	4-8 hrs (slow) 20-30 min (fast)	5 min	~2-8 hrs[2]
Suitable for which power-trains	▪ ICE ▪ HEV ▪ PHEV ▪ REEV (gasoline)	▪ FCEV ▪ REEV (hydrogen)	▪ PHEV ▪ BEV suitable for plug-in charging	▪ Special BEVs suitable for battery swapping	▪ Special BEVs suitable for induction charging
Example car	▪ All ICEs	▪ Hyundai ix35 (FCEV)	▪ Renault Zoe (BEV)	▪ Special model of Renault Fluence	▪ N/A (few pilot cars)
Current availability in Europe	Widely available: ~131,000 stations	Very limited: ~80 stations	Limited availability: >20,000 (slow) >1,000 (fast)	Very limited ~50 stations	Not available (few pilots in progress)

1 Time need for full refueling or recharge. For fast-charging of battery, time to reach 80% of battery capacity is commonly used
2 Since induction charging is still in pilot stage, common duration and power level are not yet established; power levels of 22 kW have been achieved

Figure 2.21 Electric powertrains: charging infrastructure archetypes [34]

To further decrease the range anxiety problem, incumbents and new entrants are therefore working to improve the battery performance, develop range extenders or other related technological solutions. Other solutions such as battery swapping and induction charging are also being developed by new entrants to overcome the problems of limited range and inconvenient recharging intervals, as depicted in Figure 2.21. These solutions are described below:

- The battery swapping model is a way to avoid long charging intervals. The solution suggests that discharged batteries are exchanged with fully charged batteries in exchange stations. The battery can also be owned by the respective service provider in order to reduce the capital cost for consumers. Nevertheless, this requires a high degree of standardisation of batteries and the way they are attached in the car. This business model was developed by a new entrant, BetterPlace, and tested in Denmark and Israel. It was also tested by a Chinese consortium in Hangzhou [32]. Although the company went bankrupt in 2013, the idea is still viable. Indeed, another new entrant, Tesla, has demonstrated battery swapping capability for its Model S and has announced that it will pilot battery swapping stations in the USA at its existing Supercharger stations.

- Inductive charging is another way of avoiding the inconvenience of long charging periods. It represents a technology that uses an electromagnetic field to recharge a vehicle without having to plug into an electric grid. Electric charging may be achieved in a fixed charging station. For example buses can be charged when they stop at their terminal station. Another example is that charging may be done when a vehicle is running on condition that an induction coil is built into the road under the surface and power is taken by vehicles equipped with a second coil which drive on the road. However, such technology is still far from commercial maturity due to reasons of safety, energy losses and high infrastructure costs [32]. Yet, as explained by the European industry roadmap for electrification of road transport (milestone 3) [52], such technology might still be required in dedicated areas in future. In this respect, some new entrants are aiming to develop inductive charging technology.
- Another solution is intermodal transport. It describes the combination of two or more types of transport on a journey. By combining high-speed and high-range modes such as trains with lower speed local transport alternatives such as BEVs and bikes in a smart way, journeys might become faster and car travel might be less attractive. Yet, this requires business models that provide the local means of transport and software solutions so as to plan, book and pay intermodal journeys. Some new entrants are developing such software solutions [32].

(3) To ensure energy supply and optimise energy usage: Several new entrants are developing solutions to improve electronic communication between cars, grids and charging stations to make BEVs more user-friendly and harmonise the requirements of transport and electric grids. For example, Bosch has acquired two new entrants, INST and Inubit which develop software that integrates information regarding the location and availability of charging stations. This is being tested in a field trial in Singapore. Several other new entrants are also developing smart charging and billing software which allows drivers to pay electricity from their smart phones. Both large carmakers and newcomers also develop cloud services for smart transport systems. Finally, energy supply from renewable sources shows substantial fluctuations. Thus, grid stability is an important issue. If BEVs can use energy at times when renewable production is abundant, grids might be stabilised. In the future, it may also be possible to give energy back from the

battery to the grid. To achieve that and make the vehicles grid-friendly, software is needed. In this respect, several newcomers are developing software solutions [32].

(4) For recycling: Owing to the high cost and shortage of key materials such as lithium and rare earths that are increasingly required for energy storage and information technology solutions for BEVs, several innovative solutions are developed. Besides, new lightweight materials require valuable scarce resources. Carbon fibres may substitute many steel parts in the future. Production of these fibres is expensive as well as energy intensive. Thus, concepts to recycle, reuse or develop secondary use options are a major issue. Some newcomers are aiming to solve such issues [32].

(5) For new niche market BEVs: Some new car producers have taken advantages of the paradigm change by producing BEVs in small volumes for niche markets. International examples are Tesla in the USA and Bolloré in France. Nevertheless, most newcomers have gone bankrupt or failed to secure funding for a large-scale roll-out of their car models [32, 185].

In short, the transition to BEVs requires new products and services and creates niche markets which are especially attractive for new entrants since some of these areas are neglected by the established companies [76]. Newcomers include both start-ups and diversifying established firms moving into new markets [65]. Yet, recent studies found that start-ups compose the majority of those companies in EV niches [25, 76]. Start-ups are defined as the earlier phase of micro, small and medium sized enterprises (SMEs) [186].

SMEs are a varied group with regards to size and sector diversity. As countries also adopt different criteria in terms of employment, sales and turnover for definition purposes, it is difficult to clearly define what an SME is [187]. In this regard, there are different SME definitions in different regions. However, according to Nwankwo and Gbadamosi [188], recognising the main difference between the large company and the SME is crucial to understand what an SME is. With regards to objective measures, the large company has *"high levels of capitalisation, sales, employees, debt, stakeholders and so on"* while the SME compared against these measures is smaller. Besides, they argue that sectoral analysis is significant for defining the SME. For example, a small motor manufacturer such as the "Morgan Motor Company" would be dissimilar to a small firm in the plumbing sector with regards to employees, sales, profitability, etc. Even though both

Morgan and the company in the plumbing sector were identical compared against those measures, Morgan would be identified as a niche player in the automotive sector whereas the other company would be recognised as a large organisation in the plumbing sector. In another study [189], it is also claimed that the size parameters of SMEs depend highly on the countries they are operating in due to the country specific economic conditions. For example, what constitutes an SME in Germany might differ from what constitutes an SME in Bulgaria. Therefore, the use of one specific number of turnover or employees for defining SMEs might be misleading. Against this background, the EU`s SME definition is discussed below.

In Europe, the EU definition of SMEs was firstly published in 1996 and it was updated in 2004. The definition aimed to recognise the numerous different perceptions of what constituted an SME across different countries in the EU. The EU considered the altering economic environment and measured financial thresholds in order to make sure that SMEs within larger organisations did not benefit from SME support schemes. By doing that, the EU aimed to support the real SMEs. Hence, the EU definitions considered the financial backing and economic strength of an SME [188]. In defining the typology of SMEs, the EU considered three types, "the micro, small and medium sized", and identified two main factors determining whether a company is an SME are: (i) number of employees and (ii) either turnover or balance sheet total [190]. The details of this definition are displayed in Table 2.3.

Table 2.3 European SME definition [186]

SME Definition			
Company category	Employees	Turnover	Balance sheet total
Medium-sized	< 250	≤ € 50 m	≤ € 43 m
Small	< 50	≤ € 10 m	≤ € 10 m
Micro	< 10	≤ € 2 m	≤ € 2 m

In a single market such as the EU and an increasingly globalised business environment, it is significant to have a common SME definition to ensure balance in policies and support competition across member states. A common SME definition therefore improves the consistency and effectiveness of SME policies across the EU. However, as SME definition determines the eligibility for special support, a consistent and reliable definition is also very significant. Yet, the EU`s SME definition only considers the economic strength of a company without taking into account the sectoral or country-specific economic differences although the size of a company operating in a country is contingent upon the wealth of an economy as well as the relative size of the associated sector in this economy. In that context, an SME definition considering those factors might be more beneficial for the EU. For example, a recent study [189] considers the country-specific economic differences and defines SMEs as follows:

"An SME is a formal enterprise with annual turnover, in United States dollar terms, of between 10 and 1000 times the mean per capita gross national income, at purchasing power parity, of the country in which it operates".

The main advantage of this definition is that it reflects the local context. However, this definition is also limited as it does not consider sectoral differences. It is therefore recommended that the EU should consider those aspects for defining SMEs in the future to improve the effectiveness of the SME policies. Nonetheless, in this study, the current SME definition is also used for defining SMEs in Europe because it is used as a basis to define SMEs and provide support schemes in the EU.

As discussed in the previous section, the existing industry structure need to be shifted to a compatible future structure. In the existing structure, SMEs which are in the majority of newcomers [25, 76] are contributing the development and dissemination of BEVs by exploiting the technological opportunities which are created with the extension of the automotive value chain. This means that SMEs might have a role in the possible BEV based automotive value chain re-shaping. In this regard, understanding and supporting the development of SMEs in emerging BEV supply chains is very significant for achieving GHG emission reduction targets as well as improving the economy of the EU.

2.7.3 Changes in the Policy Frameworks

Previously, it was explained that a shift to BEV is not possible without significant transformation in the industrial structure. However, such transformation is very unlikely to occur all by itself within an acceptable period of time which ensures the EU`s 2050 road transportation decarbonisation pathway [80]. This is because there are a number of factors both on the demand side (the high price of BEVs relative to conventional ICEVs; the lack of refuelling/charging infrastructure; the restricted driving range compared to conventional ICEVs, and the perceived distance needs of consumers, which often do not correspond to their regular driving habits; and refuelling times that are longer than what consumers are accustomed to) and on the supply side (limited economies of scale; high initial capital investment and low returns to R&D) restricting the development of BEVs [76].

To accelerate the development of new value chain and industrial structure, policy intervention is therefore required. Policy intervention for BEVs is especially important since it is recognised that environmental innovations such as electric propulsion technologies have a so called “double-externality problem”, where the costs of development, deployment and use are borne by the innovator alone, although the society benefits from it as well [81-83]. This means that the environmental benefits of BEV use accrue mainly to society and to the environment in the form of reduced pollution and carbon emissions, whereas the performance penalty accrue mainly to the owner or purchaser of the vehicle. This problem decreases incentives for consumers and businesses alike to invest in environmental innovations. To resolve this, significant policy effort needs to be directed at solving these externalities. In this regard, target instruments need to be used by public organisations to solve both supply side and demand side challenges and balance costs and benefits in the BEV value chain.

To resolve the double externality problem and accelerate the transition to BEVs, across the EU and elsewhere in the world there has been a burgeoning array of policy measures both to support technological development and to stimulate the market with respect to BEVs since the beginning of 1990s. The 2007 European Action Plan for Energy Efficiency (2007-12) for example identified transport as one of three core areas with potential for energy savings, while Directive 443/2009 laid down the framework for CO_2/km targets. The 2011 Roadmap to a Single European Transport Area included the strong target of nil conventional ICEVs in cities by 2030. The EU fleet average carbon emissions regime is a suite of measures includes the setting of fleet average target CO_2 emissions per kilometre along with fines for non-compliance; the compulsory availability to consumers of fuel efficiency and carbon emission information; and the development of national incentives on carbon emissions reductions through vehicle taxation, benefit in kind taxation and other steps to penalise high-emitters and/or preferentially treat low-emitters.

However, owing the diversity of policy instruments that governments use such as government sponsored R&D incentives, enhancing the capacity for knowledge exchange with public private partnerships (PPPs), support for education and training, funding demonstration projects, tax credits and subsidies for consumers of new technologies, government procurement, regulatory standards and taxes [191] and different industrial goals aimed by the use of these instruments, public policies aimed at promoting electrification of road transport have taken somewhat different forms in different regions [55, 83, 98-100].

For example, The USA government has created a number of tax incentives mainly to ensure the future viability of the domestic automotive industry. The country aims to become market leading in the area of automotive batteries [86]. With Energy Independence and Security Act (EISA) in 2007 and American Recovery and Reinvestment Act (ARRA) in 2009, the government increasingly played a venture capitalist role in the automotive industry by providing loans and R&D investments [30]. However, since the Japanese automotive industry is technology leading in the area of EVs and the Japanese government recognises the lack of charging facilities as one of the most serious challenges to the widespread use of BEVs in Japan, the government has put its recent supportive efforts on the development of the charging infrastructure [86]. In contrast, the German government is following a careful strategy regarding EVs since Germany`s economy is highly dependent on its automotive industry and this is threatened by a global transition from a fossil fuel based transport towards EVs. Thus, policies by the government explicitly aim to sustain the role of German manufacturers and suppliers in the future EV based automotive value chain and to make Germany a lead market and a lead supplier of electric mobility by 2020 [55]. In this regard, mostly supply side measures such as R&D incentives, regulations and technology roadmaps are used by the government rather than demand-side measures to prepare the industry.

The United Kingdom (UK) government has also implemented a strategic innovation strategy aimed at developing the EV sector in the UK. A key priority has been the revitalisation of the domestic automotive sector by exploring the potential for EV production (both component and assembly) to become a core activity within the UK automotive sector [192]. In this regard, the UK government has created a number of funding programmes for the development, supply and use of BEVs through consumer incentives, support for recharging infrastructure, R&D and demonstration projects [86]. Government policies that have been used to support the development of EV technologies in six developed regions, USA, Japan, EU, France, Germany and the UK, since 1990 can be found in Appendix A.

Another example is Austria. Driven by the high share of renewable energy sources in national power generation (approximately 70%), Austrian government also recognised electric mobility as a top priority in order to reduce GHG emissions from transport and to increase the competitiveness of the automotive industry. Austrian government followed two main steps: the support through promotions and funding programs (R&D investments, demonstration programmes, tax reduction for EVs, exemption of BEVs from the insurance tax and Austrian registration tax, and infrastructure investments) and the increase of the attractiveness of EVs by regulatory measures. Consequently, Austrian government implemented both technology-push (e.g. 'technological lighthouses e-mobility') and demand-pull (e.g. 'model regions e-mobility') measures to support the EV industry [104].

In short, target instruments need to be used to accelerate the formation of new value chain and new industrial structure. Aligned with such perspective, across the EU and elsewhere in the world there is a burgeoning array of policy measures both to support technological development and to stimulate the market with respect to EVs based on national governments` specific EV transition targets, but given this diversity of interventions there is a need for a systematic framework to evaluate policy effectiveness. Such a framework might have the potential to support national governments in: identifying and improving the dynamics of EV innovation instruments more effectively, validating results and impacts of instruments on development of EV technologies and selecting the most appropriate instruments for their country based on their transition goals.

2.7.4 Theoretical Context

In previous sections, it was explained that achieving 2050 GHG emission target of the EU might be possible with an industrial structure which enables the mass production of BEVs; understanding and supporting the development of SMEs which are in the majority of companies in BEV niches and the use of target instruments by governments. In this section, the use of such strategy to overcome the electrification challenge will be theoretically elaborated by examining the socio-technical transition literature.

As discussed before, a transition from ICEV to BEV involves overcoming barriers that go far beyond purely technological innovation; and that economic, business, infrastructural, institutional and societal innovations are just as important [33, 40-48]. Therefore, a transition from ICEV to BEV is a co-evolutionary long-term process comprising numerous actors and social groups [33, 49]. In this respect, an integrated analytical framework is required to understand, analyse and study the technological transition in the automotive sector.

The multi-level perspective (MLP) on socio-technical transitions which describes the structure and dynamics of socio-technical systems is therefore frequently used in literature to understand and study technological transitions in road transport system [33, 42, 46, 51, 53-55]. It was originally developed by Rip and Kemp [40] and theoretically elaborated by Geels and others [33, 41-48]. The MLP was developed in the field of innovation studies, drawing on insights from several disciplines and literatures. It provides a way of explaining the key analytical puzzle of technological transitions that is said to be stability and radical change [33].

In literature, the MLP is used as a heuristic framework helping researchers see interesting patterns and mechanisms and lead their attention to appropriate questions and issues regarding socio-technical transitions. It signifies a certain epistemological style (interpretive research) to study and understand technological transitions [33]. The framework is called MLP as it identifies three analytical levels within socio-technical systems (e.g., the automotive system): niches, socio-technical regimes and an overarching socio-technical landscape. Niches form the micro-level in which radical EV innovations emerge. The sociotechnical regime forms the meso-level, which comprises dominant institutions and ICEV technologies and, thus, accounts for the stability of existing automotive system. The macro-level is formed by the sociotechnical landscape which is an exogenous environment outside the direct influence of niche and regime actors and it represents trends and contextual drivers and barriers to change [33].

In the MLP, linkages between elements at above discussed levels might initiate technological change and result in new configurations in the industrial structures [51]. Figure 2.22 illustrates an ideal-typical illustration of how the three levels interact in a dialectic manner in the unfolding of socio-technical transitions. Even though each technology transition is unique, transitions are generally initiated by the interaction of developments at the three analytical levels: (a) niche-innovations build up internal momentum (bottom-up), (b) changes in the overarching landscape level create pressure on the regime (top-down), and (c) destabilisation of the regime creates windows of opportunity for niche-innovations [33]. As a result, old technology regime is replaced by the new radical technology and a transition is occurred. The new technology also results in changes in the old industrial structure. Transition theory is described more in depth below for understanding the drivers of technology change in the automotive industry.

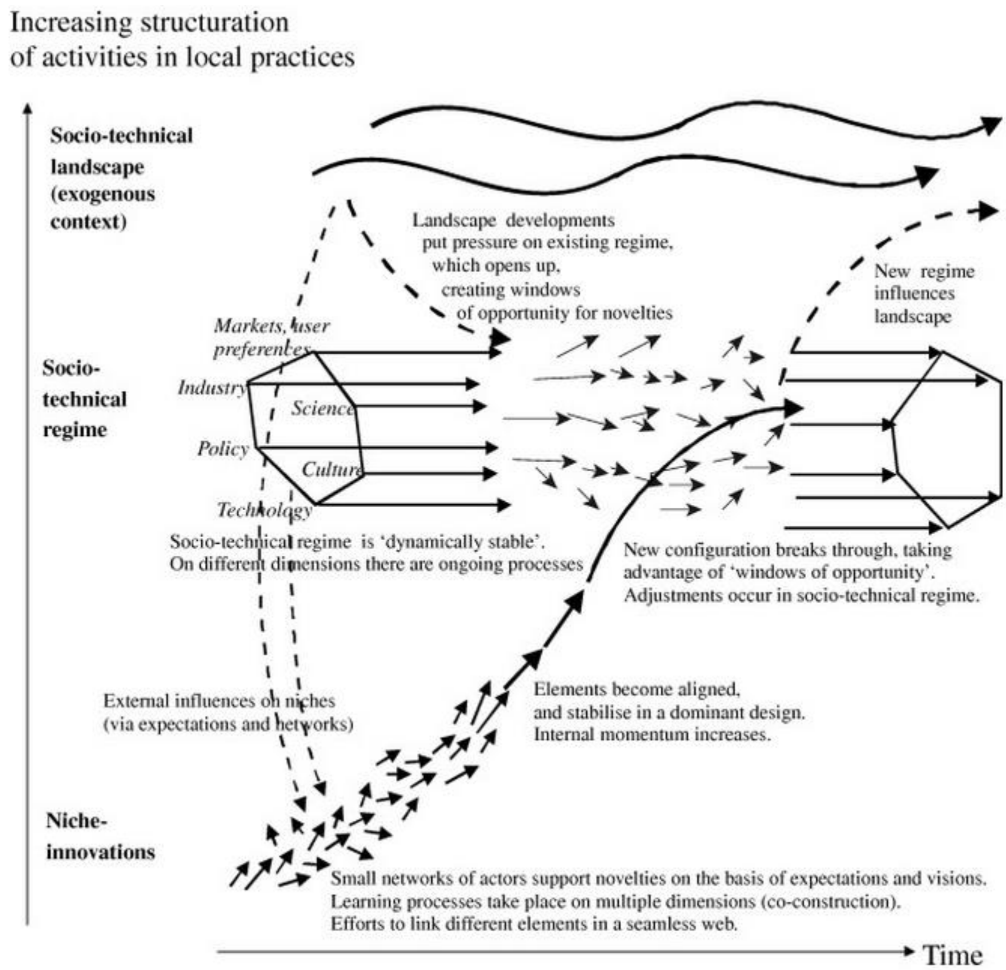


Figure 2.22 Multi-level perspective on transitions [33].

According to Wells [193]:

"*Socio-technical transitions theory [41] posits the notion of an embedded regime in a state of dynamic equilibrium for any given ensemble of technologies and related practices. At the core of the automotive regime remain the major vehicle manufacturers and their entrenched technology packages of the all-steel body, the ICE and a distinctive business model predicated on centralised manufacturing economies of scale, long inbound and outbound logistics lines, franchised retailers, and the outright sale of cars (and associated finance) as the primary source of revenue [27]. In other words, at the level of the vehicle manufacturers there is a suite of core product and process technologies that are combined with a distinctive pattern of value creation and capture – and it is these two aspects in combination that form the fundamental basis of the existing* *socio-technical automotive regime [194]. However, around this core has accreted a multi-layered "shell" of supportive commercial activities, social frameworks, practices, infrastructures, legal norms and enforcements, behaviours, attitudes, normative values and beliefs all of which contribute to and largely reinforce the established socio-technical regime. Importantly, many of these accreted constituent elements act, implicitly or explicitly, to allow the reproduction of the incumbent regime as currently constituted and on the "terms" of the established regime participants*". In this regard, technological and societal development can be described as path dependent.

The transitions theory therefore suggests that the dominant ICE technology is very firmly embedded within society and the economy, and all of the actors and rules are geared towards this technology [159, 195]. The "lock-in" concept is used to describe such situation. In this respect, achieving a transition from ICEV to BEV requires a regime change which means significant changes in the whole automotive value chain. This also involves changes in the value creation and capture resulting in changes in the automotive industrial architecture. Nevertheless, such situation threatens established companies which have vested interests in the existing industrial structure. Thus, automobile manufacturers innovate mostly incrementally by continuously improving ICE technology in order to defend their current positions and business models [47].

Since automobile manufacturers and other regime participants such as fuel providers and consumers generally resist the radical technology change by favouring the production and consumption of established ICEVs, the transitions theory underlines that [33, 41, 46] a transition from ICEV to BEV (or to any other radical technology) only comes about if there is a pressure from the landscape level on the ICEV regime which destabilises current practices and creates opportunities for BEV technologies that are developed in niches to break through. Previous studies recognised that such pressures could be climate change, rising oil prices and related policy measures for BEVs [41, 47, 55, 84, 85]. Indeed, as discussed previously, triggered by the GHG regulations which are the results of the environmental pressure, automobile manufacturers around the world has started electrifying the powertrain although the automotive industry's main strategy is still the improvement of the ICE technology [21-28]. Averagely, around 80% of the industry's patents are thought to be awarded to ICEV related technology, against only about 20% for technologies associated with BEVs, PHEVs and HEVs [24].

Therefore, socio-technical transitions theory explain that radical technologies (BEVs in this case) are firstly developed for niche markets to respond to the pressure in the landscape level and experiment the new technology. However, at the niche level, it can be observed that the socio-technical transitions literature [33, 41, 46] has a tendency to focus on the contribution of new entrants (outsiders to the existing regime) or, alternatively, grass roots movements, that might establish the enclaves or destabilisation forces from which systemic change can radiate out. The reason for such focus is that established companies or incumbents have difficulty in dealing with radical technologies to defend their positions [70, 71, 132, 150]. On the contrary, small companies or outsiders to the existing regime which are called as new entrants [65] are more capable of developing radical technologies [33, 65, 71, 196] as they have little to lose and no vested interests compared to large established companies [71]. Besides, radical innovations lower entry barriers and open up windows of opportunity for new entrants to enter the market [28, 64-71], which is usually very difficult for a new firm to enter the market with regards to established technology [72].

According to the transitions theory, the relationship between those levels (niche, regime and landscape) might be seen as a nested hierarchy with regimes being embedded within landscapes and niches existing inside or outside regimes as shown in Figure 2.23. Based on this fact, in the case of the automotive industry and personal private mobility it may be observed that, currently at least, technological innovations are rather layered on top of (or into) the existing regime rather than displacing it - just as new practices and behaviours may be layered into existing practices owing to the previously described electrification strategies of the automobile manufacturers. Therefore, BEV technologies are currently developed in niches by the contribution of both incumbent companies and new entrants.

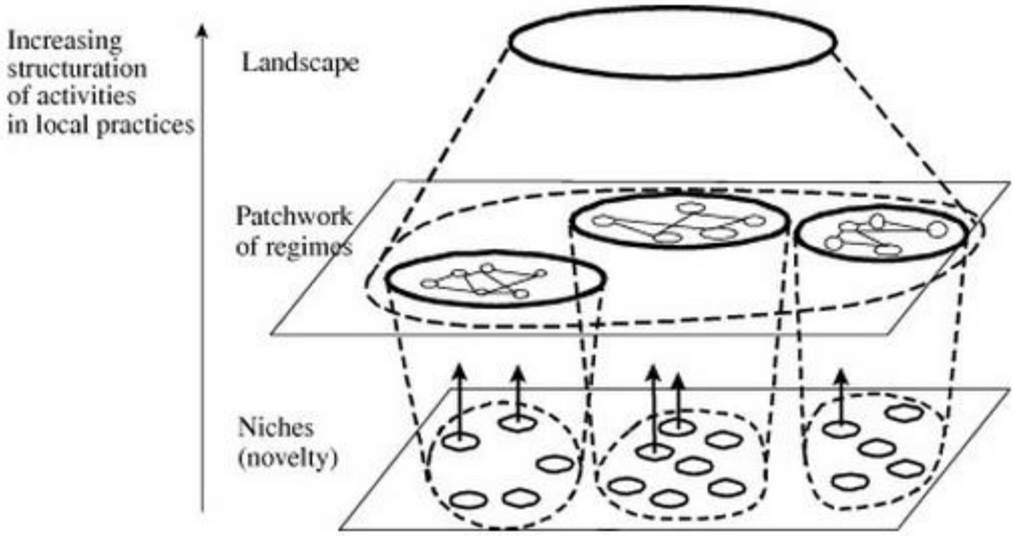


Figure 2.23 Multiple levels as a nested hierarchy [41]

Overall, the transition theory also suggests that a transition from ICEV to BEV is only possible with an industrial structure which favours the production and consumption of BEVs rather than ICEVs. However, to achieve such architectural change, BEV technologies that are developed in niches by incumbent companies and, especially, new entrants need to be further developed and landscape pressure (policy intervention with target instruments) need to be increased. The significance of new entrants for the development and dissemination of BEV technologies also makes it crucial to understand and support those actors in emerging BEV niches in order to achieve technical transition in the automotive sector.

2.8 Research Strategy to Achieve 2050 GHG Emission Reduction Target

In previous sections, it was clarified that achieving the 2050 GHG emission target of the EU requires a transition from ICEVs to BEVs [32]. Yet, such transition is more than a technological challenge [33, 49, 50] and it demands substantial changes in the whole automotive value chain which, in return, entails significant changes to the existing industry structure and policy framework [12]. In this regard, the required changes in the industry structure and policy framework are discussed below to articulate this research`s strategy to support the automotive sector responding the 2050 GHG emission reduction challenge.

- Achieving the aforementioned target requires the mass production of BEVs. However, this is not possible with the existing industrial structure. To mass produce BEVs, the existing industry structure need to be shifted to a compatible future structure: Chapter 3 will explore the existing industrial structure and compatible future structure for the mass production of BEVs, identify challenges associated with such architectural change in the automotive industry and develop a set of strategies aiming to overcome such challenges in order to support the development of a commercially strong BEV sector in Europe.

- In the existing industry structure, SMEs which are in the majority of newcomers [25, 76] are significantly contributing to the development and dissemination of BEVs by exploiting the technological opportunities which are created with the extension of the value chain. Thus, with the transition from ICEV to BEV, SMEs might have a role in the possible BEV based automotive value chain re-shaping. In that context, understanding and supporting SMEs in emerging BEV niches is very significant for achieving GHG emission reduction targets as well as improving the economy of the EU: Chapter 4 will explore the approach of SMEs to the emerging BEV sector to understand SMEs and identify support areas they need to have a role in the possible BEV based automotive value chain re-shaping in order to stimulate the BEV technology and business in Europe.
- The transformation in the industrial structure is very unlikely to occur all by itself within an acceptable period of time which ensures the EU`s 2050 road transportation decarbonisation pathway [80]. To solve supply and demand side challenges, and accelerate the formation of new value chain and industrial structure, target instruments need to be used. However, a framework is required to enable the pre-implementation analysis of putative policy measures intended to assist in the creation of benign path dependencies and hence transitions to sustainable mobility: Chapter 5 will develop a framework which can be used to predict the technology development of EVs based on national governments` different technology strategies. In Chapter 6, the developed framework will be trialled by applying it to Austrian innovation instruments with the support of Austrian Research Promotion Agency (FFG).

2.9 Summary

To cut GHG emissions from the automotive industry and comply with UNFCCC`s 2° C global warming target, several governments have introduced fuel economy and GHG emission regulations because transport, especially road transport, is a key contributor to GHG emissions [1]. One of the most ambitious regulations were adopted by the EU. The

EU adopted a regulation which established a CO_2 emission target of 130 g/km for the average of new cars sold by 2015. In 2014, the regulation was amended and established a stricter emission target of 95 g/km by 2021. The EU also set a long term target of achieving overall at least 80% CO_2 reduction by 2050 compared to 1990 levels [7], which indicates at least a 60% reduction target for transport [8] and at least a 95% reduction for the road transport [9]. The 2050 target also translates into a CO_2 emission target of 130 g/km for the automotive industry [10].

There are several technological alternatives for automobile manufacturers to achieve these targets. These technologies might be collected under two technology pathways: (i) improving the ICEV efficiency and (ii) a transition from ICEVs to EVs. With regards to these options, the main technology strategy implemented by OEMs is the improvement of the ICEV efficiency [21-28]. Although such strategy might be viable to comply with the 2021 target [32-34], it is not feasible to achieve the 2050 target [4, 10] since it is not possible to decrease transport emissions below 80-90 g/km with the best diesel ICEVs. Even with the best diesel hybrid vehicles, it is not possible to reduce emissions below 60 g/km [12]. Besides, even though the existing regulation remains the same until the year 2050 (95 g/km), the ICE technology will progressively phase out. Yet, the ICE technology needs to be phased out quicker and a gradual shift from ICEVs to BEVs with HEVs, PHEVs and REEVs as bridging technologies need to be achieved in order to achieve the 2050 target [10].

However, achieving a transition from ICEVs to BEVs is more than a technical challenge which will not be motivated by single factors [33, 49, 50] since electric propulsion technologies are radical technologies [35-39]. Indeed, such transition involves substantial changes in the whole automotive value chain as demonstrated by the "European Industry Roadmap for Electrification of Road Transport" identifying the actions required to tackle the challenges of deploying EVs on a large scale until 2025 [52] and those radical changes in the value chain cannot be attained without significant changes to the existing industry structure and policy framework as explained by the transition scholars [41, 47, 55, 84, 85].

By using the transitions theory and MLP as a heuristic framework, this research`s strategy to overcome the electrification challenge in the automotive industry was clarified. It is argued that achieving such radical transformations in the automotive value chain requires i) a compatible industry structure which enables the mass production of BEVs ii) understanding and supporting the development of SMEs in emerging BEV supply chains and iii) use of target instruments by governments to accelerate the development of BEV value chain and industrial structure. In this respect, each of these challenges will be discussed in the following chapters for supporting the development of BEV technologies in the automotive sector in Europe in order to support the sector to reach the EU`s 2050 GHG emission reduction target.

CHAPTER 3 – BATTERY ELECTRIC VEHICLE SECTOR OF TODAY AND THE FUTURE

A part of this chapter has been published in International Journal of Electric and Hybrid Vehicles

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And an international conference in Belgium:

Ernst, C., Özel, F., Davies, H., Olschewski, I. and Pieper, M. *The Development of the E-Mobility Supply Chain in Europe-Results of the European Project ENEVATE,* in *European Electric Vehicle Congress (EEVC)* November 19-22, 2012 Brussels, Belgium.

3.1 Introduction

To achieve a transition from internal combustion engine vehicles (ICEVs) to battery electric vehicles (BEVs), BEVs need to be mass produced. Nevertheless, this requires new technologies and automotive architectures as well as new competencies, which, in return, creates opportunities for newcomers whereas the substitution of old competences creates risks for established companies. Thus, value-added is reallocated between the existing industrial players and newcomers. This also has significant implications on the make-or-buy decisions of automobile manufacturers. In this regard, a transition from ICEV to BEV requires changes in the existing industrial structure which favours the production and consumption of ICEVs. The industrial restructuring has already started with the experimentation and production of electric vehicle (EV) models by the existing industrial players and newcomers. However, to achieve the European Union`s 2050 target, transformation in the automotive industry structure need to be accelerated and the existing industry structure need to be shifted to a compatible future structure for BEVs.

To support the transition from ICEV to BEV in the automotive sector in Europe, this chapter explores the existing industry structure and compatible future structure. To achieve this aim, the automotive sector in North-West Europe (NWE) was analysed to examine the implications of BEVs on the supply chains and find out what competences and capacities might be needed for mass production of BEVs in Europe by conducting production structure analysis, make or buy analysis, value-add analysis, white spot analysis and competitor analysis. The aforementioned analyses were conducted by the "European Network on Electric Vehicles and Transferring Expertise" (ENEVATE) partnership". The results of these analyses were then used as a guide to explain the changes in the industrial structure by the author of this study. The author also discussed the challenges and strategies for a commercially strong BEV sector in Europe.

3.2 Methodology

A transition from ICEV to BEV requires new supply chains which have significant impacts on the automotive industrial architecture. Theoretically, the socio-technical transition literature also explains that a technical transition in the automotive industry requires industrial restructuring [33, 42, 46, 51, 53-55]. Similarly, another theoretical model focusing on technical change in literature, Product Life Cycle (PLC) approach, describes that a radical technology change in an industry is accompanied by substantial changes in the industrial architecture [56, 57].

Establishment of new supply chains of co-ordinated actors who together will bring BEVs to market is a long-term process which involves the integration, coordination and collaboration between previously largely isolated actors both within the established automotive industry and outside it. To support the transition to BEV, competencies therefore need to be found and connected to develop a strong supply chain. In this respect, as part of the ENEVATE project, a database was developed in order to capture the competencies within the existing ICEV and nascent electric mobility sectors across NWE. The approach used to develop this database is outlined in Figure 3.1. The final database provides both a list of relevant companies like system and component suppliers, universities and research and development (R&D) centres.

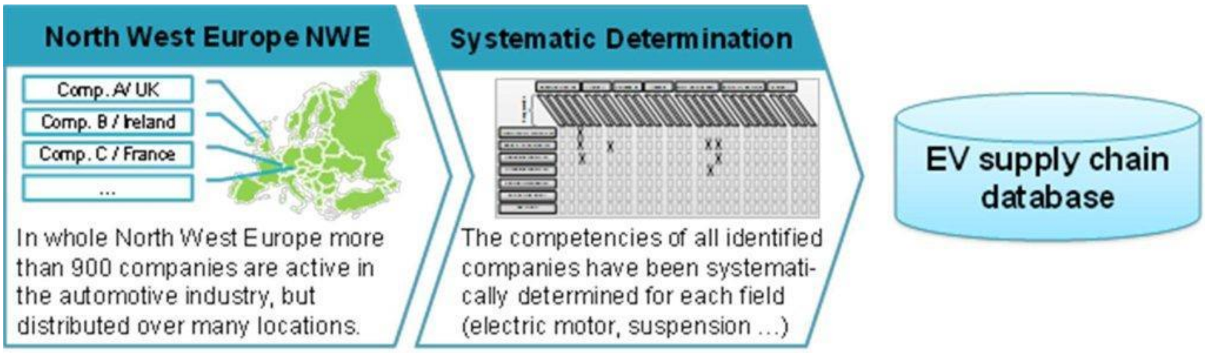

Figure 3.1 EV supply chain database

The analyses of this database were then used to guide the development of a number of strategies (short-term, medium-term and long-term) that aim to facilitate the development of a commercially strong BEV sector in the NWE region. These analyses are described in the following sub-sections. Furthermore, the database is an online tool, integrated in the www.enevate.eu homepage, which helps companies to identify possible strategic development and production partners for BEV.

3.2.1 Production Structure Analysis

A shift from ICEV to BEV based industry structure requires new supply chains. A supply chain can be thought of as a single virtual organisation involving several business units such as manufacturers, suppliers, distributors and retailers, and operations [197]. Its purpose is to obtain raw materials, transfer those raw materials into consumable products (in this case cars), and distribute those consumable products to retailers and customers [198]. The productivity of a supply chain is critical as companies compete via their supply chains rather than competing alone [199-201].

The automotive industry has a "tiered" supply chain structure, as illustrated in Figure 3.2. Upstream from the automobile manufacturer or original equipment manufacturer (OEM) are called "Tier 1 suppliers". These firms typically supply some of the largest components or sub-systems for the cars such as suspension assembly or gearbox. These companies are also called as "system integrators". Components to "Tier 1 suppliers" are typically provided by "Tier 2" suppliers. Some examples of these components are pump units and bearing assemblies. The Tier 3-x suppliers might also provide the Tier 2 suppliers with anything from brackets, seals through to machined components etc. [202].

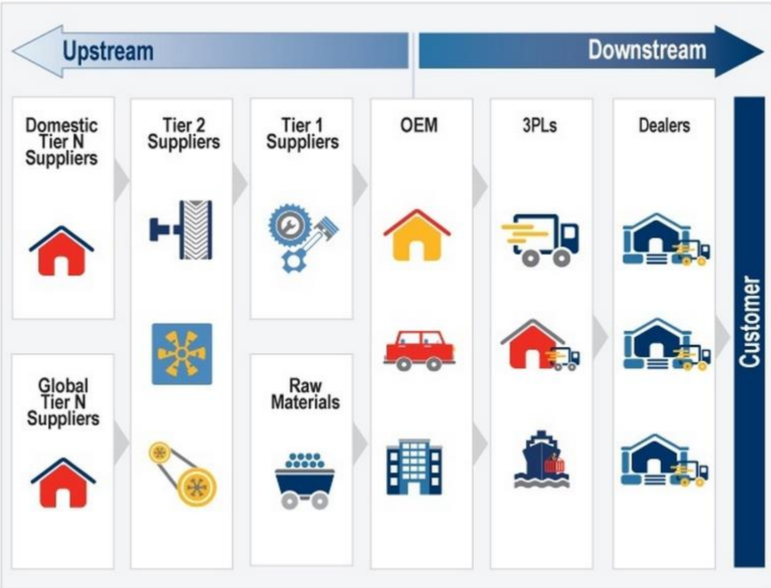

Figure 3.2 Automotive supply chain [202]

Owing to such tiers in the automotive supply chain, "Tier 1 suppliers" represent the most important suppliers for automobile manufacturers. Thus, they usually have a manufacturing plant located close to the carmakers to support "Just-In-Time" type production processes. Yet, Tier2-x suppliers might be located anywhere in the world. In fact, several companies have established manufacturing plants in countries which have lower labour costs such as China and India. In addition to the tiered suppliers, there are also raw material providers such as steel manufacturers providing sheet products directly to the OEMs [202].

Downstream from the OEMs, the third party logistics (3PL) providers distribute finished vehicles to storage compounds and vehicle distribution hubs located across the globe. From these locations, vehicles are shipped to dealer networks when required to sell the vehicles to consumers.

The distribution of roles between firms in the above mentioned “tiered” supply chain structure of the industry (upstream supply chain) is closely related with the modular production principle [203]. In this regard, the existing industry structure and the impacts of the BEVs on this structure is discussed below by examining this production principle.

In principle, modularisation might be described as the partition of a product (in this case cars) into sub-systems constituting complete functional units which can be designed and produced independently. Thus, automobile manufacturers coordinate outsourced design and manufacturing activities by implementing modular design and production principle [203]. Whereas automakers were provided a large number of different parts and components that were assembled in to complete vehicles at final assembly plants from a huge supply base in the past [154], today suppliers integrate a significant share of these components into families of related component (systems and modules) and supply to the automobile manufacturers as complete functional units. Some modules in the automotive industry are suspension, doors, headliners (including components such as grip handles, lighting, wiring, sunroofs, sun visors, and trim pre-assembled), ventilation (including heating and air-con units), seats, dashboards and engines (including engines, transmission and axles) [156].

Modular production therefore allows carmakers concentrating on their core activities (car assembly, the design of complete vehicles, the manufacturing of core technologies) and encouraging suppliers to conduct a significant amount of the R&D activities. Currently, approximately 75% of vehicle production and nearly 50% of automotive R&D is said to be performed by suppliers [156]. Such outsourcing trend therefore results in the reformation of activities in the automotive supply chain [203]. This means that a significant part of the authority and control over the design and production of BEV technologies are distributed from automobile manufacturers to the suppliers [156].

However, BEVs are considered as a new product or as a new industry since BEVs require new parts and they do not require some of the vital parts of ICEVs. For example, while the number of parts necessary for manufacturing an ICEV is said to be in the range of 20 to 30 thousands, a BEV needs new parts such as an electric motor and battery and does not require other parts such as an ICE and exhausted gas system, which would reduce the number of parts to a range of a few hundreds to ten thousands [159]. Besides, in the transition from ICEV to BEV there would be a loss of value-add associated with the ICE and transmission as well as additional components which correlate with a design optimised on an ICEV. At the same time, there would be additional value-add tied to the BEV component costs. This means that the move to electric propulsion requires new supply chains [78]. Before exploring the impacts of BEVs on supply chains, it is worthwhile recapping how existing relationships in the automotive supply chain have developed.

The auto industry was dominated by mass production by using assembly line speeds and techniques in the 20th century after the combined introduction by Ford of mass produced standardized components and the moving assembly line, the development by Budd of the all-steel body and the drive by General Motors (GM) to put in place the key elements for a mass market for cars [204]. However, this situation started to change after the Second World War owing to the significant shortages of economic, human and material resources in Japan [154]. To overcome these problems, Japanese manufacturers created an innovative, well-organised, process-oriented system that is also defined as "Lean Manufacturing" under the guidance of Japanese business leaders such as Toyoda, Taiichi Ohno and Shigeo Shingo [205]. This approach built on the existing Ford-Budd-GM mass production system, but in the absence of true economies of scale, instead focused on flexibility, process control, optimization, waste elimination, closer integration of manufacturing and distribution, and people utilization rather than lowering costs through volume. This system brought great success to Toyota. After Toyota`s success, much of the auto industry adopted "Lean Manufacturing" approaches, such as just-in-time processes and moved more towards a built-to-order approach where possible [206].

With these developments, particularly the impact of the Japanese and later Korean manufacturers, after the mid-1980s the world automotive industry started to become an integrated global industry rather than distinct national industries [207] with significant transformations in the automobile industrial architecture and OEM`s vertical disintegration trends [208]. Since 1980s, most of the automakers have adopted a pro-active attitude towards the reduction of the environmental impact of their production processes. Besides, the pressure to decrease costs has encouraged carmakers to work towards resource productivity and minimisation of waste. In this respect, platform consolidation and modular assembly were adopted in the 1990s to increase overall resource productivity in automobile manufacturing and the chances of reaching greater economies of scale [209]. With the implementation of modular design and production principle, the responsibility for pre-assembling, logistics and coordination of upstream suppliers was distributed from automobile manufacturers to large tier 1 suppliers, also referred as “system integrators” or “turn-key suppliers” [156]. After the late 1990s, in particular, the developments in modularity enabled the creation of very large system integrators such as Canadian firm Magna, completing this shift.

Today, the supply chains are therefore closely linked. System integrators integrate the modules and components produced by either technology specialists or process specialists (Figure 3.3). The growth of system integrators has resulted in a decrease in the total number of directly linked suppliers for the vehicle manufacturer. Thus, current automotive supply chain exists increasingly on a “one:few” relationships [155].

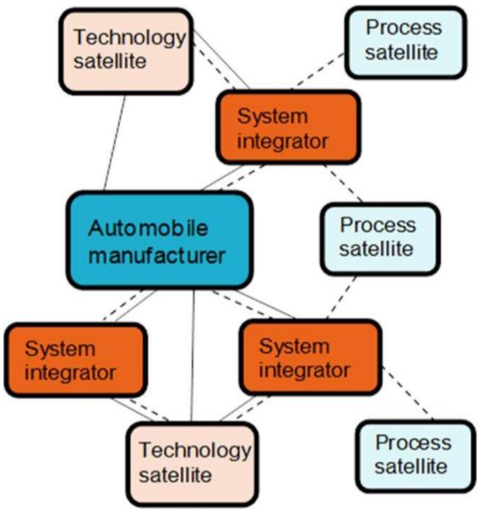

Figure 3.3 Production structure of the ICEV of today [210]. The dashed lines represent joint logistics / supply chain. The solid lines represent joint product development.

However, as discussed before, a transition from ICEV to BEV is accompanied by significant changes in the automotive supply chain [78]. The type of change is explained below with a well-known theoretical model focusing on technical change in literature, PLC model.

The PLC model describes a recurring process of transition where a radical innovation initiates an era of ferment, which is ended by the emergence of a dominant design introducing an era of incremental innovation, which in turn is ended by the next radical innovation [64, 211, 212]. This model describes that, in each cycle, the number of firms increases in the early or ferment period, reaches a peak with the emergence of the dominant design, decreases until a few firms dominate the industry, and then restarts again when a radical innovation creates the conditions for a new wave of entry and the re-enactment of the industry life cycle [56, 57]. According to this model, one of the characteristics of a radical innovation is the entry of many firms [211] as radical innovations lower entry barriers and open up windows of opportunity for new entrants to enter the market [28, 64-71]. This is a different situation in comparison to a mature technology where a small number of firms control the bulk of the market share and it is difficult for a new firm to enter the market [72].

Utterback [65] identified high numbers of competitors that entered the market during eras of ferment for industries such as automobiles, televisions and semi-conductors. He demonstrated that the entry of firms to the American automobile industry began in 1894 somewhat slowly. However, it accelerated fast after 1900. In 1923, the number of firms involved in the industry reached a peak of 75. However, from 1923 to 1925, 23 firms accounting for the third of the industry left or merged. By 1930, 35 more firms had exited. During the following Great Depression period, which lasted from 1929 to the early 1940s, 20 more firms left. Although few firms entered and then exited after World War II, the number of firms in the American automobile industry was nearly stable between 1940s and the early 1990s.

The PLC model therefore proposes that radical BEV technologies introduce an era of ferment that entry of many firms to the automotive supply chain is expected. Recent studies found that electric propulsion is in the era of ferment [25, 213]. Analysis of the ENEVATE database also demonstrated that there are more than nine hundred companies active in the new automotive supply chain in NWE and micro, small and medium sized enterprises (SMEs) compose a majority of those companies. This means that BEV sector currently relies on "one:many" relationships where technology and process satellites provide the necessary product and expertise to the automobile manufacturer, as suggested by the PLC model (Figure 3.4).

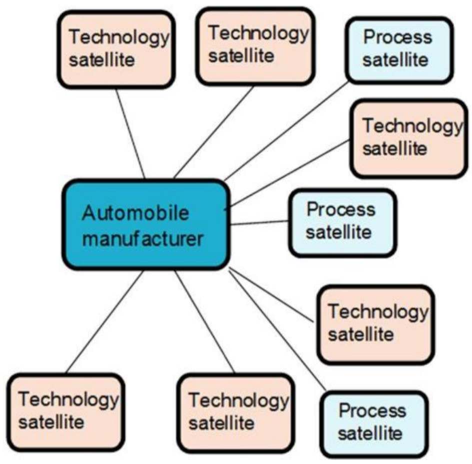

Figure 3.4 Production structure of the typical EV today

Analysis of the database accompanied by site visits to a number of BEV manufacturing facilities across NWE also showed that the production process for BEV is characterised by small job lots driven by irregular demand. Besides, present BEV fleet is a mix of 1st and 2nd generation designs. The 1st generation BEVs are largely based primary on classic ICEVs (conversion design). Such design involves using the existing ICEV design and chassis, and inserting the "electric motor, power converter and battery" in place of the engine and related equipments for the body design of EVs. Examples include E-WOLF [214] and German E-Cars [215]. Whereas such design supports the low volume production of BEVs with some economy, this approach adds extra curb weight to the vehicle resulting in "higher centre of gravity" and "unstable weight distribution" and hinders optimising the vehicle performance [216].

However, the 2nd generation of BEV move towards a purpose design ("ground-up design"), which may include flexible body design concepts that are open for any drive train like gasoline, liquefied petroleum gas or BEV. The purpose design will realise more revolutionary design changes i.e. also in the chassis. Examples of this move to a purpose design include the Nissan Leaf [217]. This 2nd generation design also represents a move towards the mass-production. It is expected that the increase in production heralded by the introduction of 2nd generation vehicle designs will encourage the establishment of system integrators.

In summary, with the move from 1st and 2nd to 3rd generation designs it is expected that the production structure will be required to evolve from the pre-series models with a "one:many" relationship to an "one:few", as suggested by the PLC model. It is expected that this transition will be facilitated by increase in demand and higher production numbers that will enable the production process to be synchronised and enable the establishment of system integrators, who offer the full electric drivetrain as integrated solutions.

3.2.2 Portfolio (Make or Buy) Analysis

As discussed previously, the modular production allows automobile manufacturers focusing on their core competencies and transferring non-core activities to upstream suppliers. However, BEVs are considered as a new product or as a new industry due to their completely different composition. This means that there needs to be changes in the make or buy decisions of carmakers with a transition from ICEV to BEV based supply chains. Since the main differentiation between the ICEV and the BEV is expected to be the drivetrain, a portfolio analysis was conducted for the drivetrain to provide an insight on the future task sharing.

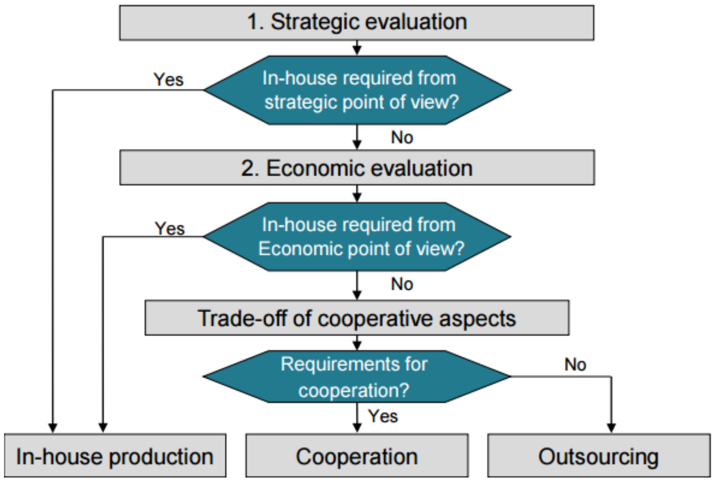

Figure 3.5 Procedure of a make or buy decision

Companies consist of resources, assets and capabilities which are defined as a portfolio. For make or buy decisions, OEMs focus on their core competencies and position these competencies in their portfolio. To position the competencies in the portfolio, two dimensions are considered: significance of the resources for generating value for the customers and superiority or inferiority of the resources in terms of their competence strength [218]. The evaluation procedure is divided into two steps: strategic evaluation and economic evaluation, as displayed in Figure 3.5. In this regard, the in-house production for a component might be reasonable from strategic or economic point of view. A cooperation or outsourcing might take place if both criteria do not indicate an in-house production for the component. Some target areas for strategic evaluation and a typical make or buy analysis matrix is displayed in Figure 3.6.

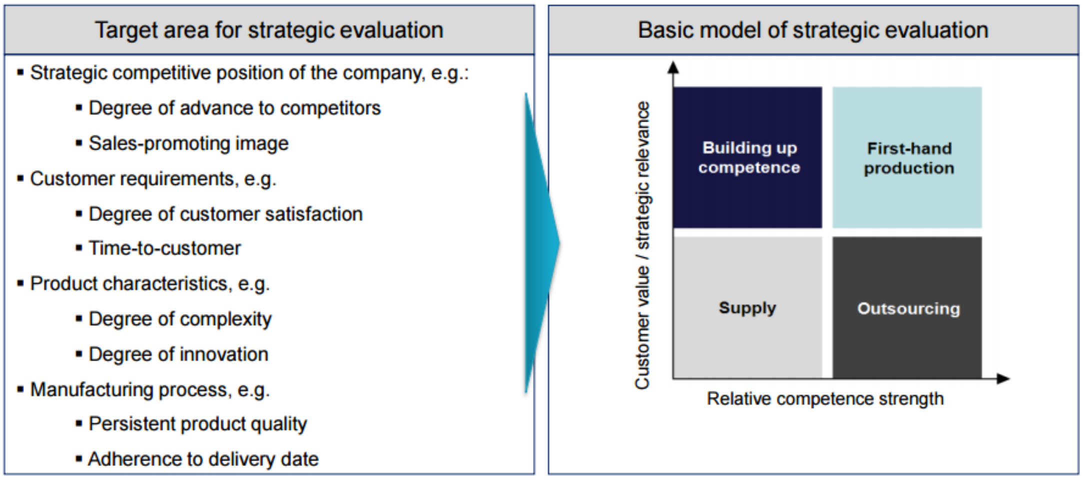

Figure 3.6 Sample target areas for strategic evaluation and make or buy analysis matrix

To provide an insight on the future task sharing and explore changes to the supply chain with the production of BEVs, the ENEVATE partnership conducted an analysis based upon a competence mapping in the different partner regions with feedback from the industry. For the ICEV, it was found that the engine and the gearbox were the highest value added components in the drivetrain area (Figure 3.7 - numbers 1 and 3). The competence strength was the highest for the engine. This was not surprising as all major OEM view the engine as a core competence and they are building up a broad expertise in that field. In contrast, both the exhaust system and the engine auxiliaries were viewed as low value added components and the drive electronics as medium added value. Consequently, whereas internal production by the automobile manufacturers was seen as a suitable strategy for engine and gearbox, supply strategy was seen as suitable for exhaust system, engine auxiliaries and drive electronics (Figure 3.7 - numbers 2, 4 and 5).

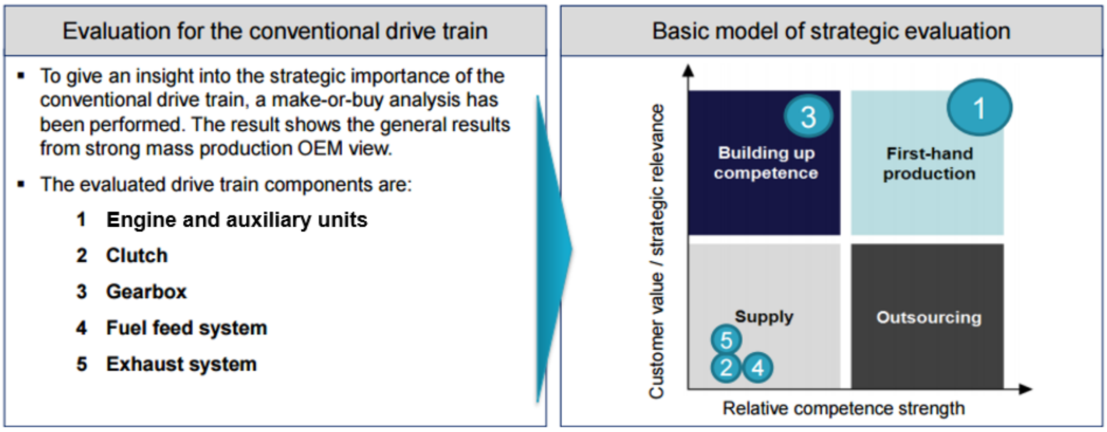

Figure 3.7 For the ICEV the basic engine and the gearbox are first-hand production and focus of OEM R&D.

A similar analysis was conducted for the BEV drivetrain. In this regard, electric motor, battery system, transmission, thermal management and electronics were analysed, as displayed in Figure 3.8.

Electric motor	1	Component production
	2	Engine assembly
	3	Engine electronics
	4	Engine management
	5	Wheel hub motors production
Battery system	6	Component production
	7	Cell production
	8	Module production
	9	Assembly of battery
	10	Integration of battery
	11	Battery management
Trans-mission	12	Component production
	13	Assembly of transmission
	14	Integration of transmission
	15	Transmission control
Thermal manage-ment	16	Climate/heating systems
	17	Climate control
Electro-nics	18	Control electronics
	19	Power electronics
	20	Software
	21	Integration of electronic systems
	22	High voltage wiring
	23	Fuses

Figure 3.8 Analysed components for make or buy analysis for BEV

The results of the analysis are shown in Figure 3.9. As can be seen, the analysis was resulted in a completely different outcome. Engine management, integration of batteries and electric systems, software, thermal and battery management were all viewed as high value-add and therefore suitable for internal production. This meant the following systems required for production of BEV would need to be bought in from suppliers: transmission, battery modules/cells, climate systems, motor and power electronics, high voltage wiring etc. This represents a considerable challenge for OEMs as the expertise for the value-add activities are under-represented within these organisations. To buy-in this expertise would dilute the value-add and reduce the profit that can be leveraged out of the manufacturing activity.

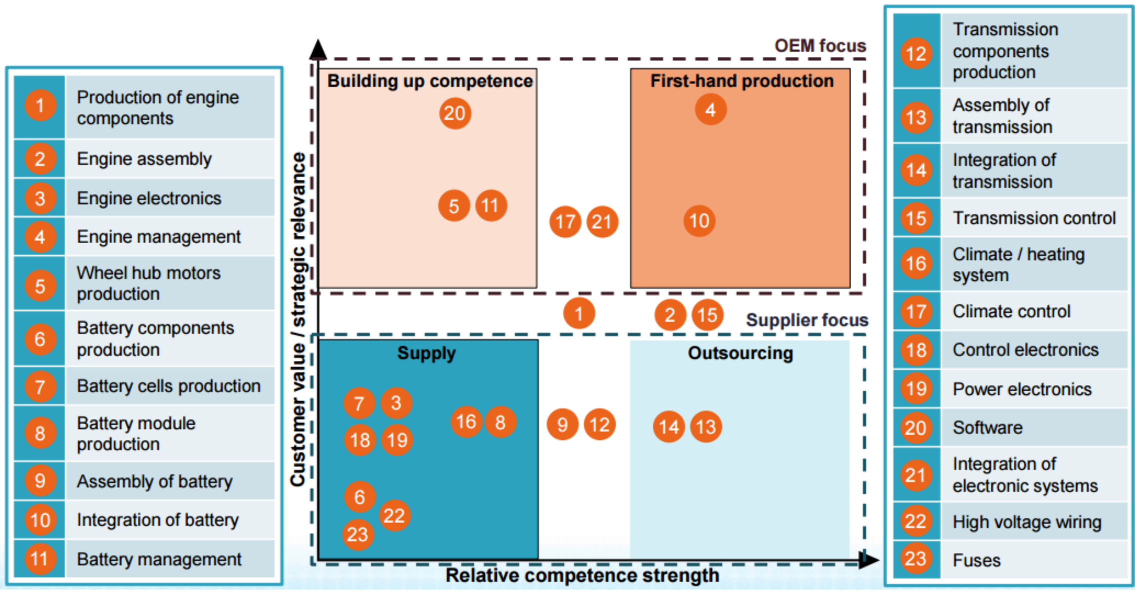

Figure 3.9 OEM and supplier focus for the BEV

3.2.3 Value Add Analysis

The change to the make or buy analysis has implications on the success, or otherwise, on the OEM and supplier communities in NWE and, more broadly in Europe. The transition from ICEV to BEV will alter the players in the supply chain and create new players such as battery (cell) producers and suppliers of electric motor components. Several newcomers are already investing in these fields to be competitive in the future BEV based automotive supply chain. Besides, OEMs will need to ensure that they continue to add sufficient value to the product to remain competitive in the market. An assessment was therefore undertaken by the ENEVATE partnership in order to determine the value added difference between ICEV and BEV.

For the assessment of the ICEV, approximately 33% of the total value added per vehicle is being generated in the drivetrain as displayed in Figure 3.10. Of this added value nearly two thirds is attributable to the basic engine and gearbox – both the mainstay of the OEM. The remainder – drivetrain electronics, engine auxiliaries and exhaust system – are primarily the domain of the supplier.

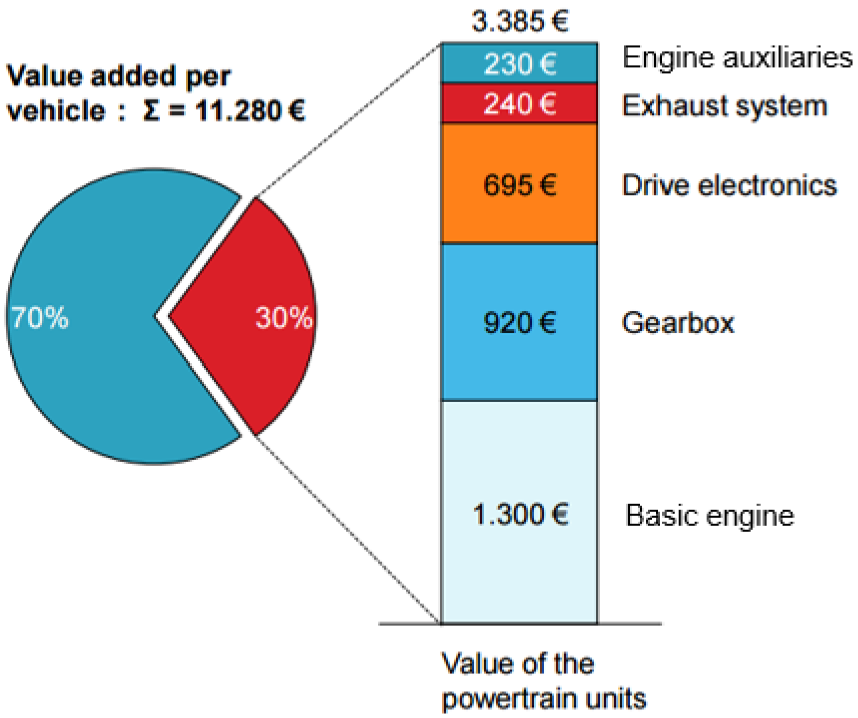

Figure 3.10 Value added for the ICEV

For the assessment of the BEV, the value added by the drivetrain is a far more significant 60% of the total as illustrated in Figure 3.11. Of this nearly 85% is attributable to the battery, which is currently the domain of the supplier. The electric motor and power electronics contribute approximately 12% of the total power train value, whilst other parts of the BEV power train only add 3% more value. These components are almost all the exclusive domain of the electronics industry at the moment.

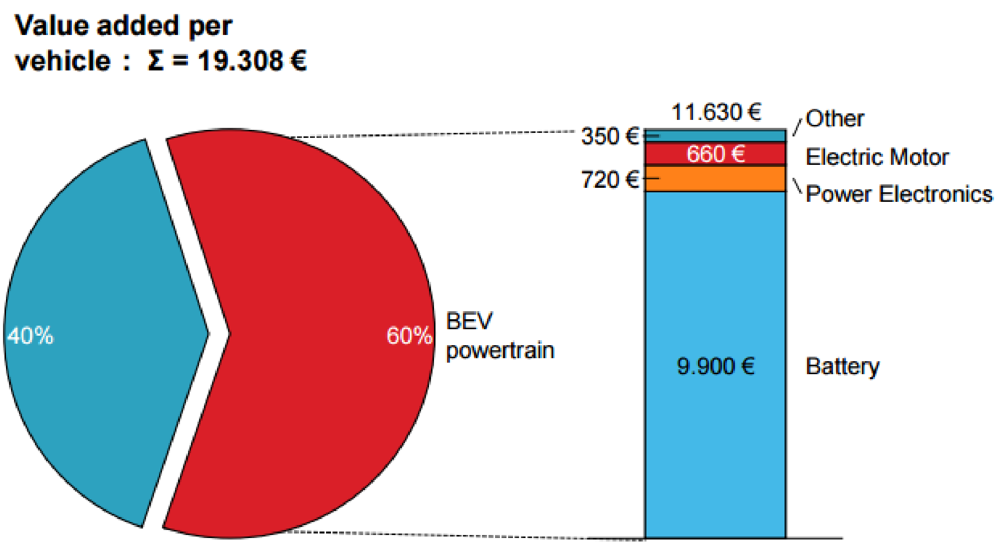

Figure 3.11 Value added for the BEV

Thus, in moving from ICEV to BEV, there is going to be a considerable change in the value-add creation for the OEM. Firstly there would be a loss of value-add associated with the ICE and gearbox as well as additional components which correlate with a design optimized on an ICE, i.e. components for thermal engine management (columns two and three of Figure 3.12). Secondly, there would be additional value-add tied to the BEV component costs, which at this time are the exclusive domain of the supplier (column four of Figure 3.12).

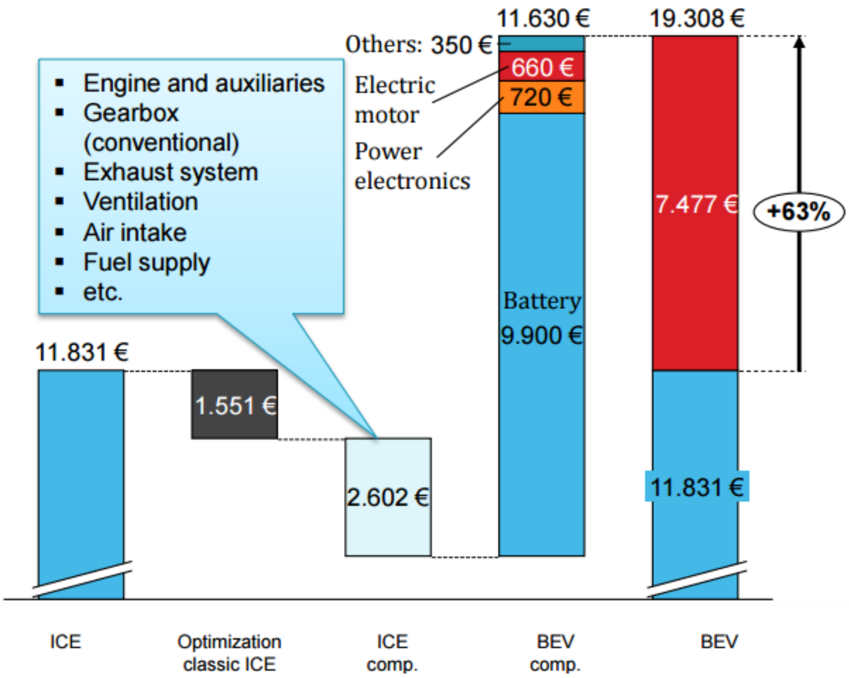

Figure 3.12 Change in the value added creation between the ICEV and BEV

Overall, the total value-add would be far higher for the BEV – by approximately 63%. However, the move from ICEV to BEV could represent a significant loss in value-add from the point of view of the OEM – circa 75% of the present value added by the powertrain. This means that the OEM will have to claim their part in the electric component part of the supply chain if the value added associated with the ICEV is to be maintained.

3.2.4 White Spot Analysis

The ability to add value to the BEV supply chain is dependent on the competencies and capacity of the automotive sector. As discussed previously, in NWE more than nine hundred companies have been identified through the ENEVATE study as being active in the automotive sector, but geographically they are distributed over many locations. The ENEVATE partnership systematically determined the competencies of all identified companies in regards to BEVs (electric motor, suspension, etc…). With this approach a

SWOT (Strengths, Weaknesses, Opportunities and Threads) analysis was performed to identify white spots in the supply chain for BEVs for each region. A summary for the NWE region as a whole is presented in Figure 3.13.

	North West Europe (>900 companies)	
Research and Development	●	Fully covered
Testing and validation	●	Fully covered
Manufacturing (Low / High volume)	◕	Nearly all important BEV components are available within NWE
Reuse & Recycling	◔	Recycling for classic components is available but still a white spot for electric components

Figure 3.13 White spot analysis for BEV competencies and capacities in NWE

According to the analysis, BEV technologies are mostly at R&D status which means they just start being commercialised. From the manufacturing perspective, almost all significant BEV components exist in NWE region. The analysis also showed that testing and validation of BEVs is also presently available within the region. Although reuse and recycling is covered, it is likely to pose a problem for BEVs if numbers are to increase significantly. This requires further investigation.

The EV database and, hence, white spot analysis does not include all companies that have a potential contribution to EV technology in Europe as this is a continually evolving area. To develop a stronger database and more precise results, information from other companies is aimed to be gathered and integrated with the existing system.

3.2.5 Competitor Analysis

International benchmarking was also required to establish the position of NWE in the BEV sector in comparison with competing regions. The three key competing regions for electric mobility are Europe, Asia and United States of America (USA). In that context, an interview study was conducted with stakeholders (OEMs, 1st tier suppliers and non-governmental organisations (NGOs)) from the automotive industry in USA by the ENEVATE partnership. The following three questions played a crucial part in the interviews:

- What form will electric mobility take in USA?
- What are the major advantages and disadvantages of the different competing regions?
- What are the tangible measures to be taken in order to reach the main goal of accelerating electric mobility?

The interview questions were developed in order to both inform the interviewees about electric mobility development in NWE and learn their opinions about the current and future development in their region. The interview questions featured the following main categories:

- Research and development in general
- Product and market potential of EVs
- Component analysis
- R&D locations
- Utilization
    - Energy generation
    - Recharging
    - Customers
- Opportunities and risks of electric mobility
- Necessary measures to accelerate the development of electric mobility

A total of 16 people (8 people from OEMs, 4 people from suppliers and 4 people from NGOs) were interviewed. All interviews were held in the related headquarters of the interviewed stakeholders. Interviews with the representatives of the NGOs were held in Chicago. For the OEMs and suppliers, the interviews were held in Detroit greater area. The key results of the interview study are presented in Table 3.1.

Table 3.1 USA interview results for the competitor analysis

Main Topics		*Interviewee Answers*
R&D	Current R&D	R&D is high in USA, medium in Europe and low in Asia
	Future R&D	While R&D is expected to decrease to low or medium level in USA, it is expected to increase in Europe and Asia with private sector`s investments
Product and Market Potential	Preferred Vehicle in 2020	Preferred BEVs are expected to be medium and large sized cars with a share of 5-10% in USA, small and medium sized cars with a share of 4-8% in Europe and mini and small sized cars and scooters with a market share of 10-15% in Asia
	EV market share in 2020	Hybrid vehicles will dominate the EV market with around 75% market share (BEVs 25%)
	Interoperability	Cooperation exist between cities and companies for building charging stations in USA
Component Analysis	Make or Buy Strategy	Battery System: Supply Strategy, Electric Motor and Power Electronics: No clear strategy
	Customer Value	More practical thinking in USA and more environmental thinking in Europe. Reliability, appearance and emotion are key attributes for customers in USA
	Standardization	Potential exists on battery cells, motors and power electronics
R&D and Production Locations	R&D Locations	USA is found to be more advantageous than Europe owing to higher incentives and tax credits, more accessible tools in universities and more practical organisations such as Fraunhofer
	Product Locations	USA is found to be more advantageous than Europe owing to higher tax credits, better infrastructure and legal situation, and lower labour, production and energy costs
Utilization	Energy Generation	Very strong and close cooperation between the automobile industry and energy suppliers (Resulting in several joint projects in USA) No mandatory renewable energy targets on federal level, but there is in some states in USA
	Recharging	Charging stations are not widely available only in some cities such as Chicago
	Customers	Cooperation exists among cities, OEMs and energy suppliers in USA USA Government buys BEVs for its own fleet (such as postal services and military) Realised incentives for customers are tax refunds, special lanes, free charging, free parking, subsidies of $7000-8000 and emission free zones
	Ownership Models	The primary ownership model for BEVs is expected to be same as for ICEVs
Global Electric Mobility Development	Chances	Discussions over GHG effect, energy security and independence from fossil fuels create opportunities for BEVs Development of smart grids and vehicle to grid technologies present opportunities for charging BEVs Development of renewable energy technologies also make BEVs more attractive Increase of BEVs in governmental fleets are recognised as pilots for customers and increase the attractiveness of BEVs BEVs offer new driving experience for drivers
	Risks	There are issues regarding the safety of batteries Performance of batteries are not comparable with ICEV technologies Market acceptance of BEVs is still very low Charging infrastructure needs to be developed Carbon footprint with energy generation (i.e with coal) reduces attractiveness of BEVs for consumers who purchase BEVs as a part of their environmental responsibilities

As can be observed, the interviewees believed that USA is advantageous for accelerating the electric mobility and leading the BEV industry owing to high R&D investments, government support and incentives, better infrastructure and legal situation, more practical organisations, more accessible tools in universities, lower labour, production and energy costs, and strong cooperation among cities. It is however expected that R&D investments will decrease to low or medium level in the future; this brings significant risks to the expected leading role of USA in electric mobility and presents opportunity for NWE and Europe as a whole.

As shown in Table 3.1, the interviewees also acknowledged that there are several developments in the global agenda such as discussions over GHG effects, energy security and independence from fossil fuels benefiting the transition from ICEV to BEV. Similarly, other developments such as developments in renewable energy and vehicle to grid technologies also support the transition. Nevertheless, there are still issues such as safety and performance of batteries, low market acceptance and undeveloped infrastructure to be solved for accelerating such transition. Solving these issues requires government support which will be discussed in more detail in Chapter 5.

3.3 Challenges and Strategies

A transition from ICEV to BEV requires mass production of BEVs, which is not possible with the existing industry structure. In previous sections, implications of BEVs on the automotive supply chains were examined and competences and capacities required for BEVs were discussed. Based on these findings, challenges and strategies for a commercially strong BEV sector for Europe are discussed below.

Short Term – As suggested by previous research studies [25, 213], the supply chain database shows that the BEV sector in NWE is in the early period of transition since the industrial structure (production network) relies on “one:many” relationships. The database also shows that SMEs compose a majority of those companies. This means that there is already intense competition in the nascent BEV supply chain in Europe. However, according to the PLC model [56, 57], more firms (especially SMEs) to this new supply chain is expected (especially to the battery value chain) as the dominant BEV design has not emerged yet. During this transition process, OEMs will have to claim their part in the electric component part of the supply chain if the value added associated with the ICEV is to be maintained as the transition from ICEV to BEV could represent a significant loss in value-add from the point of view of the OEM – circa 75% of the present value added by the powertrain. During this transition period, 1st generation vehicles are also expected to base primary on classic ICE vehicles (conversion design).

Mid Term – With the emergence of dominant BEV design which is contingent upon the dominant battery design that relies on significant cost reductions and performance improvements, the next generation (purpose design) will realise a more revolutionary design. It is also predicted that the production network will transition from a “one:many” to a “one:few” in the emerging BEV supply chain. It is expected that such transition will be facilitated by increase in demand and higher production numbers that will enable the production process to be synchronised and enable the establishment of system integrators offering the full electric drivetrain as integrated solutions. During such transition, OEM and suppliers have to check their product portfolio with the compliance to the future market demand of vehicle components. Since the value-add of BEV compared to ICEV will significantly change, the manufacturer’s make-or-buy strategy will be influenced. High value added components such as engine management, integration of electric systems, software, thermal and battery management will typically need to be produced by OEMs. In contrast, transmissions, battery cells, climate systems, engine and power electronics will typically need to be bought from suppliers. Although there will be a significant increase of value-add of the complete vehicle by approximately 63%, the OEM will lose nearly 75% of value-add by the powertrain. This will lead to a reduction of the manufacturer’s profit. In this respect, to maintain value-add, the OEM might gain the required skills and expertise via strategic alliances and acquisitions. Early strategic orientation of corporate activities to achieve a well-established market position is therefore critical.

Long Term – With the rising demand, the production capacities have to be adapted to mass production design. Electric motors, power electronics have to be scaled from small volumes of batch production to mass production. New plants are necessary for battery production capacities for the future. The strategies that are required are to strengthen company visibility and competence profile to fit the BEV. To rely on existing competencies will not be sufficient and collaborations need to be established to face the new challenges as strategic alliances. This transition will require high investment and this will be accompanied by a high economic risk as the classic business models for OEM have to be modified or developed from scratch.

3.4 Conclusions

Achieving 2050 GHG emission target of the EU is not possible without significant changes in the automotive industrial structure. This chapter explored the existing industry structure and compatible future structure by investigating the implications of BEVs on the supply chains and exploring what competences and capacities might be needed for mass production of BEVs in Europe. A production structure analysis, make or buy analysis, value-add analysis, white spot analysis and competitor analysis were conducted in that context. Based on those analyses results, challenges and strategies were discussed for a commercially strong BEV sector in Europe. Key outcomes for the study include:

- Analysis of the ENEVATE database demonstrated that the BEV sector currently relies on "one:many" relationships and SMEs compose a majority of those companies. Based on the PLC model, the transition from 1st and 2nd to 3rd generation designs, it is expected that the production network will be required to evolve from the pre-series models with a "one:many" relationship to a "one:few". It is also expected that this transition will be facilitated by increase in demand and higher production numbers that will enable the production process to be synchronised and enable the establishment of system integrators, who offer the full electric drivetrain as integrated solutions. To be successful requires that stakeholders are able to exploit economies of scale; make use and expand long-time competencies in electric engineering with automotive know-how; and build up cooperation with experts in the new value chain to facilitate the required transfer of know-how.
- The BEV has a fundamental different value structure. This represents a considerable challenge for the OEM as the expertise for the value-add activities are under-represented within these organisations. To buy-in this expertise would dilute the value-add and reduce the profit that can be leveraged out of the manufacturing activity. The new value structure requires that OEMs and suppliers capture sustainable fields of added value in the automotive industry by: positioning as a system integrator or technology specialist; adoption of significant decision and manufacturing areas; and occupation of new downstream business possibilities.
- A white-spot analysis showed that BEV technologies are mostly at R&D status, meaning they are yet to be commercialised. The analysis also showed that testing and validation of BEVs are also presently ready within the region. The investment

and support for electric mobility is on the rise in NWE. The key players need to take advantage and use this impetus to keep a step ahead by introducing leading innovations. Therefore the link between researchers and the automotive sector needs to be tightened.

- NWE and more broadly Europe has a good potential for the BEV industry owing to its innovative automotive industry, strong financial background, flexible production lines and skilled workers. However, these advantages are not adequate for the region for being a leading BEV industry base globally. The strategy is to make improvement in production, look to capture sustainable fields of added value in the automotive industry; and to continually innovate through investment and strengthening of links with the R&D sector.

CHAPTER 4 – BATTERY ELECTRIC VEHICLE TECHNOLOGY VALUE CHAIN AND MICRO, SMALL AND MEDIUM SIZED ENTERPRISES

A part of this chapter has been published in International Journal of Electric and Hybrid Vehicles

Özel, F.M., et al., *How to Strategically Position European SMEs as part of an Electric Vehicle Technology Value Chain.* International Journal of Electric and Hybrid Vehicles, 2014. **6**(3): p. 227-254.

And international conference in France:

Özel, F., et al., *Key Business Strategies of SMEs in North-West Europe*, in *21st International Colloquium of Gerpisa* June 12-14, 2013: Paris, France.

4.1 Introduction

A transition from internal combustion engine vehicles (ICEVs) to battery electric vehicles (BEVs) involves changes in the industrial structure and creates windows of opportunities for new comers which are in the majority of small and medium sized enterprises (SMEs) [25, 76, 78]. SMEs play a very significant role in competitiveness owing to their ability to innovate, increase employment and contribute to economy. Maximising SME engagement and benefit from the transition to BEVs is significant due to their potential in triggering economic development and innovation via the exploitation of emerging EV business opportunities.

Europe 2020 is a 10-year strategy proposed by the European Commission on 3 March 2010 for development of the economy of the European Union (EU). It aims at "smart (developing an economy based on knowledge and innovation), sustainable (encouraging a more resource efficient, greener and more competitive economy) and inclusive growth (fostering a high-employment economy delivering social and territorial cohesion)" with greater coordination of national and European policy [219]. It follows the Lisbon Strategy for the period 2000 and 2010. According to Europe 2020 strategy, EU targets to reduce CO_2 emissions and grow SMEs. Yet, there are motivators [28, 37, 78] and barriers [79] for SME involvement that are either preventing or stimulating growth and innovation.

It is proposed that EU can achieve both economic growth and emission reduction targets by supporting SME development. Hence, the support areas SMEs need to have a role in the possible BEV based automotive value chain re-shaping was investigated by conducting semi-structured in-depth interviews with SMEs. Interview study is then linked with EU`s financial instruments to discriminate policy and delivery of EU`s financial instruments for SMEs on the basis of their perception on motivators and barriers for EV business. In so doing, it is recognised that improving the link between policy and delivery for SMEs might stimulate the EV technology and business in Europe.

4.2 Research Methodology

In the following sub-sections, methodology used in this chapter will be elaborated.

4.2.1 Basic Philosophical Assumptions

There are three epistemological approaches (philosophical assumptions) in literature: "positivist", "interpretive" and "critical". Adopting an appropriate philosophical assumption is considered to be beneficial before starting a research study [220, 221] as each philosophical assumption evaluates the research perspective in a different manner.

Besides, choosing an appropriate philosophical assumption allows the researcher to determine the suitable research strategy and explain the assumptions of the study.

The first philosophical assumption is positivism. It explains and predicts events by investigating the relations between the basic elements. With this approach, reality is seen as a series of determinable properties that are not affected by the researcher. Positivism claims that the world can be explained with fixed relationships between phenomena and their aims. Researchers adopting this philosophy examine those relationships with structured approaches [221] and they focus on the "objectivity", "repeatability" and "generalisability" of study results. Positivist studies therefore define the research questions, test the hypothesis objectively and generalise it for the universal population. However, such studies often require large sample sizes to confirm research results.

The second philosophical assumption is interpretive. Contrary to positivism, reality is not seen as objective and exterior with this approach. Interpretive studies claim that reality is constructed and made by people. Hence, interpretive researchers observe events and analyse them in their natural environments in order to understand the studied phenomenon. These researchers accept that reality is given meaning by individuals. Researchers adopting this approach therefore rarely generalise the results of the research for the larger population. Instead, the results are used for understanding the events in order to inform other circumstances [222].

The last philosophical assumption is critical. Critical studies claim that existing social systems are "time-honoured" throughout history and they are continuously repeated by individuals. Critical researchers believe that although people want to change their social situations, they cannot achieve that as social, political and cultural forces resist them. Hence, critical researchers aim to analyse and reveal the "deep-rooted" disagreements existing in the social environment, and exchange them for other social structures in order to reduce and, ultimately, remove unwanted social circumstances [223].

4.2.1.1 Adopted Philosophy

Before selecting a philosophical assumption, deciding an approach which is either "deductive" or "inductive” is important. Whereas "the deductive approach" should be selected when a theory or hypothesis is decided and the research strategy is designed to test the hypothesis, "the inductive approach" should be selected when research is conducted, data is collected and theory or hypothesis is generated based on the findings of data analysis. It is argued that deductive approach often involves the "positivist" research while inductive approach usually involves the "interpretive" research [224].

This study aimed to explore the approach of SMEs to the emerging BEV sector to understand SMEs and investigate the support areas they need to have a role in the possible BEV based automotive value chain re-shaping. In this respect, the inductive approach was a more appropriate approach since investigated areas would be clarified after conducting the research. Besides, this research aimed to link the SME responses with two recent framework programmes to discriminate policy and delivery of EU`s funding programmes for SMEs based on their perception on motivators and barriers for BEV business. This means that this research aimed to understand and inform rather than solving the "deep-rooted" disagreements or generalising results. In this respect, the inductive approach and interpretive philosophy were adopted for this research study.

4.2.2 Detailed Research Design

While there are several categorisations of research methodologies in literature, they are generally collected under two headings: quantitative and qualitative [225]. Quantitative research aims to study reality, test hypotheses and determine relationships with numerical and statistical methods. Conversely, qualitative research involves the effective collection, organisation and comprehension of data acquired from observation or conversation in order to gain more insight about the topic and recognise patterns or explanation [226]. Qualitative research was adopted for this research as it was aimed to learn from SMEs for gaining more insights about ideal conditions for SMEs.

Two most well-known qualitative research methods are interviews and case studies. Although case studies examine an explicit situation thoroughly in their natural environments [225] and allow researchers collect rich, thorough information on affairs, activities and processes during a specific period of time, they generally focus on a small number of organisations [227]. On the other hand, interviews investigate opinions of people about the research phenomenon and, therefore, more organisations might be examined via interviews [225]. In this study, interviews were used to investigate opinions of SMEs regarding the emerging BEV sector in Europe.

The literature offers three kinds of interviews: "informal conversational interviews”, “standardised open-ended interviews” and “in-depth interviews". Whereas "informal conversational interviews" do not require any predetermined questions as they are flexible, "standardised open-ended interviews" necessitate predetermined questions.

However, since interviewee can answer the questions independently with open ended interviews, more information regarding the investigated phenomena might be explored with this type of interview.

However, in-depth interviewing seeks to achieve the same level of knowledge and understanding possessed by the respondent and to understand personal experiences and perceptions within a contextualized, social framework [228]. In-depth interviews are conducted on a one-to-one basis. These interviews typically last from 30 minutes to more than an hour. They attempt to uncover underlying motives, prejudices, or attitudes towards sensitive issues. The goal is to get the deepest possible understanding of the setting being studied. This requires identifying expert participants who can provide information about the particular topic and setting being studied. For example, interviews are arranged with a predetermined number of people from different categories (e.g. by job title or rank). This type of interview is chosen as it is seen as a useful tool for enabling comparison of views of respondents from different backgrounds or if you have different people asking the questions. The first of these was a factor in this investigation. Thus, "in-depth interviews" were selected for this study.

Research interviews are also categorised as structured, semi-structured and unstructured in literature [229, 230]. In a structured interview, the interviewer asks a set of standard, predetermined questions about particular topics, in a specific order. The respondents need to select their answers from a list of options. These types of interviews are often used in surveys and questionnaires to produce quantitative data [230].

In contrast, qualitative research studies usually employ semi-structured and unstructured interviews. Semi-structured interviews are often the sole data source for a qualitative research project and are usually scheduled in advance at a designated time and location outside of everyday events. They are usually organised around an array of predetermined open-ended questions, with other questions emerging from the dialogue between interviewer and interviewee⁄s. These interviews are useful when there is a need to collect in-depth information in a systematic manner from a number of interviewees [230].

In an unstructured interview, the interviewer has no specific guidelines, restrictions, predetermined questions, or list of options. The interviewer asks a few broad questions to engage the respondent in an open, informal, and spontaneous discussion. The interviewer also probes with further questions and/or explores inconsistencies to gather more in-depth information on the topic. These interviews are often conducted in conjunction with the collection of observational data such as case studies [230].

Another important topic regarding research interviews is “interviewer bias” occurring when a specific observation or answer is affected by some attribute of the interviewer. Bias is contingent upon the type of research interview. For example, structured and semi-structured interviews might considerably reduce the possibility of interviewer bias compared to unstructured interviews [231]. According to Connaway and Powell [232], it might be a consequence, for instance, of the way in which interviewers expresses themselves, the impression they give to the interviewee, the way in which they construe answers, and the way in which they guide the respondent. Although it is difficult to notice and measure, it might affect the results significantly. In that context, Connaway and Powell [232] state that some interviewee bias might be avoided when questions use neutral language and when the interviewer does not overreact to answers of the interviewee as well as monitor the body language. They also argue that interviewer should dress inconspicuously and suitably for the environment, the interview should be held in a private setting and it should be kept as informal as possible in order to reduce or avoid the interviewer bias. Pontin [233] also claims that recording the interviews and transcribing them later is also a good strategy to protect the interview against bias and have a permanent record of the interview. Additionally, if a research study involves multiple interviews, each interview should cover the same topics [234].

Since interviews were the sole data source for collecting in-depth information from SMEs in this study "semi-structured in-depth interviews" were the most appropriate method for this research. These types of interviews are also the most widely used interviewing format for qualitative research [230]. The interviewer bias was also minimised by taking the above mentioned measures. For example, the interview was held in a private setting, and the interviewer used neutral language and monitored the body language. Besides, the interviews were recorded and an interview guide was used to cover the same topics.

4.2.2.1 Sample Selection

Although this study adopted a qualitative research methodology, it was impossible to collect data from the entire target population. Hence, data had to be collected from a sample of the target population by using a suitable sampling technique [235]. Sampling techniques for qualitative research mentioned in literature are described below.

There are several sampling techniques that can be used to choose a sample from the entire population. These techniques are usually collected under two headings in literature: probability sampling and non-probability sampling (convenience sampling) [236]. Probability sampling techniques such as random sampling, simple random sampling, stratified sampling, cluster sampling and systematic sampling allow researchers generalise the results by using statistical tools since a sample is chosen randomly with these techniques. Conversely, the sample is not chosen randomly with non-probability sampling techniques. However, as the main assumption behind "probability sampling" is generalising the sample results to the entire population and qualitative research does not aim to produce a statistically representative sample or draw statistical inference [237], non-probability sampling is generally used for qualitative research studies.

Among qualitative research sampling techniques, "purposeful sampling" or "criterion based selection", “selective sampling" and "theoretical sampling" are most frequently used in literature. Specific activities, people or organisations are chosen intentionally to provide information with "purposeful sampling" [235]. Neergaard et al. [237] claims that rigorous samples might be selected with “purposeful sampling” in qualitative research. Theoretical sampling" originally comes from "grounded theory". This theory explains that a hypothesis or a theory is created through a repetitive process. Data is collected and analysed until "theoretical saturation" is accomplished. "Theoretical saturation" means that no relevant information or data is obtained. Since saturation cannot be forecasted in advance, sample sizes are often determined on the basis of theoretical saturation during the research process [238]. On the other hand, selective sampling can be defined as a technique which determines the organisations, individuals, time and places to be interviewed before a research study begins. Sample is selected based on predetermined considerations of how, when, where and from which organisation or people the most productive information may obtain [222].

Nevertheless, there is not a big difference among these techniques. In fact, these techniques are usually described as synonyms or they are used as alternatives of each other [222, 239]. According to Neergaard et al. [237], the only difference between "selective sampling" and "theoretical sampling" is the timing of sample selection. Besides, "purposeful sampling" might be explained as an "umbrella term" including both “selective sampling" and "theoretical sampling" techniques. In that context, this research adopted "purposeful sampling” as the sampling technique. This means that a sample would be chosen intentionally from the companies which were engaged in BEV related activities in NWE. Moreover, because "purposeful sampling" includes "theoretical sampling" and, thus, "grounded theory", data would be collected and analysed until "theoretical saturation" was accomplished. Therefore, sample size would be determined by interview results.

4.2.3 Interview Methodology

There is no common procedure for research interviews. However, Kvale method of conducting interviews that comprises of seven stages is often used in literature for designing and implementing an interview study [240]. These stages are summarised below:

1. *Thematising:* Formulate the aim of the investigation and define the concept of the topic to be investigated before the interviews start.
2. *Designing*: Plan the design of the study, taking into consideration all seven stages, before the interview starts.
3. *Interviewing*: Conduct the interviews based on an interview guide and with a reflective approach to the knowledge sought.
4. *Transcribing*: Prepare the interview material for analysis, which commonly includes a transcription from oral speech to written text.
5. *Analysing*: Decide, based on the purpose and topic of the investigation, and on the nature of the interview material, which methods of analysis are appropriate.
6. *Verifying*: Ascertain the reliability, and validity of the interview findings. Whereas reliability refers to how consistent the results are, validity means whether an interview study investigates what is intended to be investigated.
7. *Reporting*: Communicate the findings of the study and the methods applied in a form that lives up to scientific criteria, takes the ethical aspects of the investigation into consideration, and that results in an readable product.

By following the Kvale method of conducting interviews, the first stage was therefore to determine the environment that SMEs operate in (stage 1 – thematising). Then, in-depth and semi-structured interviews were selected as discussed in previous sections and interview questions were prepared in order to answer the research question (stage 2 – designing). Next, the interviews were conducted based on the interview guide and on a one-to-one basis with individuals representing SMEs from the emerging BEV sector (stage 3 – interviewing). Post interview, the recorded interviews were transcribed for analysis (stage 4 – transcribing). Qualitative analysis of the interview transcripts was then undertaken to seek patterns, themes, and meanings explaining SME answers (stage 5 –

analysing). The results of the qualitative analysis were provided in tabular form with exemplars from the interview transcripts and key themes. The results were compared with the EU`s two recent framework programmes: FP7 and Horizon 2020 (stage 6 – verifying). The results of the study were then communicated with reports and papers (stage 7 – reporting). Each of these stages are explained in depth in the following sections.

4.3 Thematising

In moving from ICEVs to BEVs, it is expected that there will be changes in the established relationships within the automotive supply chain. SMEs might have a role in the possible BEV based automotive value chain re-shaping as discussed below.

Existing automotive supply chain, which saw major consolidation of the supply base with the developments over the past twenty years or so, exists increasingly on a “one:few” relationships [155]. In this network, whereas “systems integrators” and first tier suppliers that are closely linked to original equipment manufacturers (OEMs) have significant roles via “modularization” [206], second tier suppliers work for systems integrators and sometimes deliver components directly to OEMs. However, SMEs are located in the last step of this – often described as a pyramid shaped – architecture and they have only marginal roles by supplying the second tier companies mainly via subcontracting arrangements [208]. SMEs still have direct access to OEMs in the case of simple components, or in some cases specific high technology components for which the SME owns unique intellectual property rights. The conventional view of supplier “tiering” in this pyramid shape is therefore an over-simplification, although direct access to OEMs is limited resulting in marginal roles for SMEs.

With the production of BEVs, vehicle components and suppliers are changing owing to the BEVs` different composition. In the transition from ICEV to BEV there would be a loss of value-add associated with the internal combustion engine and transmission as well as additional components which correlate with a design optimized on an ICEV. There would also be additional value-add tied to the BEV component costs, which at this time are the exclusive preserve of the supplier. Although new types of components are required, no existing mass production supply chain exists for those components. Thus, BEV sector currently relies on “one:many” relationships where technology and process satellites provide the necessary product and expertise to the automobile manufacturer, or OEM. As mentioned previously, SMEs compose a majority of those companies [25, 76, 78]. This is very different from the present mainstream automotive sector (Figure 4.1).

Based on the product life cycle (PLC) model [56, 57], it is considered that the nascent BEV sector will similarly evolve from the present "one:many" relationships to a "one:few" relationships that mirrors existing automotive industry practice and SMEs might have roles in the possible BEV based automotive value chain re-shaping [78] with right support. For example, Tesla Motors which has been supported by the United States` Advanced Technology Vehicles Manufacturing (ATVM) programme has reached a market capitalization of $22 billion (General Motors` market capitalization is approximately $52 billion) in a very short time [241]. Thus, understanding SMEs and supporting them will be valuable for facilitating and accelerating the development of BEV technology and business in Europe.

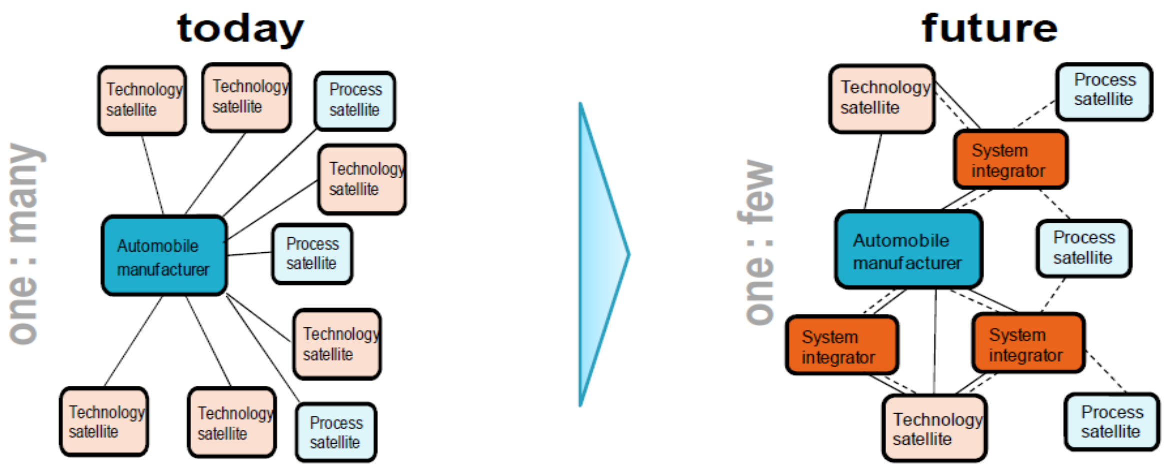

Figure 4.1 BEV sector of today and the future

4.4 Designing and Interviewing

As discussed in the methodology section, "semi-structured in-depth interviews" were adopted for this research. The selected approach was therefore conducting a number of semi-structured interviews with individuals representing SMEs from the emerging BEV sector. Since "purposeful sampling" was chosen as the sampling method for this study, the interviewees were chosen intentionally from the companies which were engaged in BEV related activities with the specific intention of providing different specialties in BEV business and a broad geographical coverage across the NWE project area (Table 4.1). Interview candidates meeting those criteria were identified by using the "European Network on Electric Vehicles and Transferring Expertise" (ENEVATE) SME database [242]. The interviews were conducted based on an interview guide (Table 4.2). The interview guide was created by the author of this study. However, the ideas of ENEVATE partners were taken into consideration during the development stage of the interview guide by sending the predefined interview questions (which was prepared by the author of this study) to the partners and asking their comments regarding these questions. The interview questions were then updated based on these comments. Based on the "grounded theory", the identification and interviewing process continued until the theoretical saturation (main support areas for accelerating innovation in BEV area) was achieved. In terms of interviewed data, the emphasis was on quality rather than on quantity.

Table 4.1 Interviewed SMEs

Country	*Company*	*Specialty*	*Size*
Germany	Company A	Electric Motor	<50
	Company B	Thermal Management System	<50
	Company C	Electric and Hybrid Powertrain Systems	<50
	Company D	BEV Manufacturer	<50
France	Company E	Mobility Services	<50
	Company F	Vehicle Electronics	<100
	Company G	Range Extenders	<10
United Kingdom (UK)	Company H	Batteries	<50
	Company I	Electric Motor	<50
	Company J	BEV - Hybrid EV Manufacturer	<200
Netherlands	Company K	Prototyping and Engineering Software	<10
	Company L	Power Solutions	<50
	Company M	Vehicle Modifications	<100
Belgium	Company N	Agent of BEV Companies	<10
	Company O	Infrastructure and Service	<10

Table 4.2 Interview guide

Area	*Questions*	*Discussion Points*
Market	Are you active in the field of coupling between smart mobility and EVs?	Yes
		No, don't think so
		No, will be in a short time
		Other
Manufacturing	How do you deal with current low demand (and why?)	Manufacturing and selling
		Outsourcing
		Other
Strategic	What is your business model (and why)?	Want to sell products or services in the EV market
		Preparing for being taken over by a Tier supplier
		Other
Strategic	What will increase the demand on EVs?	Government Incentives
		Infrastructure Development
		R&D Development
		Other
Strategic	What will be the main problem for mass manufacturing BEVs?	High EV adaptation costs (new machinery, certificates...)
		Lack of expertise
		Coordination difficulties and inertial resistance
		Change in the supply chain (suppliers, customers)
		Other
Manufacturing	What`s your plan if 10.000 units are required to produce in a year? (And why?)	We are flexible enough to speed up production volumes
		Outsource some parts and manufacture others
		Increase the system flexibility and support in-house manufacture
		Other
Strategic	What is your strategic decision for the next 3 and 10 years (and why)?	Develop and produce on your own
		Develop and produce in joint venture (with whom?)
		Develop and produce in strategic alliance (with whom?)
		Sell your ideas know-how patents to others (future opportunities?)
		Other
Market	Which market do you target? (And why?)	Big automotive mass market (passenger cars, E-scooters)
		Fleet market (buses and trucks)
		Niche market (Premium passenger cars)
		Other
Interviewer Name:		
Interviewee Name and Position:		
Company Name and Region:		

4.5 Transcribing and Analysing

Post interview, the material was prepared for analysis. In qualitative studies, the analysis is based on a common set of principles: transcribing the interviews; engaging oneself in the data to gain detailed insights into the phenomena under investigation; developing a data-coding system; and linking codes or units of data to form overarching categories or themes that can lead to the development of theory or study results [243]. In this respect, firstly, recorded interviews were transcribed. The reason for recording interviews was that it is difficult to focus on conducting an interview and jotting notes. Such approach may result in poor notes and may also affect the development of rapport and dialogue between interviewer and interviewee that is very significant in unstructured and semi-structured interviews [244].

After transcribing the recorded interviews, qualitative (thematic) analysis of the interview transcripts was undertaken to seek patterns, themes, and meanings that generate in-depth understanding of the phenomenon of interest. Qualitative analysis is approached as a critical, reflective, and iterative process that cycle between data and an overarching research framework that keeps the big picture in mind. The analysis is inherently a process of interpretation. We should not be afraid to ask questions of the data. These questions can be informed by theory or our own observations, hypotheses or hunches. If the analysis is rigorous and transparent then the data should be able to support or not support these. This is the important part - the data should support or refute our ideas; we should not fit the data into the story we want to tell.

There were two parts to analysing the data. These were as follows:

- “Content analysis” steps: Read transcripts > Highlight quotes and note why they are important > Code quotes according to margin notes.
- “Exploration analysis” steps: Sort quotes into coded groups (themes) > Interpret patterns in quotes > Describe these patterns.

In this context, codes are tags or labels for assigning units of meaning to descriptive or inferential information. Coding is the process of organising the data into “chunks” that are alike, moving from words and sentences to “incidents” [245].

The results of the thematic analysis were provided in tabular form in the following sub-sections. The region is identified and exemplars from the interview transcripts provided. The key themes (taken from the analysis of the interview data in its entirety) are then given.

4.5.1 Technology

Innovations are typically defined as either incremental or radical in innovation literature [71, 129, 130, 140-148]. Radical innovations involve significantly different core technology and they have profound impacts on firms, industries and markets while incremental innovations are associated with recognised technology, small change and status quo. When automotive industry is studied with this phenomenon, which has grown to become the single largest manufacturing sector in the world [53, 246] and it has been dominated by the internal combustion engine for more than a century [247], ICEVs are the incumbents and BEV technologies are radical innovations [35-39]. The contribution of new entrants to technological development is strong in the field of a radical technology especially during an era of ferment [64]. The BEV sector is currently in the era of ferment [25, 213]. The interview study therefore looked at the significance of the radical BEV technologies for the selected group of SMEs. Some exemplars from the interview data are provided below. These exemplars are deliberately chosen to show the themes coming through from the analysis of the interview data.

"We use advanced technologies….. That situation draws a lot of customers to the company“

“The technology was protected by patents but difficult to enforce “

“My plan at this stage is keeping 100% of the patent for myself”

“Our technology is not that protected. We have patents and designs. But, we are too small to protect it. There are paper works and lots of costs associated with it. So, our strategy is bringing the technology to the market faster and making more innovation”

As presented above, the BEV sector was defined as a technology-driven niche market by the interviewed SMEs as the technology was viewed as the primary attraction for encouraging customers (Table 4.3). Since new entrants boost the technological development of radical innovations by exploiting the novel combinations of related technological fields [248], attracting customers who were interested in high technology products was not a surprise. Yet, SMEs were cautious to exploit BEV technologies due to difficulties of protecting intellectual property (IP). The difficulties were claimed to have arisen from high avoidance costs.

Themes: Customer Base; IP Protection

Table 4.3 Technology decisions of interviewed SMEs

Country	*Technology Decisions*	*Themes*
GERMANY	"Technology plays a key role for pushing the new products such as bi-directional charger that can be used with the future smart grid applications"	Customer Base
	"We have unique technology that extends the range of vehicles. The technology plays a key role for determining the market position and pushing new products to the market. We believe that the unique technology will help us to earn money even after 12 years"	Customer Base
	"The contracts we sign become our customers' intellectual property. If we can patent the technology we develop, we also look for ways to patent it"	IP Protection
	"Our technology is not that protected. We have patents and designs. But, we are too small to protect it. There are paper works and lots of costs associated with it. So, our strategy is bringing the technology to the market faster and making more innovation"	IP Protection
UK	"Our lighter, easy to manufacture and more eco-friendly ceramic battery determines the market position. The technology also drives the company to be active in other markets such as China and India as there are more interest to the company`s technology in these countries"	Customer Base
	"Our innovative motors attract the customers. It allows us to grow without marketing and advertising. We protected the technology with patents but it did not help other companies to steal the technology. After a while, we dropped the legal fight because of high avoidance costs. To avoid the same situation again, the two materials that are used for the motors are known by no one except me"	Customer Base; IP Protection
	"We offer purity of driving. That is why our customers sometimes wait for years to buy a car from us. If we can integrate this with disruptive technology, we could do a quite good job. So, we need to combine the traditional car with modern technologies. We patented our chassis and suspension. Our company name and the shape are registered as trademarks"	Customer Base; IP Protection
NETHERLANDS	"We use advanced technologies for prototyping, manufacturing proto parts, assembly, engineering, building new vehicles and converting conventional combustion engine to a 100% electric drive. I think we built one of the first EVs built in the Netherlands. It was the first electric vehicle and the answer was due to legislation. Although we are an SME, we are running crush tests for the vehicles. That situation attracts lots of customers"	Customer Base
	"Our switch mode power technology allows us to be active in different kinds of applications areas such as audio, video, industrial, medical and automotive. For the e-mobility, charger and inverter designs ensure the optimal balance between functionality, quality and weight for on-board as well as stationary use"	Customer Base
	"We are very innovative. We are the first one in Europe that started with wheelchair accessible vehicles and low floor mini buses. We were also behind the idea of aluminium floor systems which are more flexible. The company won the innovation award at the bus exhibition. We expect to earn more money in the future due to our developments"	Customer Base
BELGIUM	"We are a leading provider of sustainable and easy to use "plugin" solutions for recharging and driving EVs. Our stylish and intelligent on street charging post has achieved design excellence with top finishing quality and is based on state-of-the-art, sustainable, reliable and proven technology"	Customer Base
	"Mostly, my customers are authorities buying EVs. it is because they have targets and they have clean up directives"	Customer Base
FRANCE	"I am eager to trial innovative vehicles. I want to run hydrogen cars or vehicles with other alternative fuels in the future. We also want to run "intermediate" vehicles such as bicycles, pedelecs, mopeds, motorbikes, quadricycles (e.g. Twizy), with or without electric engines as they are cheaper mobility alternatives for the customers"	Customer Base
	"We are in the technology business. This situation creates high pressure on the company to be agile and to constantly offer cutting-edge solutions for the industry"	Customer Base
	"My unique, innovative, simple and convenient solution helps me for marketing and contacting with bigger companies. My plan at this stage is keeping 100% of the patent for myself "	Customer Base; IP Protection

4.5.2 Motivation

According to the PLC model, one of the characteristics of a radical innovation is the entry of many firms [211] because radical innovations lower entry barriers and open up windows of opportunity for new entrants to enter the market [28, 64-71]. This is a different situation compared to a mature technology where a few firms control a large portion of the market share and it is difficult for a new firm to enter the market [72]. All of the historical successful radical technologies entered niche markets with ease and received less competition from incumbents than they would in mass markets, and often they received no competition at all [35]. An additional factor making niche markets attractive is that incumbents may not be properly serving them. This means that there already may be a demand for radical technologies. The interview study wanted to learn what motivated SMEs to be active in emerging BEV sector. Some exemplars from the interview data are provided:

“In 2006, I made research on EV infrastructure because EVs were getting popular. I saw that it is a very interesting sector and there are opportunities for business”

"We wanted to enter a market promising opportunities in future technology “

"When we were involved in vehicle electronics, we have involved with the Japanese companies. With this involvement, the company saw the growing trend of EVs“

As presented above, the BEV sector in NWE attracted SMEs since it was a niche market that SMEs can position their existing expertise and product knowledge. The emergence of the BEV sector provided opportunities for SMEs to become part of a developing supply chain, as suggested by the innovation literature. SMEs had ability to service new markets and the potential to grow the company with radical BEV technologies (Table 4.4). There was also a strong belief in the continued growth of the BEV sector and each of the organisations had a strong belief that the market had yet to establish itself fully. This belief is perhaps driven by the nature that transport and access to transport is in demand from European consumers [249] which means that there is a big market for the companies if the technology is to change from ICEV to BEV.

Themes: Market; Growth

Table 4.4 Initial motivation of interviewed SMEs

Country	*Initial Motivation*	*Themes*
GERMANY	"With the crisis, all product range went down. In order to keep the business up, we started developing our own e-power train"	Growth
	"Developing an environmentally friendly refrigerant. Since the refrigerant was proven to be more efficient, we wanted to develop an air conditioning system based on the refrigerant carbon dioxide for the automotive sector"	Market
	"We wanted to enter a market promising opportunities in future technology"	Market
	In 1973, there was an oil crisis. Because of the crisis, the oil prices increased. In that time, I thought that would be a market for electric vehicles. Electric vehicles offer opportunities.	Market
UK	"The company is a start up from a zero base with no commercial products. We wanted to achieve a substantial commercial position in the battery industry with innovative know-how"	Market
	"The company was created after the invention of a very successful and innovative electric motor"	Market
	"We understood the market is going there and carbon emissions are big problems for the entire world. Basically, we wanted to build a lightweight car by using the latest drivetrain technology and we wanted it to be fairly efficient"	Market
NETHERLANDS	"I wanted to fill a gap in the market OEMs left by converting cars"	Market
	"The company wanted to fill a gap in the market on know-how on making cost efficient, robust, efficient power conversion applications"	Market
	"The transportation sector is changing and that is resulting in the integration of public transportation sector and taxi companies. After the integration, the change will be on cleaner technologies which we identify as an opportunity"	Market
BELGIUM	"In 2006, I made research on BEV infrastructure because BEVs were getting popular. I saw that it is a very interesting sector and there are opportunities for business"	Market
	"I got my very first training on BEVs in the army, strangely. After working in different places for a couple of years, I wanted to look at the horizons of electric mobility because of the opportunities"	Market
FRANCE	"We believe that offering innovative solutions (technology and service innovation) and meeting specific, local mobility requirements of customers will attract more customers for the company"	Growth
	"When we were involved in vehicle electronics, we have involved with the Japanese companies. With this involvement, the company saw the growing trend of BEVs. It was all about finding the customers of customers in BEV. And, progressively, we have been pulled down to BEV routes supplying equipment to companies in the manufacturing batteries"	Growth
	"I wanted to solve both the price and range issues of BEVs by not increasing the total cost of ownership. I wanted to produce range extenders that is rented and attached to back of the car only when needed"	Market

4.5.3 Main Challenges

Identifying main challenges was one of the most significant parts of the study in order to define the ideal conditions that will stimulate the growth of SMEs for the benefit of NWE. Again, some exemplars from the interview data are provided.

"Big Players don't necessarily allow SMEs to grow. You don't get most of the components, if you don't take a big demand" and "[your involvement is a] political decision of big automotive players and Tier 1 suppliers"

"A lot of big companies see this business some kind of hobby. We have to prove ourselves" and "the customers want to see a working prototype"

"We are poorly supported by the local governments. Government`s policy for SMEs and innovation are relatively bad"

The dominant theme, as described above, in this case was establishing relationships. Firstly, it was claimed that establishing relationships between the SME (the newcomer) and the established automotive sector was challenging (Table 4.5). It was argued that the focus of the established player on volume was restrictive. Existing practices were seen as counterproductive to development. This situation was raised especially in Germany owing to the strength of existing automotive supply chain and the issue of breaking into this chain as an independent organisation with a business model outside of the traditional automotive supply chain. Secondly, establishing relationships with customers was also seen as a challenge. Some SMEs claimed that it was necessary to demonstrate working prototypes for convincing the customers and establishing long-term relationships. Lastly, lack of government involvement to take any initiative in favour of accelerating electric mobility was also seen as a challenge for some SMEs. It was clear that technology alone was not sufficient to be able to establish a place in this emerging market and this was very restrictive for SMEs.

Themes: Relationship, government involvement

Table 4.5 Main challenges for interviewed SMEs

Country	*Main Challenges*	*Themes*
GERMANY	"Big Players don't allow SMEs to grow. You don't get most of the components, if you don't take a big demand"	Relationships
	"Political decision of big automotive players and Tier 1 suppliers for not using carbon dioxide as a refrigerant cause high pressure on the green manufacturers. You don't get most of the components, if you don't offer a big demand"	Relationships
	"We are poorly supported by the local governments. German government`s policy for SMEs and innovation are relatively bad"	Government Involvement
	"There is pressure from OEMs because they want to keep their market. Finance also challenges us"	Relationships; Raising Finance
UK	"Because of the little interest of UK government to lead/acid batteries, we are looking for new markets in developing countries (China and India) to raise finance"	Government Involvement; Raising Finance
	"Financial challenges limit our investments"	Raising Finance
	"Different markets require different products. For example, we are having problems with safety issues because USA is more safety concerned than Europe"	Standardization
NETHERLANDS	"A lot of big companies see this business some kind of hobby. Especially in this kind of field (if you are converting cars) they mainly see you as a hobbyist. So, we have to prove ourselves"	Relationships
	"The customers want to see a working prototype. Financing challenges our growth"	Relationships; Raising Finance
	"People want to see a working prototype. We cannot deliver the built cars to Asia or Australia because of high logistics costs. Because the customer of the public transportation is cities or governments and the concessions normally require 8-10 years, the most current concessions are based still mainly on diesel or natural gas resulting on low number of BEVs on the roads."	Relationships; Raising Finance; Government Involvement
BELGIUM	"In this business, most of the initiatives are coming from private sector. I mean, sun is not shining very brightly in anywhere. But, government needs to have a right vision. In terms of infrastructure, there are de facto standards. But, France has type 3 standards"	Government Involvement; Standardization
	"Sometimes, the government is making wrong choices. My business is in very big need of cash because I buy the vehicles, physically buy them, and sell them "	Government Involvement; Raising Finance
FRANCE	"Financial and technical incentives such as free car parking, helping the individuals to install charging stations at home, and allowing the green drivers to drive in bus lanes are not adequate"	Government Involvement
	"Financing challenges the company`s growth. Contacting with big players is difficult"	Raising Finance; Relationships
	"It is difficult to getting grants from regional public funders. Contacting with big players outside of France is challenging "	Government Involvement; Relationships

4.5.4 Financing

If an SME exploits a new emerging market then SME requires finance for overcoming challenges. In innovation literature, it is recognised that finance is a very important limitation for the entry and growth of SMEs. Thus, they need to be supported with funding instruments [76]. Throughout FP7, SMEs were actively encouraged to get involved especially under the Cooperation programme and Joint Technology Initiatives. A funding rate of 75% for R&D activities of SMEs and a guarantee fund which would cover the financial risks of project participants were offered by FP7 in order to support SMEs [250]. The interview study looked at the approach of the selected group to financing growth and whether or not they use European funding programmes. The exemplars are provided below in support of the analysis of the interview data:

"We look at the product, the money we generate from that return to back to the developments and developments grow. That is basically how we fund the developments"

"I have no funding whatsoever directly to my company. So, the only funding that is interesting for me is the subsidies of all my products"

"The projects get through the auto cluster and you are peer-reviewed from experts. It helps getting financed because then you have the experts having validated your project. They don't have the money but they have the networking"

The underlying theme for the SMEs interviewed was that they intended in the short term to fund growth through existing margins gained from the sales of the products (Table 4.6). Only a few of the SMEs interviewed used European funding programmes for financing their projects, often feeling that the system was bureaucratic and the risk that the investment made in pursuing such funding streams was too high given other pressures on the business. One SME stated that there was an auto cluster peer-reviewing the activities and giving some degree of confidence to SMEs in order to go forward looking for other investment and grant opportunities.

Themes: Growth; Grant Availability; Networking

Table 4.6 Financing decisions of interviewed SMEs

Country	*Raising Finance*	*Themes*
GERMANY	"We invest without any funds from the government. We invest completely with our money but we are looking for partners for buying bigger amounts and investing more money into the business."	Grant Availability, Networking
	"The company is funding itself with the margins gained from the sales of the products. Incentives always help but there is not a substantial business case behind it. It just gives an early start. Mostly, the governments of states or the federal government in Germany say that these are successful projects we have supported. So, that gives us an additional insight. We are looking for partners in order to buy bigger amounts"	Grant Availability, Networking
	"The weakest point of Germany`s funding strategies is funding the innovation. If we were designing components, our funding from the local government could be relatively easier. We are poorly supported by the local governments because German government`s policy for SMEs and innovation are relatively bad"	Grant Availability
	"There are two owners of the company. We are investing for our company. But, we are discussing for having external investors for our company. Right now, we are in a national project. It is a local funding project from Hessen region. We are only taking advantage of regional level funding currently because it requires time consuming procedures, a lot of paperwork. It is attractive but it is hard for us"	Growth; Grant Availability
UK	"We are looking for partners to finance the company and increase the production. Actually, we want to be active in China and India because the UK government`s interest to lead/acid batteries is not enough"	Growth; Grant Availability
	"To roll the company, we built partnerships with investors. Financing challenges our intention to invest in new machineries which can decrease the production time of motors significantly. I do not think applying to government incentives because they are difficult and they take lots of time"	Growth; Grant Availability
	"The funding is coming from internally. We use one third of our profits for investing. My personal opinion is that the government cannot run the business. But, little help is appreciated. The government support is not bad. Still, it can be improved a little bit"	Growth; Grant Availability
NETHERLANDS	"The company is funding itself. We are looking for a partner who can take care of the production line. I am struggling everyday how to survive in the market. We need support from government or from European community to go ahead. It is just support from the back, it is not to survive. But if you apply for such a project you need at least 10 companies. To enter as an SME to these programmes, only as an SME, it is not possible. I think that markets like in Germany are investing much more for SMEs"	Networking; Grant Availability
	"We look at the product, the money we generate from that return to back to the developments and developments grow. That is basically how we fund the developments. Of course, if you find a funding programme that fits and helps you, it would be good to do that. But, I don't believe in any of those funding programmes anyway. We want to have partners"	Grant Availability; Networking
	"The company is funding itself with its developments. Funding programmes are also explored to accelerate the current projects. We want to be integrated with tenders, government officials, our partners and customers to survive. We cannot deliver the built cars to Asia or Australia because of high logistics costs"	Grant Availability; Networking
BELGIUM	"I am financing the company. There are no subsidies made available. Growth rate depends on external parameters which you cannot control such as government involvement and how supportive they are. In Belgium, there is no initiative whatsoever from the federal government. I cannot also rely on to European Projects to grow my company. You need to hire someone to analyse those kinds of projects. They have been set up for bigger companies"	Grant Availability; Growth
	"I try to keep my overhead costs as little as possible because my business needs lots of cash to buy the vehicles and sell them to the cities and municipalities. So, there are terrible cash flow peaks. There are projects funded entirely by the network providers. But, I have no funding whatsoever coming directly to my company. The only funding that is interesting for me is the subsidies of all my products"	Grant Availability; Networking

Country	*Raising Finance*	*Themes*
FRANCE	"All the funding is coming from internally generated revenue. We are looking for partners. More financial and non-financial incentives are required to increase the demand on BEVs"	Grant Availability; Networking
	"We are looking at having external partner because we have come to the limits of what we can reasonably do. To fund the growth of the company, we just plug out everything back into the company. We are the shareholders. If the company is going to carry on, the amount of capital you need just carries on increasing. But, we are on the limits. With an outside partner, we can ramp up"	Grant Availability; Growth
	"The company tries to finance the projects with the grants from regional public funders. I am looking for partners in order to build the tenders and set up the rental network. Because the funding process of regional public funders is very detailed, onerous and slows down the commercialization process, only people who initially have the money and the contacts can go through"	Grant Availability; Networking

4.5.5 Business Models

According to a research study, the number of companies producing electric vehicle (EV) models has substantially increased with start-up firms comprising a majority of that growth since 2004. The number of start-up firms has increased from 2004–2011 especially from 2006 onwards. It was argued that serving niche markets might be a reason behind the increase of start-up firms in BEV market [25]. The interview study therefore wanted to understand whether or not SMEs in NWE serve to the niche markets, and what kind of business models they adopt to support their market intake. Some exemplars are provided as below:

“We don’t want to compete in a mass market, it is not our business. We are looking for niche market”

"We want to be taken over by a bigger company where we can have some kind of independency inside the company”

"We are partnering up with the investors to provide funding to grow the company”

“We are absolutely in a niche market. But, because our vehicle is pedal assisted, we are a niche market within the niche”

It was found that SMEs in NWE were serving to niche BEV markets as expected and they adopted different business models (Table 4.7). These ranged from a technology provider that indicated its very existence relied on exploiting niches and it would move onto the next emerging niche as the existing one transitions to the main stream. Others were positioning themselves to either grow in response to market expansion by becoming part of a larger group or partnering up. Nearly all the SMEs interviewed demonstrated a need for strategic partnerships. It was clear that the role of SMEs in the emergent BEV sector in NWE was limited by the confidence in the market and the need for resources.

Themes: Market Penetration; Partnerships; Business Takeover

Table 4.7 Business model decisions of interviewed SMEs

Country	*Business Model Decisions*	*Themes*
GERMANY	"We launched Germany's first mass-produced BEV. We don't want to come in a mass market because when OEMs come with products, it will be very difficult for us to sell more cars. We are looking for niche market and partnerships especially for buying bigger amounts and using the technologies in different applications"	Market Penetration; Partnerships
	"Our core competency is developing, manufacturing and distributing refrigeration machines. We want to be more active at BEV business as long as it continues to be a niche market. If the demand increases a lot, we will move to another niche. We are also looking for partnerships in order to buy bigger amounts and using the technologies in different applications"	Market Penetration; Partnerships
	"We are an engineering outfit for vehicle integration of alternative vehicles. We are an internationally linked company with many partners. We want to be small enough for flexibility and not to have financial burdens. But, we also want to be big enough to demonstrate that we are ready for big projects with OEMs"	Market Penetration; Partnerships
	"We produce a human-electric hybrid vehicle to carry two passengers and cargo. Until now, we produced 1000 vehicles. We are absolutely in a niche market. Because our vehicle is pedal assisted, we are in a niche market within the niche. Still, it is necessary to have your own market since we are competing against Renault and Volkswagen by creating our own market"	Market Penetration
UK	"We develop lead/acid batteries for different applications such as e-bikes, scooters, motorcycles, hybrid and electric vehicles. We want to enter China and India market in a short time. In these markets, we look for partners to sell our plate (conductive ceramic) to increase the profit rate"	Market Penetration; Partnerships
	"We develop electric motors for the industry and supply to the cross broad spectrum of the BEV Market. We also convert 2, 3 and 4 wheeled vehicles, boats and trains. We are partnering up with the investors to finance the company. We want to stay in the BEV Market, explore new opportunities there and grow with the market"	Market Penetration; Partnerships
	"It is a family run business. We produced 640 cars in 2007. We have good dealer network worldwide. Our aim is building a strong sales network in the world. Until now, we sold 30.000 cars in the world and we want to hold spares and service them without facing any problem. With a new BEV we want to produce, It will be a new niche for us"	Market Penetration; Partnerships
NETHERLANDS	"We develop and construct prototypes of new vehicle concepts, BEVs or special vehicles. We make focused conversion based on the requirements of the customers. We are moving towards to a change and being more active in engineering software for interfaces. We want to be taken over by a bigger company where we can have some kind of independency inside the company. We want to stay in the niche market and grow with it"	Business Takeover; Market Penetration; Partnerships
	"The company designs and manufactures products and solutions for a broad range of markets, such as chargers and AC inverters. We are willing to work for bigger companies as a sub-contractor. We are also looking for businesses with bigger companies and OEMs. Lack of making business with these kinds of companies will result in looking for new niche markets"	Market Penetration; Partnerships
	"We develop vehicles adaptations based on the standard vehicles. We are also specialized in the development, testing and construction of vehicle modifications. We aim to be integrated with tenders, government officials, our partners and customers to survive in the market"	Partnerships; Networking

Country	Business Model Decisions	Themes
BELGIUM	"We are a leading European service provider in electric mobility. We offer the most appropriate charging infrastructure for the individuals and businesses. We also offer services and support for our customers. We won the European green fleet awards and green business award"	Market Penetration
	"I am a Belgian agent of a company. I offer a few brands. 90% of my work is on the small city trucks. Mostly, my customers are authorities buying BEVs. It is because they have targets. I am working with larger organizations and associations to roll out the electric mobility"	Market Penetration; Partnerships
FRANCE	"We are a global mobility service operator offering a panel of transport solutions on our own or in conjunction with other organisations. We provide mobility services including car-sharing services with BEVs. We work both with local authorities and private businesses"	Market Penetration; Partnerships
	"We are a French subsidiary of a small European group of companies. We are involved in the electronics area. We have been supplying equipment to companies involved in manufacturing batteries. We also supply production equipments to electronic manufacturers. We are looking for partners and want to grow with the niche market"	Market Penetration; Partnerships
	"The company is just created with a purpose of building range extenders that is rented and attached to the back of the car only when needed. I want to either sell the patents and charge for per tender or offer subscription to the rental network in our car dealership in order to allow the car maker to sell their cars. I managed to access some of the top people in the BEV sector in France. If I cannot find partners in Europe, I will try the Chinese and Indian Partners"	Market Penetration; Partnerships

4.5.6 Manufacturing

After business model decisions were clarified, the question was how SMEs link their business model with their manufacturing base. The interview data disclosed that manufacturing decisions demonstrate the same trend with the business model decisions. Opinions of some SMEs on their manufacturing decisions are given below:

"Current low demand is dealt with batch production."

"We want to scale up the production and allow low cost companies to manufacture our battery"

"We have built prototypes but we do not manufacture anything. We build prototypes to demonstrate that we are capable of doing everything"

"Although new machinery can support the production by decreasing the cycle time, it is not considered currently because of the financial burdens"

"For our next model, we want to produce 500 a year and we want to assemble it on our own."

Since the demand was low [78], adopted approach was small volumes of production which was flexible according to demand (Table 4.8). Yet, most of those companies either outsourced the non-core competencies or bought them from suppliers (generally partners of SMEs) to manage demand fluctuations and lower risks involved with manufacturing and holding inventory. SMEs also identified a risk on how to move to the next level on business where investment is required but the market potential is uncertain. This resulted in a disconnection between the potential of SMEs to become part of the future BEV supply chain based on technology and based on manufacturing capacity.

Themes: Flexibility; Demand; Investments; Supply Chain

Table 4.8 Manufacturing decisions of interviewed SMEs

Country	*Manufacturing Decisions*	*Themes*
GERMANY	"The demand is low. We manufacture cars and outsource powertrain. If the demand increases a lot, we can increase the flexibility with automation. I would go into a bigger amount for battery packs or charger. I would produce higher quantities (10000-15000) if there is a market I see for longer period. If I see 1 year peak demand and 1 year low demand then I don't. But, I do not want to invest in new assembly lines or facilities"	Demand; Flexibility; Investments; Supply Chain
GERMANY	"Current low demand is dealt with manufacturing some parts and buying compressors. We are a middle-sized company. We are not able to manufacture all the components needed. Buying and outsourcing also lowers the risks for the business. System flexibility is low "	Demand; Flexibility; Supply Chain
GERMANY	"We have built prototypes but we do not manufacture anything. We build prototypes to demonstrate that we are capable of doing everything. If a customer comes and tells us, he needs 300 components within a year or two, we will do it. But, we outsource it. We do not want to invest in money on that. We would like to build a capable supply chain with partners rather than investing money for manufacturing purposes"	Demand; Investments; Supply Chain
GERMANY	"In 2002, we took over the production. Our next models will be higher volume series. For our next model, we want to produce 500 a year and we want to assemble it on our own. One further model will be more cost optimized and specific product. For these products, we will radically increase the manufacturing output and come to mass manufacturing. We are 12 people. So, we cannot produce everything in-house. We have tools for components. Our suppliers produce them and send the components to us. Then, we just assemble them"	Demand; Flexibility; Investments; Supply Chain
UK	"Current low demand is dealt with batch production. Whole battery is produced and sold. However, we want to scale up the production and allow Chinese companies to manufacture our battery"	Demand; Investments; Supply Chain
UK	"The demand is low and we produce in batches. Although offering 3 kinds of motors and 15 different options, we use same line, same castings (3 castings types) and same material for the production and modify the finished products to meet the demand. Producing the motors with hand increases the production time (up to 7 hours for a motor). New machinery can support the production. It can decrease the cycle time up to 5 hours. But, I do not want to invest that much money"	Demand; Flexibility; Investments
UK	"We buy the chassis from USA. All the cars are assembled by hand here. Wood frames are also built here in the factory. Production output is approximately 800 cars a year. We work quite well with BMW. They are manufacturing engines for us. We are very flexible. We have a platform that can adopt itself. That is why we think we can fit a BEV to our production as well"	Demand; Flexibility; Supply Chain
NETHERLANDS	"We are mainly producing proto parts and being more active with our services. We are looking for a partner who can take care of the production line"	Service; Supply Chain
NETHERLANDS	"What we mainly do is that we hire the hands to manufacture it. All the practical technical product documentation: sort of recipe, how to make a product...All those things come from my company. It means that we are taking care of everything, except than manufacturing. So, we sub-contract the manufacturing to a company in Indonesia and other places and we deliver the products ourselves. The demand is medium"	Supply Chain; Demand
NETHERLANDS	"Because of seasonal demands we need to be very flexible resulting in growing and decreasing continuously. We can start the production anywhere in the world within 6-12 months because of our know-how and previous experiences. We produce nothing in-house. The parts that are sub-assembled by the partners are assembled in-house and delivered to the customers. If we get orders, we can get loose but if there are not big orders, we will remain the same"	Demand; Flexibility; Supply Chain; Investments

Country	*Manufacturing Decisions*	*Themes*
BELGIUM	We offer charging infrastructure, services and support for our customers. So, we do not manufacture anything.	Service
	I am an agent for an international company. I buy the vehicles and sell them to the customers. I do the service. I do the transportation of the vehicle and I give the basic training for all the users"	Supply Chain; Service
FRANCE	"Because we are in a service business, we do not manufacture anything"	Service
	"We manufacture nothing. We distribute, buy and resell. However, the products we supply require programming, installation and training"	Supply Chain; Service
	"Small-scale batch production is adopted for manufacturing the tenders. Components such as engine, electric machine, wheels and suspension will be purchased from the partners and the assembly of those components will be subcontracted as they are fairly standard components. If the demand becomes higher, production can be increased by outsourcing the manufacturing of some components"	Supply Chain; Flexibility

4.5.7 Customer Relations

There are a lot of barriers mentioned in the literature to the adoption of EVs such as: unfamiliarity with BEVs, range anxiety, unavailability of home charging, public infrastructure, prices and cost of ownership [251]. However, one of the main challenges is also establishing relationships with customers as found in "main challenges" section. The question to SMEs was therefore how they would overcome this challenge. Some exemplars are given below:

"Consumer is the main business unit for our company. We make focused conversion based on the requirements of the customers"

"To keep in touch with our customers, we create newsletter, we offer after sales support, we send e-mails and invite them to the fairs. We give presentations to them."

"We are looking for long term relationships with the customers."

"The benefit of [cluster organisations] is that we know our competitor and our customers, we can discuss with them and share our knowledge. Basically, we cooperate with each other. At the end, we both benefit."

The strategy was clearly as described above valuing networking opportunities and establishing long term relationships with customers (Table 4.9). Interviewed SMEs had close relations with the customers even after the sale. To establish relationships, cluster organizations (for those that have worked in such forums) were seen as invaluable.

Themes: Relationships; Networking

Table 4.9 Customer relation decisions of interviewed SMEs

Country	*Customer Relations*	*Themes*
GERMANY	"Consumer is the main business unit for the company. We want to design, manufacture and deliver products in close cooperation with our customers"	Relationships
	"Consumer is the main business unit for our company"	Relationships
	"Our customers are exclusively business: tier 1 suppliers and OEMs. We do not serve to private customers at all. It is because they cannot afford the service we are providing. It is also the service we provide such as local safety traffic boards are totally irrelevant for private customers. They do not bother"	Relationships
	"In most cases, our customers are private people with business backgrounds. Mainly, customers find us. We also go to the fairs and contact with people there. To keep in touch with our customers, we create newsletter, we offer after sales support, we send e-mails and invite them to the fairs"	Relationships
UK	"Our company wants to design, manufacture and deliver products in close cooperation with the customers"	Customer Relationships
	"Whenever the petrol prices increase, the more customers are drawn to the market. We don’t use marketing. People know me from my customers"	Relationships
	"Customer relations are very important for us. We start communicating from the very beginning. The waiting list for a car is approximately one to two years, although it has been as high as ten years in the past"	Relationships
NETHERLANDS	"Consumer is the main business unit for our company. The user is always looking at the cost. We understood what the customer wants and then we made focused conversion based on the requirements of the customer"	Relationships
	"We are looking for long term relationships with the customers. The benefit of forums is that we know our competitor and our customers, we can discuss with them and share our knowledge. Basically, cooperating with each other. At the end, we both benefit"	Relationships; Networking
	"The customer of the public transportation is cities or governments. The total cost of ownership is being more important for customer choices. We are very much busy with safety regulations, explaining staff, giving differences, giving a to do list because people are not sure with BEVs"	Relationships
BELGIUM	"Customer satisfaction is very important for us. We do not just build infrastructure, we also offer services. To support our customers, we offer BEV information helpdesk, management platform and BEV consultancy"	Relationships
	"I am not only making a good sale but I am also offering a good service. I created enough confidence with my customers. Some of them travels quite a lot to buy from me and only from me"	Relationships
FRANCE	"The company's strategy is basically linked to address people's mobility needs. We try to draw more customers and compete with large transport service operators by offering technology and service innovation and meeting specific, local mobility requirements with a high level of customer service"	Relationships
	"The company grows owing to the professionalization and consolidation processes and by responding the customer requirements. That situation creates a lot of customers for us even if the customers are always changing and makes the company more efficient and agile. I have heard about databases that 900 names in it. I am hoping that databases those 900 names in it has got basic ecosystem in which we can work. That is why I came to this sort of event."	Relationships; Networking
	"My project minimises the people`s risk perception and satisfies the customer by dealing with both range and cost issues. So, I draw more customers into the market. I contacted with large guys because my idea is simple, innovative and it solves a really serious issue"	Networking

4.6 Verifying and Reporting

Verifying relates to the 'reliability' (or how consistent the results are) and 'validity' (or whether an interview study investigates what is intended to be investigated) of the data. The interview structure was deliberately chosen to place the researcher in the position of SMEs so that he learnt from SMEs as opposed to confirm pre-held ideas and concepts. The results are also compared below with two recent framework programmes (FP7 and Horizon 2020) as they are the EU`s main instruments for implementing its common scientific and innovation policy.

SMEs are very significant for the BEV sector since they are more capable of developing radical BEV technologies [28, 37, 78]. This research found that although BEV market in NWE was a technology driven niche market, SMEs were cautious to exploit BEV technologies due to difficulties of protecting intellectual property. Horizon 2020 brings opportunities for SMEs with IP SME corner. It is an official IP service initiative of the European Commission providing free-of-charge, first-line advice and information on intellectual property rights [252]. It is a very beneficial service to inform SMEs about managing intellectual property rights. Yet, more specific technology protection measures for SMEs need to be considered. Such measures can significantly increase patent filings in the region and increase the development, diffusion and use of BEV technologies in the emerging supply chain.

SMEs need financial resources for development and commercialisation of BEV technologies. This research found that SMEs were funded through existing margins gained from the sales of the products. This was restrictive as sale revenues were used both to fund existing business and to make new investments. Small amount of funding left for new investments were rarely sufficient to fund up-scaling of production and development to the levels needed to feed into mass production processes at OEMs. The EU financially supported clean transport research, technical development and innovation with EGVI PPP grants and ECTF loans under FP7. For SMEs, specific funding opportunities especially with the Cooperation programme and Joint Technology Initiatives were also offered with FP7. Yet, only a few of the SMEs interviewed used these programmes often feeling that the system was bureaucratic and the risk that the investment made in pursuing such funding streams was too high given other pressures on the business. With the launch of Horizon 2020, most of the rules for participation, dissemination, evaluation and implementation were simplified. Simpler rules for grants were introduced and time to grant was reduced by 100 days. Fewer, better targeted controls and audits were also introduced. Moreover, SME instrument programme was launched. The instrument provides full-cycle business innovation support from the stage of business idea conception and planning (phase I- €50,000 grant) over business plan execution and demonstration (phase II - €500,000 to 2.5 million grants) to commercialisation (phase III – measures for commercialising such as networking, training, coaching and mentoring etc.). Participants of SME instrument programme are also able to call on business innovation coaching for the duration of their project in order to enhance the company's innovation capacity and foster their project's long-term commercial sustainability. Another opportunity for SMEs under Horizon 2020 is National Contact Points. They provide information and guidance to SMEs wishing to participate in the EU research and offer personalized support in the proposer's own language [253]. All these support can now be accessed by using a single IT platform called "Participant Portal". Yet, SMEs need to be informed about these opportunities to join these projects.

Interviewed SMEs demonstrated a need for strategic partnerships to both build a capable supply chain and share risks. However, it was very challenging to contract with larger organisations. Thus, while some SMEs wanted to exploit niches and move to the next emerging niche when the existing niche EV market transitions to the main stream, others wanted to position themselves to either grow in response to market expansion by becoming part of a larger group or partnering up. Establishing relationships are very significant to support SMEs to step up to the next level in the possible BEV based supply chain. Although FP7 supported establishing relationships by prioritising collaborative projects, it was not found attractive by SMEs owing to the perception that procedures were difficult. For both FP7 and Horizon 2020, three independent legal entities from three different Member States or Associated States are required to join collaborative projects [250]. With Horizon 2020, most of the procedures are simplified and various partner search services such as National Contact Points, Enterprise Europe Network and CORDIS Partner Search are offered. With Enterprise Europe Network, SMEs that want to apply for Horizon 2020 funding can find business partners and they can get information about the EU legislation and regional funding opportunities [253]. Stakeholder workshops, clusters, forums, networks, exhibitions and demonstrations might be suitable to stimulate required networking processes. Especially, the protection and networking offered by cluster organisations are thought to be beneficial. For example, a mobility cluster in France presented opportunities for SMEs by pre-evaluating their ideas. Projects that successfully passed the peer-review process were awarded with a label helping to finance

45% of the project. Even if the auto cluster did not finance the projects directly, they helped SMEs to be financed by providing a network and offering collaboration. In that context, auto clusters and projects offering SME-OEM cooperation should be encouraged.

4.7 Conclusions

This chapter explored the approach of SMEs to the emerging BEV sector to understand SMEs and investigate the support areas they need to have a role in the possible BEV based automotive value chain re-shaping. It did this by conducting a number of in-depth and semi structured interviews with SMEs in NWE. SME responses were then linked with FP7 and Horizon 2020 programmes to improve the link between policy and delivery. It was found that:

- The role of SMEs in the emergent BEV sector in NWE was limited by the confidence in the market and the need for resources. There was also a disconnection between the potential of SMEs to become part of the future BEV supply chain based on technology and based on manufacturing capacity.
- Profits from small volumes of specialist products were rarely sufficient to fund up-scaling of production and development to the levels needed to feed into mass production processes at OEMs.
- SMEs needed strategic partnerships to both build a capable supply chain and share risks. However, it was very challenging to contract with larger organisations.
- SMEs were cautious to exploit BEV technologies due to difficulties of protecting intellectual property.
- For interviewed SMEs, it was also difficult to engage with FP7 since they needed more support for protecting technology, establishing relationships and funding investments. Such kinds of support might further stimulate SMEs to step up to the next level in the possible BEV based supply chain.
- Horizon 2020 is more aligned with expectations of interviewed SMEs compared to FP7 as it offers many opportunities for establishing relationships and raising finance for SMEs. However, they need to be informed about those opportunities. Specific technology protection measures for SMEs are also required.

CHAPTER 5 – DEVELOPMENT OF A POLICY INTERVENTION EVALUATION FRAMEWORK FOR ELECTRIC VEHICLE TECHNOLOGY DEVELOPMENT

Some parts of this chapter and the following chapter (Chapter 6) have been published in two international conferences

Özel, F. and H. Davies, *A Policy Intervention Evaluation Framework for Electric Vehicle Technology Development* in *European Electric and Hybrid Vehicle Congress (EEVC)* December 02-05, 2014: Brussels, Belgium.

Özel, F., Davies, H. and Wells, P. *Development and Application of an ANFIS based Policy Intervention Evaluation Framework for Electric Vehicle Technology Development* in *23rd International Colloquium of Gerpisa* June 10-12, 2015: Paris, France.

5.1 Introduction

A transition from ICEVs to BEVs requires substantial changes in the whole automotive value chain including significant changes in the industrial structure [32]. Nevertheless, such transformation is not possible to happen on its own within an acceptable period of time which ensures the EU`s 2050 road transport decarbonisation pathway since ICEV based value chain is strongly invested [21-28]. Besides, electric propulsion technologies have a so called “double-externality problem” that decreases incentives for consumers and businesses alike to invest in these innovations. To accelerate the development of new BEV value chain and industrial structure, instruments targeting supply and demand side challenges therefore need to be used by governments. In transition literature, it is also recognised that prescriptive policy interventions are essential for achieving a transition from ICEV to BEV [41, 47, 55, 84, 85].

Within the EU and more broadly, there is an increasing set of policy measures to accelerate the development and dissemination of electric propulsion technologies, but given this diversity of interventions there is a need for a systematic framework to evaluate policy effectiveness. Such a framework might have the potential to support national governments in: identifying and improving the dynamics of EV innovation instruments more effectively, validating results and impacts of instruments on development of electric propulsion technologies and selecting the most appropriate instruments for their country based on their transition goals.

To support national governments in making informed decisions, a framework providing an ex-ante impact of various innovation decisions is developed in this chapter. This framework is based on “adaptive neuro-fuzzy inference system” (ANFIS) which is a hybrid scheme that uses the learning capability of the artificial neural network to derive the fuzzy if-then rules with appropriate membership functions worked out from the training pairs, which in turn leads to the inference [101]. For developing ANFIS framework, a dataset is generated by analysing EV innovation policies of United States of America (USA), Japan, EU, Germany, France and United Kingdom (UK) and comparing them with the actual EV technology development that is measured by patent filings in those regions. Subsequently, an ANFIS model is constructed by specifying an equation and transforming the generated dataset into input-output data pairs. Lastly, the data pairs are used for training and validating the ANFIS framework by using the MATLAB software.

5.2 Methodology

The emerging EV sector is a complex system with numerous relationships operating at multiple levels. Hence, designing innovation policies to support development of the sector presents a significant challenge. This is especially so as variable interrelationships in the automotive socio-technical system can lead to inaccurate and incomplete understanding of factors underpinning a particular policy and therefore lead to less effective transition policies.

To enable the pre-implementation analysis of policy measures upon the EV innovation system, a model of that system is required. Modelling of systems is significant in many fields as it enables the investigator to understand, simulate and predict system behaviour [254]. Predictive modelling can be drawn from statistics, database techniques, soft computing etc. [255]. Among these techniques, it is argued that soft computing that is a collection of methodologies such as fuzzy system, neural networks and genetic algorithm can be effectively used for modelling large-scale complex processes and systems since this technique is basically designed to exploit tolerance for imprecision, uncertainty and partial truth [254]. One popular soft computing technique is “adaptive neuro-fuzzy inference systems” or ANFIS. In this regard, a framework based on ANFIS was developed.

ANFIS is a hybrid combination of adaptive neural networks (ANNs) and fuzzy inference systems (FIS). The idea behind neural network and fuzzy inference combination is to design a system model that uses a fuzzy system to represent knowledge in an interpretable manner and has the learning ability derived from a neural network that can adjust the membership functions, parameters and linguistic rules directly from data in order to enhance the system model performance. In this regard, the trained ANFIS algorithm can be adopted to predict the technology development of EVs based upon national government policy strategies.

The ANFIS approach is described in more detail below:

ANNs represent a promising new generation of information and they comprise several simple, highly interconnected processing elements (nodes or units) in an architecture inspired by the structure of the cerebral cortex of the brain [256]. ANNs are generally characterized by their learning ability and known as useful predictive modelling tools. In literature, it is acknowledged that ANNs are better candidates for modelling highly complex nonlinear relationships [255] such as government interventions for inducing EV technologies.

Usually, an ANN is an adaptive system that changes its structure on the basis of external or internal information flowing through the network during the learning phase (training). Training a neural network model basically performs by selecting one model with minimum cost from the set of allowed models. The input/output training data are essential in ANNs as they convey the essential information to ‘‘discover’’ the optimum operating point. An input is presented to ANN and a corresponding desired or target response is set at the output. An error occurs due to the difference between the desired response and the system output. The error information is then fed back to the system and the system parameters are adjusted in a systematic fashion. This process is repeated until the system performance is deemed acceptable and when training is completed, the ANN parameters are fixed. Yet, a significant issue regarding ANNs is the over-fitting problem. This is because an ANN training phase captures useful information contained in the given data set and unwanted noise. Accordingly, the validation of the output of the trained ANN becomes crucial. The validation could be done by comparing the output with a set of new data that has not been employed for the training [255].

However, information regarding the emerging EV industry is often expressed in qualitative terms, verbally or diagrammatically (good relationships among stakeholders, good government support and low impact innovation policies) [257]. This situation makes the training of the ANN model difficult. In order to gain better insight into the effects of various relationships among different innovation policies, these aspects need to be incorporated in the model. It is the use of fuzzy inference system or FIS, which adopts the fuzzy if-then rule that overcomes such a problem since FIS provides a unified framework for considering the gradual or flexible nature of variables, and representation of incomplete information [258]. FIS also allows modellers to use linguistic terms such as “good” or “bad” rather than numbers. When employing FIS, the major key tasks are to formulate an appropriate approach for: transforming the national government’s policy interventions into rule based data; and calibrating the membership functions so as to minimise the output error.

Combining the two techniques. ANN with FIS, delivers an Adaptive Neuro-Fuzzy Inference System or ANFIS. ANFIS works well with optimization techniques, mathematical analysis tools and, thus, it is used frequently for modelling and controlling purposes. It was proposed to improve the performance of the fuzzy controllers relying on knowledge acquisition and the availability of human experts. Knowledge acquisition problem was solved with automatic generation of the knowledge in the form of fuzzy if-then rules. A learning method based on a special form of gradient descent (back propagation) was also used to construct the fuzzy controller without any necessity of human experts. Thus, ANFIS constructs an input-output mapping based on expert knowledge (in the form of fuzzy if then rules) and generate input-output data pairs by using a hybrid learning algorithm that is the combination of the gradient descent and least square estimates [101]. The trained algorithm can then be adopted to predict the technology development of EVs (output parameter) based on national governments` different technology strategies (input parameters).

For example, it might be assumed that the input parameters of an ANFIS is x, y, and the output parameter is z. The pre-defined fuzzy inference if-then rules on the basis of Takagi and Sugeno fuzzy rule set [101] can be illustrated as in Figure 5.1:

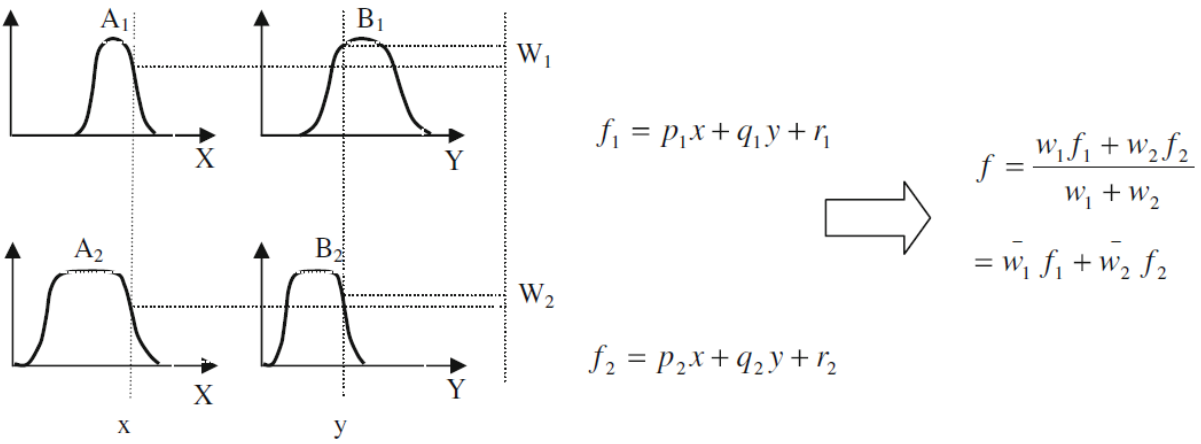

Figure 5.1 Fuzzy inference system [259]

Rule1: If x is A_1 and y is B_1, then $f_1 = p_1 x + q_1 y + r_1$

Rule2: If x is A_2 and y is B_2, then $f_2 = p_2 x + q_2 y + r_2$

which, A_1, A_2: fuzzy set corresponding to x; p_1, p_2: membership degree for input signal x belongs to fuzzy set A_1, A_2; B_1, B_2: fuzzy set corresponding to y; q_1, q_2: membership degree for output signal y belongs to fuzzy set B_1, B_2; r_1, r_2: constants; f_1, f_2: output signal rule 1 and rule 2. The architecture and learning procedures, on the basis of Jang`s works [101], are shown as in Figure 5.2 and Table 5.1.

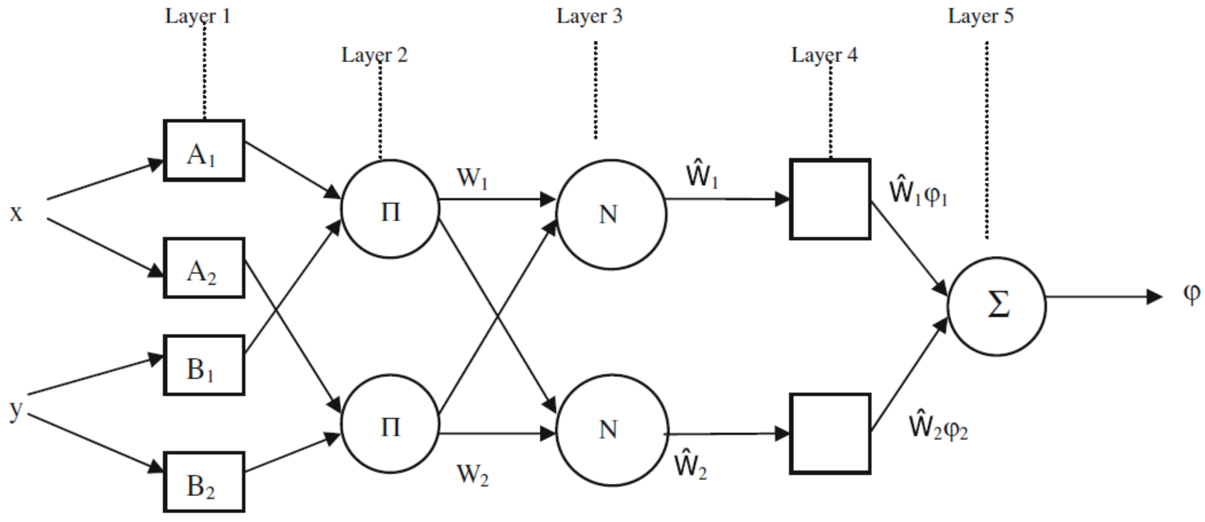

Figure 5.2 ANFIS structure [101]

Table 5.1 Description of the ''layers'' in ANFIS structure in Figure 5.2 [255]

Layer	Description
1	Every node i in this layer is a node with a node function representing the membership function $\mu A_i(x)$ of A_i and it specifies the degree to x which the given satisfies the quantifier A_i (i = 1, 2 here).
2	Every node in this layer is a node labeled Π which multiplies the incoming signals and sends the products out. Each node output represents the firing strength of a rule.
3	Every node in this layer is a node labeled N. The i-th node calculates the ratio of the i-th rule's firing strength to the sum of all rules' firing strengths (i = 1, 2 here).
4	Every node i in this layer is a node with a node function: $\hat{W}_i\varphi_i = \hat{W}_i\,(p_i\,x + q_i\,y + r_i)$ where $\hat{W}_i$ is the output of layer 3, and $(p_i + q_i + r_i)$ is the parameter set. Parameters in this layer will be referred to as consequent parameters (i = 1, 2 here).
5	The single node in this layer is a node labeled Σ that computes the overall output as the summation of all incoming signals.

The methodology for developing and validating the ANFIS framework involved three stages: data generation regarding input and output parameters, model construction, and model training and validation. For data generation stage, EV innovation policies (input parameters) of USA Japan, EU, Germany, France and UK were analysed and compared with the actual EV technology development (output parameter) that was measured by patent filings in those regions. Secondly, analysed policies and technology development rates were evaluated and linked based on years to create a data set. In the model construction stage, an empirical model was specified and the generated dataset was transformed into input-output data pairs. In the last stage, the data pairs were used for training and validating the ANFIS framework by using the MATLAB software. Each of these stages are described in more detail in following sections.

5.3 Data Generation

The initial step in the development of the ANFIS framework involved extensive collection of data regarding input and output parameters. EV innovation policies emerged after 1990s as a response to the environmental stress. This is a short term period to collect such extensive data. Besides, public policies aimed at promoting EV technologies have taken somewhat different forms in different countries [55, 83, 98-100] owing to differences in environmental, energy and, particularly, industrial goals. In order to address these issues, this study examined EV innovation policies of USA, Japan, EU, Germany, France and UK that had been introduced since 1990. These policies were then evaluated and linked with the actual technology development rates that were measured by patent filings in these regions to generate a data set as explained in the following sub-sections.

5.3.1 Input Parameters

To accelerate the formation of new EV based value chain and industrial structure governments might use several instruments. Before exploring these instruments, it is worthwhile to understand the nature of innovation and how it occurs. In this regard, theories about the drivers of innovation and implications on government policies for inducing technical change are discussed below.

5.3.1.1 Policy-induced Technical Change: Review and Hypotheses

Several theories have been developed to analyse and understand the nature of innovation and how it occurs in diffusion of technological innovations studies in literature. According to Rothwell [260], there are five historical generations of theories about how the innovation process occurs: *"technology-push, demand-pull, coupling model, interactive model and network model"*. However, some recent studies [261, 262] also describe "open innovation model" as another type of theory. These theories are discussed below.

The first and second generation models which are technology-push and demand-pull theories emerged after Solow`s work [263] explaining that technology plays an important role in economic growth, and Schumpeter and Usher`s studies [264, 265] describing the process of innovation as an evolutionary process of continuous development. Whereas the technology-push concept assumes that developments in scientific understanding determine the rate and direction of innovation [266], the demand-pull concept that was formulated by Schmookler [267] suggests that estimated market demand is the main driver of technical change as it incentivises research into new directions.

After the success of Manhattan Project that was a research and development (R&D) project resulted in the first atomic bombs during the Second World War, a very influential version of the “technology push” concept was expressed by Bush [266]. This concept which is also known as “post-war paradigm” or the “linear model” became prominent in 1950s. Studies supported this concept argued that *“knowledge progresses linearly from basic science to applied research to product development to commercial products”* [191]. Dosi [152] recognised this reasoning to several well-known aspects of the innovation process: *“the increasing importance of science in the innovation process, increasing complexity requiring a long-term view, strong relationships between R&D and innovative output, and the inherent uncertainty of the innovation process”.*

As a response to “technology push” concept, the second generation model which is also known as “demand-pull” concept emerged and it became very influential in 1960s [268]. According to this concept, rate and direction of innovation are driven by the demand since changing market circumstances create opportunities for companies to invest in innovation in order to satisfy unmet customer requirements. Hence, the reason for innovation is actually created by the demand as it “steers” companies to work on certain problems [269]. As a result, it was argued that “geographic variation in demand” [270], “the identification of potential demand” [267, 271] and markets [272] are reasons for investing in innovation.

Owing to the juxtaposition of these two theories, there were numerous research studies in 1970s. During those years, pure technology-push and demand-pull models of innovation were found extreme. Studies argued that whereas “technology push” concept ignored “market circumstances”, demand-pull concept ignored “technological capabilities” [260]. In those years, several studies also reached a consensus that a combination of technology-push and demand-pull factors is essential for the innovation as they closely interact [273-276]. Freeman [275] also explained that successful innovations demonstrated the ability to connect, or “couple” a technical opportunity with a market opportunity by conducting a survey of 40 innovations. Similarly, Mowery [273] claimed that it is theoretically complicated to differentiate a demand-pull situation from a technology-push one due to the interrelated nature of the curves of demand and supply. These arguments changed the "linear" aspect of the innovation models to the "sequential" character and it resulted in the emergence of the coupling theory which became dominant during the 1970s and early 1980s [260].

The coupling theory recognises the influence of technological capabilities and market needs within the framework of the innovating firm, and, hence, accepts interaction between different elements and feedback loops. One of the most well-known sequential innovation process models is the "Stage-Gate model" [277]. This model divides the product innovation process into stages with defined gates acting as decision points between the stages. At the end of each stage, there is a stage gate consisting of a phase review to evaluate whether the previous phase or stage was successfully completed. If the project is reviewed positively, work proceeds to the next phase. If not, then work continues or repeats within that phase until it can successfully pass the gate. However, this theory was criticised by some researchers as it was argued that the gates might be too rigorous, especially in the early stages of idea and concept generation. Besides, though such a sequential approach with evaluation gates improves the effectiveness and efficiency of incremental innovation processes, it is not found very useful for explaining radical innovations which are characterised by high uncertainty [261].

In 1980s, firm level capabilities were recognised for the progress of innovation. During those years, several research studies also examined the success of Japanese companies as they (especially the Japanese automobile and electronics industries) innovated more rapidly and efficiently than their Western competitors. Those studies found that successful Japanese companies integrated suppliers into the new product development process at an early stage while at the same time integrating the activities of the different in-house departments involved, who work on the project simultaneously (in parallel) rather than sequentially [260, 268]. This so-called "*rugby approach to new product development*" [260] influenced researchers towards the fourth generation innovation process model which is also known as the interactive approach. In this model, the innovation process is seen as parallel activities across organisational functions with the emphasis on the functional integration. This model therefore combines technology-push and demand-pull models and emphasises integration within firms and external linkages [261].

In 1990s, the discussion regarding innovation models continued as developed models failed to explain the whole innovation process. During those years, some studies stressed the significance of "feedbacks, interactions, and networks" during the innovation process [142, 274, 278]. Based on these ideas, Mowery and Cohen [279, 280] claimed that companies must invest in scientific knowledge to increase their "capacity to absorb" knowledge and exploit opportunities emerging from the "state-of-the-art" in another place. Another study also argued that adoption of one particular technology usually relies on other complementary innovations and the potential of one innovation might motivate investing in the other innovation [281]. Hence, *"the cumulativeness, networks, interactions and feedback effects on the progress of innovation"* was recognised [281]. Consequently, the fifth generation model which is also known as the network model emerged to explain the complexity of the innovation process. According to this approach, innovation happens within a network of internal and external stakeholders. Hence, establishing links between all the stakeholders are very significant [261].

However, the fifth generation models, as they were mainly closed networks of innovation, were also criticised. Traditionally, new business development processes and the marketing of new products took place within the firms. Besides, employees within the firm developed ideas internally and in secrecy. However, the internal and external ideas alongside internal and external paths to market rather than only focusing on internal idea generation and development are significant for today`s businesses. Hence, the sixth generation model or open innovation model recognising networking and collaboration for the progress of innovation emerged [261, 262]. One significant advantage of this model is that it suggests a much larger base of ideas and technologies from which to draw to drive internal growth. Besides, it is recognised as a strategic tool to explore new growth opportunities at a lower risk by leading companies [261].

In short, innovation models evolved from linear technology-push and demand-pull concepts to more complex models emphasising the internal and external factors. To reflect these changes, instruments used by the public organisations to influence technical change also developed. Besides, according to Loorbach [282] *"over the last decades, a shift from the centralised government-based nation-state toward liberalised, market–based, and decentralised decision-making structures was experienced, especially in Western countries. Hence, the power of central government to develop and implement policies in a top-down fashion has decreased, resulting in progressively diffuse* *policymaking structures and processes stratified across subnational, national, and supranational levels of government"* Rhodes [283] also states that *"such situation has drawn attention to an array of smart and soft governance instruments that are seen to allow governments to steer society towards transition targets instead of dictating a certain way of getting there".*

With those developments, there has been a reduction in the number of studies explaining the innovation with technology-push and demand-pull concepts in literature. Nevertheless, this dichotomy of technology-push and demand-pull are still used frequently in policy debates to analyse the effect of policy on innovation and, hence, to design innovation policies [81, 191, 284, 285]. Therefore, in this study, public policy instruments used to develop EV value chain were also examined under these headings.

5.3.1.2 Instruments as Tools to Support the Development of EV Value Chain

Application of the push–pull framework to policy decisions creates a classification differentiating government actions affecting the size of the market for a new technology from those influencing the supply of new knowledge directly. Governments can thus encourage innovation in two ways: *"they can implement measures (instruments) reducing the private cost of producing innovation, technology-push, and they can implement measures increasing the private payoff to successful innovation, demand-pull".* During the formulation and implementation of public policy, non-state and private corporate actors and networks might also involve [191].

Examples of technology-push policies include: "government sponsored R&D incentives, enhancing the capacity for knowledge exchange with public-private partnerships (PPPs), support for education and training, and funding demonstration projects". Conversely, examples of demand-pull policies include: "tax credits and subsidies for consumers of new technologies, government procurement, regulatory standards and taxes on competing technologies" [191]. These policies are often referred as "innovation policy instruments" in literature [286-289]. In that context, governments` role for inducing innovation in EV field might also be explained as actively influencing the demand and supply sides of EV market with "technology-push" and "demand-pull" (or "technology-pull") instruments [286].

Borrás and Edquist [288] argue that *"since instruments are used as tools to influence technical transitions by public organisations, the choice of policy instruments constitutes* *a part of the formulation of the policy, and the instruments themselves constitute part of the actual execution of the policy. This double nature of instruments recommends that it is significant to examine how they are chosen and the praxis concerning execution of the policy".*

They also explain that each policy instrument used by a government or public agency is unique. Instruments are usually chosen, designed and executed with a particular problem in mind, in a specific policy context (EV innovation policy in this case), at a certain point in time, and in a specific political–ideological situation of the government. The strong contextual nature of the choice and specification of policy instruments is a critical aspect in the design and use of policy tools. However, the uniqueness of policy instruments does not obstruct their taxonomy according to the logic behind public action [288].

Owing to the significance of instruments for designing innovation policies, there are several studies focusing on the typology of policy instruments in literature [87, 287-290]. According to Borrás and Edquist [288] such typologies provide two main benefits: (i) *"reducing the complexity of policy instruments"* (ii) *"providing a basis to define some beneficial criteria for the choice and design of instruments in the formulation phase of innovation policy".*

According to two recent studies [87, 287], the typology of policy instruments supporting the development of EV technologies might be explained as *"command and control (regulatory) instruments, economic instruments, procurement instruments, collaborative instruments, and communication and diffusion instruments".* Pal, Farrukh and Probert [290] also categorise instruments as *"regulation, expenditure, and information provision".* Similar to this typology, some other studies also claim that there are three main categories for policy instruments: (i) regulatory instruments, (ii) economic and financial instruments, and (iii) soft instruments [288, 289]. This three-fold typology of policy instruments is recognised as the "sticks", the "carrots" and the "sermons" of public policy instruments. As this typology is the most recognised in literature on innovation instruments, and continues to be the most regularly used in practical contexts [288], this typology was also adopted for this study.

The first type, regulatory instruments, uses legal tools for the regulation of market interactions [288] and they are implemented at a country wide level [87]. The rationality behind these instruments is *"the enthusiasm of the government to outline the frameworks* *of the interactions happening in the society and in the economy"* [288]. Although there are many different types of these instruments (laws, rules, directives, etc.) [288], the common feature of such instruments is that they enforce the stakeholders in EV system to provide products which are in compliance with quality or safety standards [87]. These measures are usually bundled with threats of sanctions such as fines or temporary withdrawal of rights in cases of non-compliance [288].

The second type, economic and financial instruments, provides specific financial incentives (encouraging, promoting) and/or disincentives (discouraging, restraining) and support specific social and economic activities [288]. For example, tax incentives or subsidies provide financial incentives to potential buyers and push the demand for EVs, hence increase the number of EVs and enable for scale economies in their production [87].

According to Borrás and Edquist [288] *"soft instruments are recognised as being non-coercive. With these instruments, governed actors are not subjected to obligatory measures, sanctions or direct incentives or disincentives by the government or its public agencies. Instead, these instruments provide recommendations, make normative appeals or offer voluntary or contractual agreements*". Examples of these instruments are "campaigns, codes of conduct, recommendations and PPPs". These instruments are very diverse, but mostly based upon persuasion, on the mutual exchange of information among actors, and on less hierarchical forms of cooperation between the public and the private actors. Such instruments take a coordinating role between manufacturers, researchers, authorities and customers. Some of these instruments also inform and educate the public in order to develop their interest for and acceptance of EVs [87]. The popularity of those instruments is rising especially in Europe and USA owing to the changes in the decision making structures in these regions. With the growing interest to these instruments, the role of government is also transformed from being a provider and regulator to being a coordinator and facilitator [288].

Governments` role for promoting innovation in EV field might therefore be explained as influencing the demand and supply sides of EV market with "technology-push" and "technology-pull" instruments that are collected under three headings: regulatory, economic and financial, and soft, as summarised in Table 5.2. In addition to the instruments that are defined by Browne et al. and Leurent and Windisch [87, 287], setting long-term goals and creating technology roadmaps were also added to the soft instruments package as mentioned in one of the recent reports [291]. Setting long term goals is significant for the industry since governments are accepted as being responsible for identifying a vision for the future and prioritising goals, which can then be translated into policy frameworks that can trigger industrial action [291]. Such goals might contain emission reduction and EV market diffusion targets. Similarly, technology roadmaps promote knowledge sharing and facilitate the development of a collective vision that can lead to action and collaboration [292-294]. As can be seen in Table 5.2, some instruments (i.e. network management and technology roadmaps) are classified as ”Technology Push/Pull” as these instruments might be used to support both supply and/or demand side. For example, technology roadmaps may be used to define future R&D projects required to develop critical vehicle technologies (supply side) or to describe infrastructure development plans (demand side) or they may be used to define both measures.

Table 5.2 Instruments for promoting innovation in EV field adapted from [87, 287]

Instruments for Promoting Innovation in EV Field	*Instrument Typology*	*Technology Push/Pull*
Tax incentives	Economic and Financial	Technology Pull
Subsidies, Staggered payment schemes	Economic and Financial	Technology Pull
Infrastructure Subsidies	Economic and Financial	Technology Pull
Purchase of EVs by the government	Economic and Financial	Technology Pull
Mandatory use in public sector fleet	Regulatory	Technology Pull
R&D investments for storage	Economic and Financial	Technology Push
R&D investments for infrastructure	Economic and Financial	Technology Push
Demonstration programmes	Soft	Technology Push
Infrastructure investments	Economic and Financial	Technology Pull
Public-private partnerships, Network management	Soft	Technology Push/Pull
Emissions regulations	Regulatory	Technology Push
Long term goals and visions, technology roadmaps	Soft	Technology Push/Pull
Traffic regulations (Free Parking, Bus lane access)	Regulatory	Technology Pull
Consistent codes and standards	Regulatory	Technology Pull
Market advertising, Eco-labelling of vehicles	Soft	Technology Pull
Awareness campaigns, Education and Training	Soft	Technology Push/Pull
Lobbying activities	Soft	Technology Pull
Targeting niche markets	Economic and Financial	Technology Push
Patent Regulations	Regulatory	Technology Push

In short, “technology push” and “technology pull” instruments summarised in Table 5.2 were used as input parameters for ANFIS framework. In order to gather data for those parameters, EV innovation policies of USA, Japan, EU, Germany, France and UK that had been introduced since 1990 were examined. Detailed information regarding these policies can be found in Appendix A.

5.3.2 Output Parameter

For measuring the innovative performance of a firm or an economy, patents have been used as a valuable source of information for researchers [295]. Although some studies have used production models and partnerships as technological indicators [23, 25, 28, 296, 297], patents have been accepted as a better indicator for actual technological development in literature [298-300] and they have been used as technological forecasting indicators [301, 302].

A patent contains the content of technical embodiments, technology classification codes, cited information and owner information [303]. Patents are not directly connected with products, but are distinguished primarily by their technical implications [94]. According to Pilkington, Dyerson and Tissier [37]:

"The use of patent information is gaining increasing attention in the fields of innovation and technology management. Patent data represent a valuable source of information that can be used to plot the evolution of technologies over time" ([37], p. 5).

Indeed, since most patent data are computerized, technical trends in detail [304, 305] technology levels, and commercial values might be understood with patent analysis [306, 307]. Besides, patents are available in large quantities in long time series allowing comprehensive analyses [298-300]. The innovative output and performance of countries, regions or technological fields might also be understood with patent applications [37, 308, 309]. Significantly, there are very few examples of economically significant inventions which have not been patented [310, 311].

However, it is significant to mention that patents do not truly represent the technological development of an artefact as there are other ways, such as secrets, know-how, time and cost required for duplication of the invention as well as learning curves. Furthermore, not all sectors use the patent as a way of protecting innovation, and the propensity to patent varies significantly across countries and industries. Yet, patent data is recognised as an important methodological tool to analyse technological development [312] and patent analysis is accepted as a representative technology prediction method in literature [37]. In that context, patents were chosen as output parameter for ANFIS framework. The details of data collection for this parameter are outlined below.

In this study, the focus was on 1990-2011 period as changes in the global agenda have resulted in policy measures supporting the transition from ICEV to BEV since the beginning of 1990s and patent data after 2011 were unreliable due to the eighteen month secrecy period before patent publication [28]. Patent filings during this period was also studied to examine the development of EV technologies in literature [313]. It was found that there are three distinguishing periods during 1990-2011 period: *"an R&D period (1990-2000), a period of inactivity (2000-2006) and a commercialisation period (2007-)"*. Over the timeframe 1990-2000, a strong increase in R&D activities regarding EV technologies with some production models which were mainly triggered by the California Air Resources Board`s (CARB) Zero Emission Vehicle (ZEV) mandate were identified. During the 2000-2006 period, automobile manufacturers only filed a small number of patent applications and introduced a few production models compared to previous period. However, during 2007-2011 period, high number of patents were filed and several EV models were introduced by automobile manufacturers indicating that automobile manufacturers considered EVs as a commercially viable opportunity [313].

For extracting and counting the patent data, different authorizing organizations and databases such as "The State Intellectual Property Office of the People's Republic of China" (SIPO), "the United States Patent and Trademark Office" (USPTO) and "the European Patent Office" (EPO) might be used [94]. In this study, EPO was used since it gives more results than other databases [37] and provides information about the published patents collected from 81 patent authorities worldwide [94] ensuring a comprehensive capture of technological development globally [28]. For counting the patent data, there is a fundamental difference between counting publications, applications or inventions. This decision is also highly related with considering different dates in patents that are (earliest) priority date, date of filing and date of the first publication. However, since a significant amount of patent documents did not provide information on patent grants at the time of indexing, this study used patent applications instead of patent grants. Similarly, this research used patent applications by the date of their worldwide first filing. In literature, patent applications by the date of their worldwide first filing were also used to demonstrate the EV technology development [28, 314].

EPO allows users to acquire patent data with different methods: theesp@cenet system, "Global Patent Index" program and "Worldwide Patent Statistical Database" (PATSTAT). In this study, PATSTAT was used as it creates tailor-made results allowing analysing and visualising of the data. PATSTAT also contains about 25 tables with bibliographic data, citations and family links of about 70 million applications of about 90 countries [315]. Moreover, PATSTAT provides a graphical user interface accepting SQL (structured query language) queries to acquire tailor-mode results. This study used SQL queries to acquire patent data. SQL queries are written by using the International Patent Classification (IPC) method. IPC is a hierarchical system of symbols which is globally used to systematically order all patents and utility models according to their technological area worldwide [94]. The advantage of the IPC classification is that it is application-based and thus facilitates identification of EV technology classes. The IPC is updated annually and revised every three years to capture technological change more effectively. Existing data are adjusted to the current version of the IPC, or put simply, it is "classified backwards" [316-318]. Two studies in literature also used IPC codes to measure the technology development of EVs [37, 94].

IPC Codes for EV Related Technologies were determined by using World Intellectual Property Organization (WIPO) website. The website was scanned thoroughly to gather IPC codes regarding EV technologies. Two possible types of error are possible when searching for relevant patents: inclusion of irrelevant patents and exclusion of relevant patents from the selected classifications [319]. In contrast to some other 'environmental' technologies, EV technologies have the advantage that these types of errors are largely minimised because the definition of the relevant patent classifications allows easy identification of the relevant patents. In WIPO website, EV technologies were defined under the B60L IPC code representing "propulsion of electrically-propelled vehicles" including several types of environmentally friendly vehicle technologies. By using this technology code and country codes, an SQL query was developed to capture EV technology development for each studied region. More information on the steps taken for search query construction can be found in the Appendix B.

5.3.3 Evaluation of Data regarding Input and Output Parameters

As explained in previous sections, "technology push" and "technology pull" instruments in six different regions were chosen as input parameters and patents were selected as the output parameter for the ANFIS framework. To create a data set for ANFIS framework, collected data for aforementioned parameters were evaluated and linked based on years as explained below.

5.3.3.1 Evaluation of Government Policies

As can be found in Appendix A, there are several "technology push" and "technology pull" instruments governments had used. These policies needed to be linked with patent filings in each region to create a data set. However, this required a method for comparing the relative performance of different innovation policies on EV technology development and converting the non-numeric qualitative data to numeric quantitative data. Hence, a key question was which methods could be used for the evaluation of policy instruments for EV technology development. This question is significant since Bovens [320] states that "*policy evaluation is an inherently normative act, a matter of political judgement*" (p. 319). To put it another way, when evaluating the effects of policy instruments, person assessing the instruments as well as the method used by the assessor is important [321]. In this regard, evaluation methods for policy instruments are described below.

In literature, evaluations of instruments are conducted by using "effectiveness" as evaluation criteria [322]. Hence, impact assessments are made based on the defined qualitative criteria [323]. For example, for evaluations of energy policy instruments, effectiveness was measured by analysis of impact of the policy instruments such as saved energy, installed capacity and reduced emissions. There are also evaluations considering policy instrument outcome and changes in, for example, technology development and in different actors' involvement and behaviour in literature. Thus, the use of parameters which can be defined as "outcome indicators" was introduced in the 1990s [324, 325]. For example, several indicators of impact for the energy field, such as environmental indicators, sustainability indicators, energy indicators and socio-ecological indicators have been developed.

Nevertheless, Neij and Åstrand [322] state that *"these types of evaluations in literature only provide limited information on the performance of different policy instruments and they focus on the results of policy implementation. Besides, these evaluations do not provide information on how policy instruments might affect technical development"*. Evaluations in literature are also based on particular characteristics of the evaluated instruments and they are not part of an integrated evaluation process [326]. Another issue is that a majority of those studies also focus on single policy instrument or policy ranking-order [327] although innovation policies usually involve the mix of several instruments. For EV technologies, there is a lack of research for evaluations of instruments.

However, one recent study which systematically reviewed 165 empirical, ex post studies examining policies that promote the development and use of low-carbon technologies assessed how different characteristics of policies affect *"ex post cost, process, and problem effectiveness, as well as accountability implications"* [321]. This study examined four main policy design characteristics: *"source of authority, type of instrument, policy target and stage of activity*". It was argued that these characteristics allowed them to better specify the way in which policy interventions sought to create behavioural change. For source of authority, two distinctions were made: "*public referring to instruments which are government-led and sanctioned, and hybrid referring to instruments originating from private authorities, such as businesses, partnerships, or multi-stakeholder collaborations*". For policy type, instruments were characterised as regulation, expenditure (financial), and information provision (soft). Besides, other policy characteristics, particularly: requirements for monitoring and compliance and the time frame of the policy were assessed. The third characteristic was mentioned as policy target and included citizens, firms, and governments as the main actors. The last characteristic was described as the stage of activity the policy targets: planning, acting and performance stages. *"Whereas planning referred to policies encouraging and/or requiring the target to change how and when it undertakes planning activities such as accident or mitigation plans, acting referred to policies encouraging and/or requiring the target to undertake specific activities in its operation. Here, the target's actual activities are being set by the policy. Performance also referred to policies that motivate and/or require the target to achieve particular outcomes, such as limiting emissions to some level per unit production"* [321].

For evaluating policies, four types of evaluation were considered, which are *"process, impact, efficiency and accountability implications"*. With each evaluation criteria, qualitative assessments of the overall conclusions were made as positive, mixed, or negative. Positive results captured instances when a study found a policy had led to success on one of the aforementioned forms of evaluation. Mixed results captured instances where the study noted both things that had gone well and things that were problems. Negative results referred to policies that did not attain their projected goals. After systematically reviewing studies, the overall positive results for the specified policy design characteristics were found as summarised in Table 5.3 [321]. As can be seen in Table 5.3, the results of the study might be used to quantitatively evaluate the policies based on the used instrument characteristics. However, one issue about this type of evaluation might be the types of policy instruments. This is because the instruments were evaluated based on the typology of the instruments (regulatory, expenditure, and information instruments) although each typology includes several different instruments as described in the previous section. Besides, each instrument has a different impact on the progress of innovation.

Table 5.3 Overall positive evaluation results for policies categorized according to different instrument characteristics adapted from [321]

Instrument Characteristics		*Positive Outcome Ratio*
Time-Frame	More than five years	0.5
	Less than five years	0.48
Reporting	Voluntary Reporting	0.05
	Mandatory Reporting	0.57
Policy Instrument	Information (Soft Instruments)	0.49
	Expenditure (Economic/Financial)	0.52
	Regulatory	0.44
Stage of Activity	Planning	0.54
	Performance	0.44
	Acting	0.57
Target of Policy	Industry or professional association	0.52
	Government	0.42
	Firm	0.48
	Citizen	0.52
Source of Authority	Threat of hierarchy	0.33
	Network coercion	0.41
	Market (customer demand)	0.55
	Hierarchy (state)	0.54

One recent study explains and evaluates potential barriers and policies for the development of EV technologies as in Table 5.4 [287]. In addition to the barriers that are defined by Browne et al. [287], difficulties of technology protection for SMEs as mentioned in the previous chapter were also included in Table 5.4. By integrating the instruments for promoting innovation in EV field that are described by Browne et al. and Leurent and Windisch [87, 287] with the significance of barriers explained in the study conducted by Browne et al. [287] and with the positive evaluation results of the policy instruments that were described by Auld et al. [321], Table 5.5 was created. As can be seen, the significance level of instruments was transformed to quantitative numbers: 1 for low significance, 2 for quite significant and 3 for highly significant in order to quantitatively evaluate the instruments. Those numbers were then multiplied with the positive outcome ratios that are displayed in Table 5.3 to create weight coefficients for each instrument. Table 5.6 presents the final evaluation guideline for EV innovation policy instruments.

Table 5.4 Evaluation of barriers for EVs adapted from [287]

Barrier Typology	*Barriers*	*Related Instruments*	*Significance*
Financial	Cost of alternative fuel	Tax incentives	Quite significant
Financial	Vehicle price	Subsidies, Tax Incentives, Staggered payment schemes	Quite significant
Financial	Cost of infrastructure	Infrastructure Subsidies	Quite significant
Financial	Production costs	Purchase of EVs by the government	Quite significant
Regulatory and legal	Production costs	Mandatory use in public sector fleet	Quite significant
Technical and market availability	Limited driving range	R&D investments for storage	Highly significant
Technical and market availability	Home or on-street charging	R&D investments for infrastructure	Highly significant
Public acceptability	Perceived reduction in comfort and safety	Demonstration programmes	Quite significant
Technical and market availability	Infrastructural challenges	Infrastructure investments	Highly significant
Institutional and administrative	Stakeholder resistance	Public-private partnerships , Network management	Quite significant
Technical and market availability	Availability of alternative fuels and vehicles	Emissions regulations	Highly significant
Regulatory and legal	Inconsistent or weak policy signals	Long term goals and visions, technology roadmaps	Low Significance
Public acceptability	Low level of visibility	Traffic regulations (Free Parking, Bus lane access)	Quite significant
Regulatory and legal	Lack of consistent regulatory standards	Consistent codes and standards	Low Significance
Technical and market availability	Inadequate marketing and promotion	Market advertising, Eco-labelling of vehicles	Low Significance
Public acceptability	Lack of awareness	Awareness campaigns, Education and training	Low Significance
Public acceptability	Inertia and scepticism among public	Lobbying activities	Quite significant
Financial, institutional and administrative	Inherent lock-in and path dependence	Targeting niche markets	Highly significant
Regulatory and legal	Difficulties of technology protection for SMEs	Patent Laws	Highly significant

Table 5.5 Evaluation of instruments for EVs

Barriers	*Related Instruments*	*Instrument Typology*	*Significance*	*Weight Coefficients*	*Technology Push/Pull*
Cost of alternative fuel	Tax incentives	Economic and Financial	2	1.04 (2*0.52)	Technology Pull
Vehicle price	Subsidies, Tax Incentives, Staggered payment schemes	Economic and Financial	2	1.04 (2*0.52)	Technology Pull
Cost of infrastructure	Infrastructure Subsidies	Economic and Financial	2	1.04 (2*0.52)	Technology Pull
Production costs	Purchase of EVs by the government	Economic and Financial	2	1.04 (2*0.52)	Technology Pull
Production costs	Mandatory use in public sector fleet	Regulatory	2	0.88 (2*0.44)	Technology Pull
Limited driving range	R&D investments for storage	Economic and Financial	3	1.56 (3*0.52)	Technology Push
Home or on-street charging	R&D investments for infrastructure	Economic and Financial	3	1.56 (3*0.52)	Technology Push
Perceived reduction in comfort and safety	Demonstration programmes	Soft	2	0.98 (2*0.49)	Technology Push
Infrastructural challenges	Infrastructure investments	Economic and Financial	3	1.56 (3*0.52)	Technology Pull
Stakeholder resistance	Public-private partnerships, Network management	Soft	2	0.98 (2*0.49)	Technology Push/Pull
Availability of alternative fuels and vehicles	Emissions regulations	Regulatory	3	1.32 (3*0.44)	Technology Push
Inconsistent or weak policy signals	Long term goals and visions, technology roadmaps	Soft	1	0.49 (1*0.49)	Technology Push/Pull
Low level of visibility	Traffic regulations (Free Parking, Bus lane access)	Regulatory	2	0.88 (2*0.44)	Technology Pull
Lack of consistent regulatory standards	Consistent codes and standards	Regulatory	1	0.44 (1*0.44)	Technology Pull
Inadequate marketing and promotion	Market advertising, Eco-labelling of vehicles	Soft	1	0.49 (1*0.49)	Technology Pull
Lack of awareness	Awareness campaigns, Education and training	Soft	1	0.49 (1*0.49)	Technology Pull
Inertia and scepticism among public	Lobbying activities	Soft	2	0.98 (2*0.49)	Technology Pull
Inherent lock-in and path dependence	Targeting niche markets	Economic and Financial	3	1.56 (3*0.52)	Technology Push
Difficulties of technology protection for SMEs	Patent Laws	Regulatory	3	1.32 (3*0.44)	Technology Push

Table 5.6 Weight coefficients for the evaluation of EV innovation policy instruments

Weight Coefficients for the Evaluation of EV Innovation Policies		
	Instrument Characteristics	*Weight Coefficients*
Time-Frame	More than five years	0.5
	Less than five years	0.48
Reporting	Voluntary reporting	0.05
	Mandatory reporting	0.57
Policy Instruments for EVs	Tax incentives	1.04
	Subsidies, tax incentives, staggered payment schemes	1.04
	Infrastructure subsidies	1.04
	Purchase of EVs by the government	1.04
	Mandatory use in public sector fleet	0.88
	R&D investments for storage	1.56
	R&D investments for infrastructure	1.56
	Demonstration programmes	0.98
	Infrastructure investments	1.56
	Public-private partnerships, Network management	0.98
	Emissions regulations	1.32
	Long term goals and visions, technology roadmaps	0.49
	Traffic regulations (free parking, bus lane access)	0.88
	Consistent codes and standards	0.44
	Market advertising, eco-labelling of vehicles	0.49
	Awareness campaigns, education and training	0.49
	Lobbying activities	0.98
	Targeting niche markets	1.56
	Patent Laws	1.32
Stage of Activity	Planning	0.54
	Performance	0.44
	Acting	0.57
Target of Policy	Industry or professional association	0.52
	Government	0.42
	Firm	0.48
	Citizen	0.52
Source of Authority	Threat of hierarchy	0.33
	Network coercion	0.41
	Market (customer demand)	0.55
	Hierarchy (state)	0.54

Overall, by using the Table 5.6 as an instrument evaluation guideline, EV innovation policies of selected regions (Appendix A) were evaluated to calculate the relative performance index (RPI) of technology push and pull levels of different innovation policies. Such an index was created to compare the different innovation policies and convert the non-numeric qualitative data into a form which is able to be used for ANFIS framework.

5.3.3.2 Evaluation of the Development of EV technologies

For examining technology diffusion and substitution, growth curve models such as the logistic curve model or simply the well-known S-curve are used significantly in literature [328-333] as technology adoption typically occurs in an S curve, as modelled in diffusion of innovations theory [334]. The method is helpful for estimating the level of technological growth or decline at each stage in the lifecycle and in predicting when a technology will reach a particular stage. Moreover, S-curve can be used to model the adoption of a new product or technology. To use S-curve, many studies use the cumulative patent data and fit a growth curve to a dataset of technological performance as S-curve depicts the cumulative normal distribution. Figure 5.3 displays the S-curve concept and patent activities over the technological lifecycle, which has four developmental stages [334]. Although EV technologies are emerging technologies, the development of those technologies is expected to follow a similar trend. In this study, cumulative patent data was also used to evaluate the development of EV technologies in different regions.

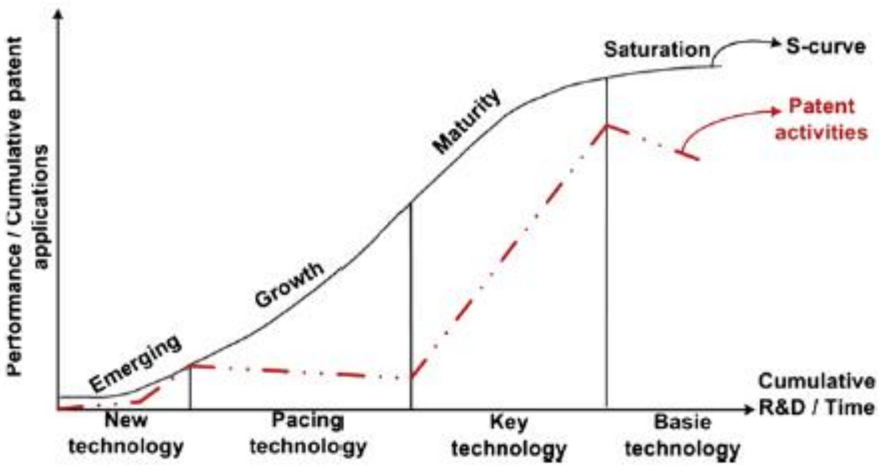

Figure 5.3 Scheme of integration for technological S-curve and patent activities [335]

5.3.4 Generated Data

In previous sections, it was discussed that, “technology push” and “technology pull” instruments were chosen as input parameters and patents were selected as the output parameter for the ANFIS framework. To create a data set for ANFIS framework, an instrument evaluation guideline was developed to calculate the RPI of push and pull levels of different innovation policies. Besides, since technological growth typically displays an S-curve, cumulative patent data was used to evaluate the development of EV technologies in different regions. The evaluated data regarding input and output parameters was then linked based on years.

Table 5.7 displays the final results. The evaluation results closely parallel the stated policy objectives of the regions and the development of those policy objectives over time, with the UK and France demonstrating more of a balance between the intensity of the technology push and pull policies, whilst Germany, USA and the EU show a bias towards the technology push in line with their stated support of industrial growth.

Table 5.7 Generated data for ANFIS use

Year	*UK*			*France*			*Germany*			*EU*			*USA*			*Japan*		
	Push	*Pull*	*Patents*	*Push*	*Pull*	*Patents*	*Push*	*Pull*	*Patents*	*Push*	*Pull*	*Patents*	*Push*	*Pull*	*Patents*	*Push*	*Pull*	*Patents*
1990	0.00	0.00	11	0.00	0.00	14	0.00	0.00	113	0.00	0.00	60	7.44	7.45	84	3.55	0.00	761
1991	0.00	0.00	23	3.06	0.00	34	0.00	0.00	271	0.00	0.00	131	15.09	10.87	185	6.71	0.00	1645
1992	0.00	0.00	43	3.06	3.52	66	0.00	0.00	468	0.00	0.00	224	18.64	14.35	339	15.23	0.00	2677
1993	0.00	0.00	65	3.06	3.52	99	0.00	0.00	706	0.00	0.00	326	22.90	17.87	500	19.49	4.26	3770
1994	0.00	0.00	84	3.06	3.52	127	0.00	0.00	960	4.24	0.00	428	22.90	17.87	738	19.49	4.26	4690
1995	0.00	0.00	108	3.06	5.99	161	0.00	0.00	1165	4.24	0.00	518	22.90	17.87	970	19.49	7.90	5669
1996	0.00	0.00	122	3.06	5.99	199	0.00	0.00	1448	4.24	0.00	642	22.90	17.87	1218	23.04	11.62	6589
1997	0.00	0.00	149	3.06	9.41	224	0.00	0.00	1739	4.24	0.00	801	22.90	17.87	1471	27.30	11.62	7641
1998	0.00	0.00	176	3.06	9.41	256	0.00	0.00	2033	11.72	0.00	966	22.90	17.87	1737	31.19	15.36	8865
1999	0.00	0.00	197	3.06	9.41	300	0.00	0.00	2357	11.72	0.00	1174	26.42	17.87	1998	34.85	15.36	10058
2000	0.00	3.19	206	3.06	12.60	338	0.00	3.19	2746	11.72	3.19	1403	26.42	21.06	2407	38.01	18.50	11234
2001	0.00	3.19	239	3.06	12.60	381	0.00	3.19	3155	11.72	3.19	1696	30.66	21.06	2844	41.17	22.12	12567
2002	0.00	3.19	264	7.30	12.60	432	0.00	3.19	3583	15.96	3.19	1956	33.82	21.06	3398	41.17	22.12	13904
2003	3.52	3.19	293	7.30	12.60	509	0.00	3.19	3993	19.61	3.19	2251	37.95	21.06	3979	44.69	22.12	15622
2004	3.52	3.19	317	7.30	12.60	578	0.00	3.19	4323	23.26	3.19	2497	37.95	21.06	4661	44.69	25.31	17272
2005	7.04	6.38	341	10.82	12.60	642	4.26	3.19	4602	26.42	3.19	2775	37.95	24.80	5421	48.58	25.31	19000
2006	7.04	6.38	357	10.82	15.79	696	8.39	3.19	4873	26.42	3.19	3092	37.95	24.80	6093	48.58	25.31	20948
2007	14.82	9.89	386	13.98	15.79	759	19.20	3.19	5171	34.10	6.93	3487	41.84	24.80	6764	56.34	25.31	23158
2008	22.23	9.89	421	22.11	23.27	831	22.57	3.19	5480	49.38	6.93	3900	54.56	24.80	7398	56.34	25.31	25779
2009	36.97	17.26	457	36.48	23.27	915	38.84	6.93	5786	56.43	6.93	4359	69.02	35.90	7966	64.12	29.05	28389
2010	40.49	21.00	503	40.74	33.81	1017	55.49	13.25	6324	59.59	17.91	5049	73.28	35.90	8673	81.72	43.38	31272
2011	40.5	36.38	545	40.74	37.55	1184	55.49	13.25	7026	62.75	20.97	6047	77.04	42.61	9407	81.72	43.38	34667

5.4 ANFIS Model Construction

The second step for developing an ANFIS model involved model specification. Although inputs and output parameters were determined and necessary data set for these parameters was generated, these parameters needed to be linked with a logical connection to create input-output data pairs for training and learning from the data.

Based on the inputs and output parameters that were explained in previous sections, the following equation was specified for developing an ANFIS model:

$$\text{Totalpatents}_{i,t} = \beta_1\text{Totalpatents}_{i,t-1}+\beta_2\text{TechnologyPush}_{i,t-1}+\beta_3\text{TechnologyPull}_{i,t-1}+\varepsilon_{i,t-1}$$

where *i* indexes country and *t* indexes year. The dependent variable is measured by the number of cumulative patent applications in EV technologies, which was described in the previous section. TechnologyPush and TechnologyPull account for the intensity of the technology push and pull activities of studied regions' EV policy regimes that are measured by RPI. It is very significant to control statistically for differences in the tendency to innovate and patent across countries [336]. In order to capture the effect of such factors for EV technologies, this study standardised the number of cumulative patent applications and included the variable $\text{Totalpatents}_{i,t-1}$ reflecting the total number of patent applications filed in the previous year. Whereas standardising the patent applications controlled differences in the effects of the size of a region's research capacity on innovation and served as a "scale", the $\text{Totalpatents}_{i,t-1}$ variable served as a "trend" variable and controlled the changes in general propensity to patent over time and across countries. All the residual variation is also captured by the error term ($\varepsilon_{i,t-1}$). Since ANFIS is capable of assigning the weights (β_1, β_2 and β_3) and calculating the error automatically with its hybrid learning algorithm, x_1, x_2 and x_3 are introduced to represent the $\text{Totalpatents}_{i,t-1}$, $\text{TechnologyPush}_{i,t-1}$ and $\text{TechnologyPull}_{i,t-1}$ respectively as inputs of the model. Similarly, $\text{Totalpatents}_{i,t}$ is represented by an output vector ***y*** in ANFIS model with respect to the input parameters (x_1, x_2 and x_3) set ***I***, and their corresponding membership functions, set ***S***. Hence, ***y=F(I, S)*** is formulated. More information about the standardisation of the data is given as below:

In the model, there is a big difference among the cumulative patent applications (different scales) in different regions as can be seen in Table 5.7. The differences in patent numbers arise from the government`s efforts (policy level intervention) as well as the capability and the will of the automobile industry (firm level decisions and competition among players) to develop the EV industry in the studied regions. Therefore, it is highly technology driven and culture plays only a limited role in terms of the development of EV technologies in different regions. The policy level interventions in different countries depend on "*levels of environmental ambition, technological preferences, market regulations and the significance attached to expected co-benefits such as exploiting green jobs, energy security and industrial growth*". Specifically, *"industrial structure and presence of incumbent firms, national policy priorities to improve environmental performance and distance from the technological frontier and size of the market"* are significant factors determining the paths followed in different countries [76]. In terms of firm level decisions, recent studies found that companies` business strategies for introducing innovations for a particular technology such as EV are determined by companies` incentives and opportunities [313, 337, 338].

Among studied regions, the highest number of patent applications were achieved in Japan. Japan is indeed technology leading in the area of EVs since Japan was among the first countries to invest heavily in battery research and EVs. The Japanese government aimed to improve fuel efficiency, decrease CO_2 emissions, diversify the energy mix, and introduce next-generation vehicles to the market on a full-scale basis. By doing so, the country's economy and employment are aimed to be improved [87]. Hence, the Japanese government aimed to affect the direction of technology development by setting long-term goals and delivering ambitious market development plans for EVs [86]. Japanese manufacturers such as Toyota, Honda and Nissan also invested heavily in EVs. Toyota, for example, is a global leader in hybrid vehicles. Those companies` move to electrification was motivated by policy support as well as the strong product development capability of those companies [213]. Japanese car manufacturers` tradition of following each other closely also contributed to the development of EV technologies in Japan [213].

USA also achieved a high number of patent filings since California Air Resources Board`s (CARB) technology forcing regulation called Zero Emission Vehicle (ZEV) mandate, introduced in 1990 compelled the seven big car manufacturers in terms of California sales to introduce EVs for an increasing part of their vehicle sales [339]. The later interventions of the government also aimed to ensure the future viability of the domestic automotive industry [86]. However, although German government followed a careful strategy and started implementing policies later than Japan and USA since the country`s economy is highly dependent on the automotive industry which is threated by a transition from ICEVs towards EVs, Germany also achieved a high number of patent filings. This is because the German automotive industry is the main driving force when it comes to the organisation and financing of R&D activities and it seems that German companies also invested in EVs to be competitive in the emerging EV industry. Indeed, previous studies demonstrated that competition plays a significant role in an innovation system [28, 56, 64, 65, 140, 213, 340-343] and some studies found that when competition increases, technological development increases as well [65, 342] and this is applicable to EV technology development [28, 213, 343].

However, differences among the cumulative patent applications might cause a possible distortion in the model. Hence, normalisation or standardisation of the data was required to bring all of the variables into proportion with one another and to make fair comparisons among them. By doing so, the ANFIS model would be better behaved since the patent data would be approximately equivalent. Technically, whether normalised/standardised, the coefficients associated with each variable will scale appropriately to adjust for the disparity in the variable sizes. Nevertheless, if normalised/standardised, then the coefficients will reflect meaningful relative activity between each variable. For example, a positive coefficient will mean that the variable acts positively towards the objective function, and vice versa, plus a large coefficient versus a small coefficient will reflect the degree to which that variable influences the objective function. While the coefficients from un-normalised/un-standardised data will reflect the positive/negative contribution towards the objective function, it will be more difficult to interpret in terms of their relative impact on the objective function.

Although both standardisation and normalisation produce identical results in terms of relative activity between each variable, this study used the standardisation method as it produces meaningful information about each data point, and where it falls within its normal distribution, plus it provides a crude indicator of outliers (i.e., anything above or below a Z-Score of ±4). Moreover, although normalisation bounds the data in the range [0, 1], standardisation does not bind the data. Standardisation of patent data has been conducted in literature as well [344] to compare different regions. Hence, the cumulative patent applications in each region was standardised by subtracting its mean from each of its values and then dividing these new values by the standard deviation of the variable. Table 5.8 displays the standardised coefficients (beta coefficients) of the cumulative patent applications with RPIs. As can be seen, the dataset is transformed into input-output data pairs**.**

Table 5.8 Input-output data pairs for ANFIS model

Year	United Kingdom				France				Germany				European Union				United States				Japan			
	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y
1990	-1.40	0.00	0.00	-1.40	-1.30	0.00	0.00	-1.20	-1.40	0.00	0.00	-1.30	-1.10	0.00	0.00	-1.10	-1.20	7.44	7.45	-1.10	-1.30	3.55	0.00	-1.20
1991	-1.40	0.00	0.00	-1.20	-1.20	3.06	0.00	-1.10	-1.30	0.00	0.00	-1.20	-1.10	0.00	0.00	-1.00	-1.10	15.09	10.87	-1.10	-1.20	6.71	0.00	-1.10
1992	-1.20	0.00	0.00	-1.10	-1.10	3.06	3.52	-1.00	-1.20	0.00	0.00	-1.10	-1.00	0.00	0.00	-1.00	-1.10	18.64	14.35	-1.00	-1.10	15.23	0.00	-1.00
1993	-1.10	0.00	0.00	-1.00	-1.00	3.06	3.52	-0.90	-1.10	0.00	0.00	-1.00	-1.00	0.00	0.00	-0.90	-1.00	22.90	17.87	-0.90	-1.00	19.49	4.26	-0.90
1994	-1.00	0.00	0.00	-0.80	-0.90	3.06	3.52	-0.80	-1.00	0.00	0.00	-0.90	-0.90	4.24	0.00	-0.90	-0.90	22.90	17.87	-0.90	-0.90	19.49	4.26	-0.80
1995	-0.80	0.00	0.00	-0.70	-0.80	3.06	5.99	-0.70	-0.90	0.00	0.00	-0.80	-0.90	4.24	0.00	-0.80	-0.90	22.90	17.87	-0.80	-0.80	19.49	7.90	-0.70
1996	-0.70	0.00	0.00	-0.60	-0.70	3.06	5.99	-0.60	-0.80	0.00	0.00	-0.60	-0.80	4.24	0.00	-0.70	-0.80	22.90	17.87	-0.70	-0.70	23.04	11.62	-0.60
1997	-0.60	0.00	0.00	-0.40	-0.60	3.06	9.41	-0.50	-0.60	0.00	0.00	-0.50	-0.70	4.24	0.00	-0.60	-0.70	22.90	17.87	-0.60	-0.60	27.30	11.62	-0.50
1998	-0.40	0.00	0.00	-0.30	-0.50	3.06	9.41	-0.40	-0.50	0.00	0.00	-0.40	-0.60	11.72	0.00	-0.50	-0.60	22.90	17.87	-0.50	-0.50	31.19	15.36	-0.40
1999	-0.30	0.00	0.00	-0.20	-0.40	3.06	9.41	-0.30	-0.40	0.00	0.00	-0.20	-0.50	11.72	0.00	-0.30	-0.50	26.42	17.87	-0.40	-0.40	34.85	15.36	-0.30
2000	-0.20	0.00	3.19	0.00	-0.30	3.06	12.60	-0.20	-0.20	0.00	3.19	0.00	-0.30	11.72	3.19	-0.20	-0.40	26.42	21.06	-0.20	-0.30	38.01	18.50	-0.10
2001	0.00	0.00	3.19	0.10	-0.20	3.06	12.60	0.00	0.00	0.00	3.19	0.20	-0.20	11.72	3.19	0.00	-0.20	30.66	21.06	-0.10	-0.10	41.17	22.12	0.00
2002	0.10	0.00	3.19	0.30	0.00	7.30	12.60	0.20	0.20	0.00	3.19	0.40	0.00	15.96	3.19	0.20	-0.10	33.82	21.06	0.10	0.00	41.17	22.12	0.20
2003	0.30	3.52	3.19	0.50	0.20	7.30	12.60	0.40	0.40	0.00	3.19	0.60	0.20	19.61	3.19	0.30	0.10	37.95	21.06	0.40	0.20	44.69	22.12	0.30
2004	0.50	3.52	3.19	0.60	0.40	7.30	12.60	0.60	0.60	0.00	3.19	0.70	0.30	23.26	3.19	0.50	0.40	37.95	21.06	0.60	0.30	44.69	25.31	0.50
2005	0.60	7.04	6.38	0.70	0.60	10.82	12.60	0.70	0.70	4.26	3.19	0.80	0.50	26.42	3.19	0.60	0.60	37.95	24.80	0.80	0.50	48.58	25.31	0.70
2006	0.70	7.04	6.38	0.90	0.70	10.82	15.79	0.90	0.80	8.39	3.19	1.00	0.60	26.42	3.19	0.90	0.80	37.95	24.80	1.10	0.70	48.58	25.31	0.90
2007	0.90	14.82	9.89	1.10	0.90	13.98	15.79	1.10	1.00	19.20	3.19	1.10	0.90	34.10	6.93	1.10	1.10	41.84	24.80	1.30	0.90	56.34	25.31	1.20
2008	1.10	22.23	9.89	1.30	1.10	22.11	23.27	1.40	1.10	22.57	3.19	1.30	1.10	49.38	6.93	1.40	1.30	54.56	24.80	1.50	1.20	56.34	25.31	1.40
2009	1.30	36.97	17.26	1.60	1.40	36.48	23.27	1.70	1.30	38.84	6.93	1.50	1.40	56.43	6.93	1.80	1.50	69.02	35.90	1.70	1.40	64.12	29.05	1.70
2010	1.60	40.49	21.00	1.90	1.70	40.74	33.81	2.20	1.50	55.49	13.25	1.80	1.80	59.59	17.91	2.40	1.70	73.28	35.90	1.90	1.70	81.72	43.38	2.10

Nonetheless, as discussed before, developing an ANFIS framework requires extensive data collection to learn from the data. Even though six regions were included to the study, the data presented in Table 5.8 was still limited. In order to create additional data sets, the regions were combined with each other. Yet, in order to prevent a possible distortion in the model, only regions with similar number of cumulative patent applications (similar scales) were combined. Appendix C exhibits all generated data sets.

5.5 Training and Validating the ANFIS Model

The final stage involved training and validating the model with MATLAB software. As discussed before, training involved learning from the data to discover the optimum operating point. When the training was completed, the model needed to be validated since the training phase captured both useful information contained in the given data set and unwanted noise. Thus, a set of new data that had not been employed for the training was used to compare the output. More information about steps involved for training and validating the model are given below.

Training the model started with creating a suitable FIS for the data. For FIS generation, model has three selections, which are designed FIS, Grid Partition and Subtractive Clustering. Grid partition divides the data space into rectangular subspaces using axisparalleled partition based on pre-defined number of membership functions and their types in each dimension [345]. Grid portioning method was used in this study as FIS is generated automatically with this method. Three Gaussian membership functions (low, moderate and high) were chosen for each input and output membership type was chosen as constant rather than linear as standardised values of cumulative patent applications were not linear.

Based on the generated FIS, the ANFIS architecture was developed. The developed ANFIS model structure with 3 input neurons and 1 output neuron along with 4 hidden layers (input membership function, rule base, membership function, and aggregated output) is illustrated in Figure 5.4. Each of input neuron is connected to three fuzzy rules. The hidden layers contain 27-27 neurons to deal the problem (for selection of the proper rule base, because the rule base are written randomly in fuzzy, the neural network selects the right optimal rule base to fire). The 3 input neurons, viz., the error, change in error is given as input to the 1st hidden layer of the ANN as shown in the Figure 5.4. This 1st hidden layer deals with various input membership functions. In the 2nd and 3rd hidden layer, the set of 27 fuzzy rules are properly identified by training and the set of optimal rules are selected. These set of optimum rules are available at the 4th hidden layer. Out of the 27 rules, the optimal rules are fired here & the de-fuzzified output is obtained as the output neuron.

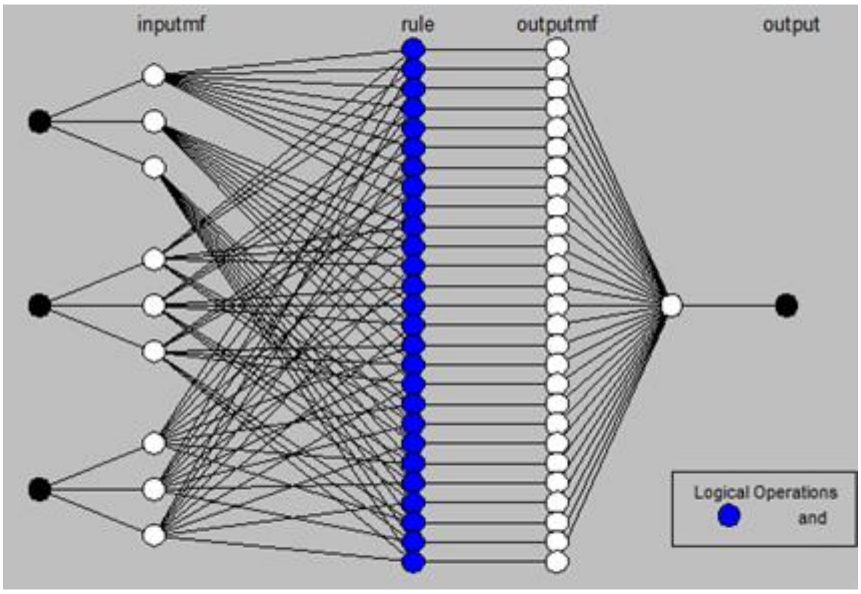

Figure 5.4 ANFIS model structure

For training and validating the model, data pairs (18 data sets) presented in Appendix C were used. In literature, usually, eighty percent of the generated data set is chosen for training and the rest of the data is used for checking the model [346]. In this respect, this study followed the same pathway stated in literature for training and validating the model. The hybrid learning algorithm that is the combination of the gradient descent and least square estimates was selected for learning algorithm as the hybrid learning approach converges much faster by reducing search space dimensions than the original back-propagation method [101]. There are two phases to the hybrid learning algorithm: a forward pass followed by a reverse pass. In the forward pass of the hybrid learning, node outputs go forward until layer 4 and the consequent parameters are identified with the least square method. The current output of the network is compared with the target or desired output and the "error" ($\varepsilon_{i,\, t-1}$) is determined. In the backward pass, the error rates propagate backward and the premise parameters are updated by gradient descent [101].

After setting the training error tolerance to zero and training epochs to 210 (lowest error was achieved on 210 epochs), training error and checking error were obtained as 0.036 and 0.052 respectively as displayed in Figure 5.5. These numbers represent the average errors based on the standard deviation from the real numbers as cumulative patent filings were standardised. The results of the ANFIS model testing with training and checking data are also displayed in Figure 5.6 and Figure 5.7 respectively. The 14 data sets in Figure 5.6 and 4 data sets in Figure 5.7 represent the share of 18 data sets (eighty percent of the generated data set was chosen for training and the rest of the data was used for checking the model) in Appendix C.

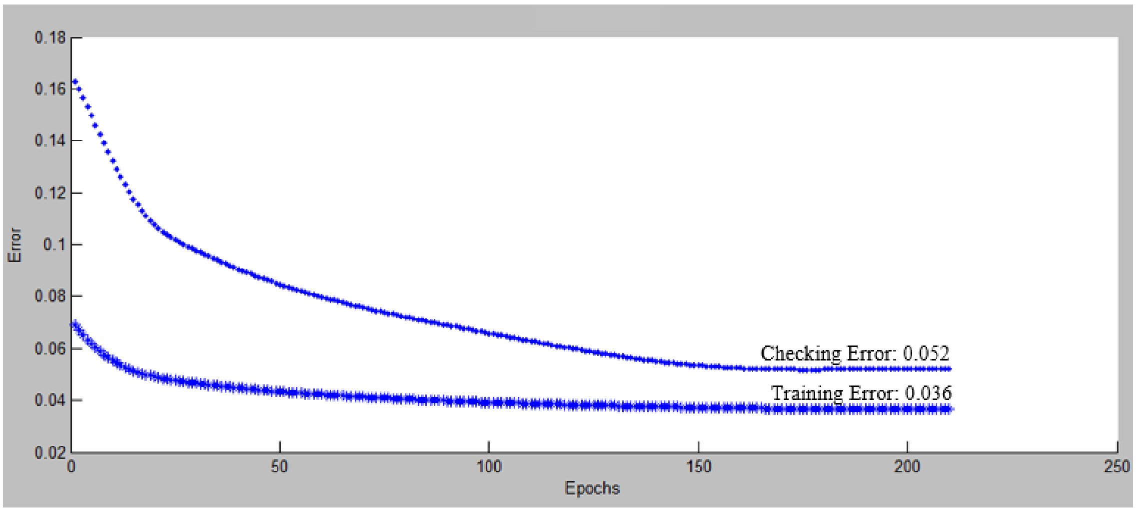

Figure 5.5 Training and checking errors during training

For training and checking the ANFIS network, the criteria is minimising the error. The main criteria regarding the outcome to be satisfactory is analysing the testing error plots to see whether or not the checking data performed sufficiently well with the trained model. When Figure 5.6 and Figure 5.7 are examined, it can be seen that data performed sufficiently well with the trained model since ANFIS predicted values were close to the checking data representing a satisfactory outcome for the developed framework.

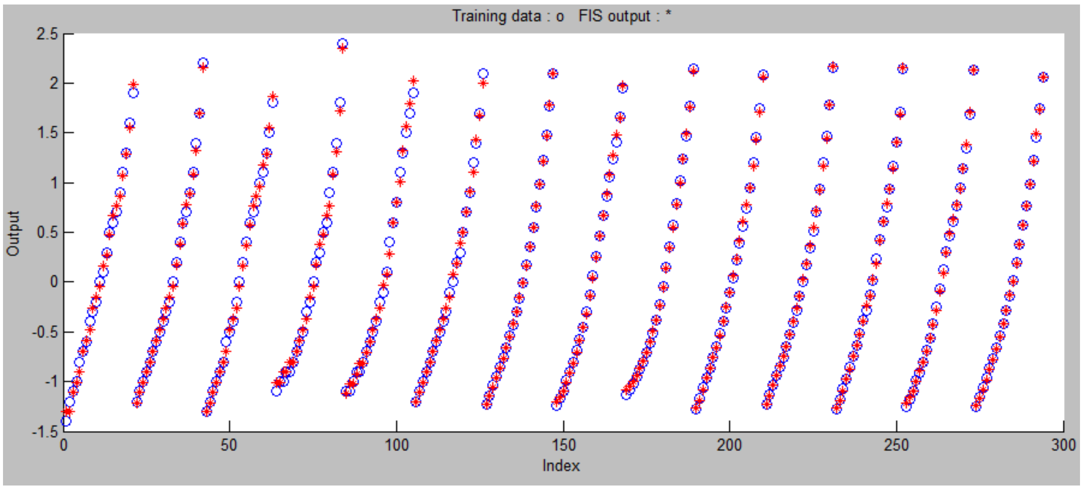

Figure 5.6 Result of the ANFIS model testing with training data

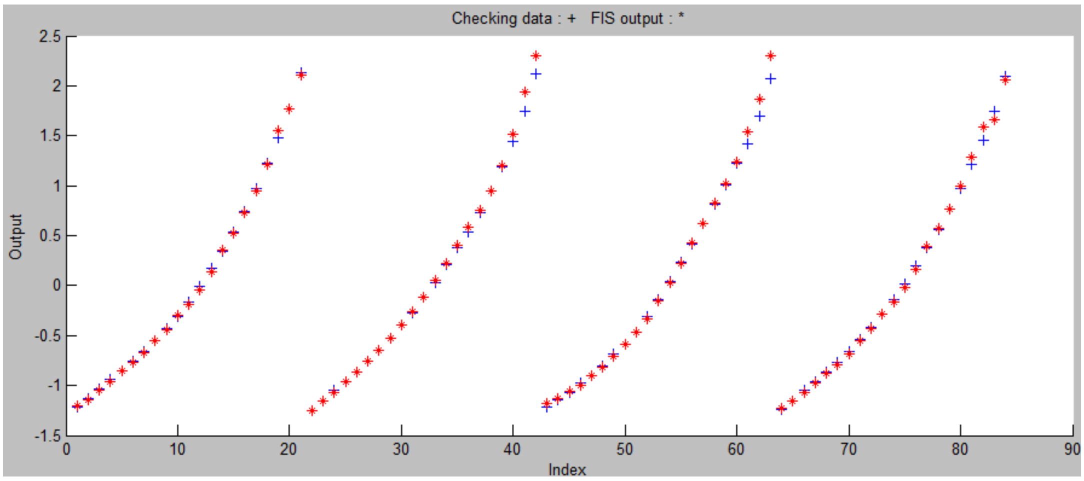

Figure 5.7 Result of the ANFIS model testing with checking data

The result presented above serves as an illustration in that ANFIS algorithm can be a reasonable approach to predict the EV technology development rates (in terms of number of patent filings) based on government interventions.

5.6 Conclusions

A transition from ICEVs to BEVs involves changes in the whole automotive value chain including substantial changes in the industrial structure. To accelerate the development of new EV value chain and industrial structure, target instruments need to be used by governments. Aligned with such perspective, national governments are increasingly forming suites of policy measures to encourage EV technologies in the automotive sector. The emergence of a diverse array of policy measures, along with the increasingly apparent need for urgency in achieving a transition to EVs, means that ex-post analysis is increasingly inadequate to the task of guiding the effective choice of policy interventions. To support national governments in making informed decisions, an ANFIS framework providing an ex-ante impact of various innovation decisions was therefore developed in this chapter. The following conclusions were made:

- ANFIS might be more appropriate for modelling highly complex nonlinear relationships such as government interventions for inducing EV technologies than traditional statistical models owing to its capability for manipulating vague and imprecise data, and for using qualitative terms rather than numbers.
- Although innovation models evolved from linear technology-push and demand-pull concepts to more complex models, they are still used to investigate the impact of policy on technology innovation and, hence, to design innovation policies [81, 191, 284, 285]. Developed model is therefore significant and it fills a gap in literature since none of the studies in literature examined the impact of technology-push and demand-pull policies on EV technology development.
- There was a gap in literature for evaluating the EV policy instruments on technical change. To evaluate the policies as well as compare the relative performance of different innovation policies in different regions on EV technology development, an evaluation guideline was developed by integrating the results of previous studies [87, 287, 321].
- A significant amount of data regarding EV innovation policies in different regions were collected. The evaluation results were closely similar to the specified policy objectives of the regions and the development of those policy objectives over time. UK and France demonstrated more of a balance between the intensity of the technology push and pull policies, whereas Germany, USA, Japan and the EU showed a bias towards the technology push in line with their stated support of industrial growth.

- Acquiring patent data with SQL codes which was written by using the B60L IPC code as well as country codes was found useful since it allowed having tailor made results (patent filings regarding propulsion of EVs based on years).
- A big difference among the cumulative patent applications in studied regions was found. The differences arise from the government`s efforts (policy level intervention) as well as the capability and the will of the automobile industry (firm level decisions and competition among players) to develop the EV industry in the studied regions. Therefore, it is highly technology driven and culture plays only a limited role in terms of the development of EV technologies in different regions.
- The training and validation of the proposed ANFIS framework shows that the model is able to predict the development of EV technologies in terms of patent filings based on used government instruments.

CHAPTER 6 - ANFIS MODEL APPLICATION TO AUSTRIAN INNOVATION POLICIES FOR THE DEVELOPMENT OF ELECTRIC VEHICLE TECHNOLOGIES AND BUSINESSES

Some parts of this chapter and the previous chapter (Chapter 5) have been published in two international conferences

Özel, F. and H. Davies, *A Policy Intervention Evaluation Framework for Electric Vehicle Technology Development* in *European Electric and Hybrid Vehicle Congress (EEVC)* December 02-05, 2014: Brussels, Belgium.

Özel, F., Davies, H. and Wells, P. *Development and Application of an ANFIS based Policy Intervention Evaluation Framework for Electric Vehicle Technology Development* in *23rd International Colloquium of Gerpisa* June 10-12, 2015: Paris, France.

6.1 Introduction

Austria which has a high share of renewable energy sources in national power generation (approximately 70%) is recognised as a significant driving force propelling the European automotive industry. The country is the home of the AVL that is the world's largest privately owned company for development, simulation and testing technology of powertrains and it is known as an important research and development (R&D) location for international companies which are active in the electric mobility such as Magna, Samsung SDI and Bosch. There is also strong automotive supply industry with a focus on propulsion systems (BMW, Opel/General Motors) in the country [105]. In this regard, Austrian government recognises electric mobility as a significant opportunity to reduce transport emissions as well as increase the competitiveness of the automotive industry [104].

In this chapter, the developed ANFIS framework is applied to Austrian innovation instruments to make suggestions about Austrian future innovation policies for supporting EV technology development. This was done with the support of Austrian Research Promotion Agency (FFG). The FFG is the main public body to support industrial research, development and innovation in Austria and it is the biggest Austrian funding agency for applied research. The Austrian Federal Government aims to "*further develop and direct policy instruments for the preparation of the market for electric mobility in the sense of an intelligent incentives system, so that the transition from the market preparation phase to that of launching electric mobility on the market is accelerated"* [106]. This study aims to support this objective by making suggestions about the country`s future innovation policies by using the developed ANFIS framework. In support of this aim, a dialogue was established with FFG for designing EV innovation policies for Austria. Based on this dialogue, data for Austria was gathered and checked with the ANFIS model to test the validity of the model. Secondly, three different innovation policies or as it is referred here three different "scenarios" were developed. Two of these scenarios were developed by FFG in cooperation with the Austrian Ministry for Transport, Innovation and Technology. The last scenario was developed theoretically based on the results of Chapter 4 which investigated support areas micro, small and medium sized enterprises (SMEs) need to have a role in the possible battery electric vehicle (BEV) based automotive value chain re-shaping in Europe [257]. Those scenarios were then used as inputs for the ANFIS model to calculate the effect of those scenarios on the innovation output. Finally, qualitative cost-benefit analysis (CBA) was used to understand the wider impacts of policy scenarios on a range of cost and benefit components.

6.2 Checking the Validity of the Model with Austrian Data

In order to test the validity of the model, the first part of the study involved gathering data for Austria and checking it with the ANFIS framework as explained below:

- *Data Gathering:* Technology push and pull instruments (input parameters) used for promoting EV technologies in Austria were provided by FFG as can be found in Appendix D. Patent data (output parameter) for 1990-2011 periods was gathered from "Worldwide Patent Statistical Database" (PATSTAT) by using the B60L international patent classification (IPC) code as displayed in Figure 6.1.

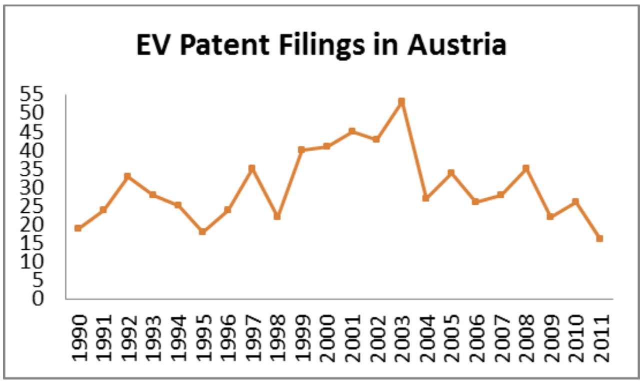

Figure 6.1 EV patent filings in Austria

- *Data Generation for ANFIS Model:* The input and output parameters were then evaluated and linked based on years. For evaluating the relative performance indexes (RPIs) of technology push and pull levels of Austrian innovation policies, an evaluation guide that was developed in Chapter 5 (Table 5.6) was used. For evaluating the output parameter, cumulative patent data was used. Final results are summarised in Table 6.1.

Table 6.1 Generated data for ANFIS

	Austria		
Year	*Push*	*Pull*	*Patents*
1990	0.00	0.00	19
1991	0.00	0.00	43
1992	0.00	0.00	76
1993	0.00	0.00	104
1994	0.00	0.00	129
1995	0.00	0.00	147
1996	0.00	0.00	171
1997	0.00	3.19	206
1998	0.00	3.19	228
1999	0.00	3.19	268
2000	0.00	6.38	309
2001	0.00	6.38	354
2002	6.90	6.38	397
2003	6.90	6.38	450
2004	6.90	6.38	477
2005	6.90	6.38	511
2006	10.42	6.38	537
2007	10.42	6.38	565
2008	17.44	18.12	600
2009	25.49	18.12	622
2010	29.01	21.84	648

- *Input-Output Data Pairs for ANFIS Use:* The cumulative patent applications for Austria were standardized and Table 6.2 demonstrating input-output data pairs was created by using the specified equation ($Totalpatents_{i,t} = \beta_1 Totalpatents_{i,t-1} + \beta_2 TechnologyPush_{i,t-1} + \beta_3 TechnologyPull_{i,t-1} + \varepsilon_{i,t-1}$). As can be seen, Table 6.2 includes both Austrian data and other two regions` data combined with Austrian data. The reason for combining regions was creating additional data sets for Austria since Austrian data was limited although 1990-2011 period was studied. However, Austrian data was combined only with the data of United Kingdom (UK) and France as only these two regions demonstrated similar EV technology development rates based on the number of cumulative patent applications compared to Austria among studied regions in Chapter 5.

Table 6.2 Input-output data pairs of Austria for ANFIS model

Year	*Austria*				*UK+Austria*			
	x1	*x2*	*x3*	*y*	*x1*	*x2*	*x3*	*y*
1990	-1.54	0.00	0.00	-1.43	-1.52	0.00	0.00	-1.42
1991	-1.43	0.00	0.00	-1.27	-1.42	0.00	0.00	-1.27
1992	-1.27	0.00	0.00	-1.14	-1.27	0.00	0.00	-1.14
1993	-1.14	0.00	0.00	-1.02	-1.14	0.00	0.00	-1.02
1994	-1.02	0.00	0.00	-0.93	-1.02	0.00	0.00	-0.90
1995	-0.93	0.00	0.00	-0.82	-0.90	0.00	0.00	-0.80
1996	-0.82	0.00	0.00	-0.65	-0.80	0.00	0.00	-0.63
1997	-0.65	0.00	3.19	-0.54	-0.63	0.00	3.19	-0.49
1998	-0.54	0.00	3.19	-0.35	-0.49	0.00	3.19	-0.32
1999	-0.35	0.00	3.19	-0.16	-0.32	0.00	3.19	-0.19
2000	-0.16	0.00	6.38	0.06	-0.19	0.00	6.38	0.03
2001	0.06	0.00	6.38	0.26	0.03	0.00	6.38	0.21
2002	0.26	6.90	6.38	0.52	0.21	6.90	6.38	0.44
2003	0.52	6.90	6.38	0.64	0.44	10.42	6.38	0.58
2004	0.64	6.90	6.38	0.81	0.58	10.42	6.38	0.74
2005	0.81	6.90	6.38	0.93	0.74	16.58	9.57	0.85
2006	0.93	10.42	6.38	1.07	0.85	20.10	9.57	1.01
2007	1.07	10.42	6.38	1.23	1.01	27.88	13.08	1.20
2008	1.23	17.44	18.12	1.34	1.20	42.31	24.82	1.36
2009	1.34	25.49	18.12	1.46	1.36	61.31	32.19	1.56
2010	1.46	29.01	21.84	1.54	1.56	71.51	39.65	1.72
Year	*France+Austria*				*UK+France+Austria*			
	x1	*x2*	*x3*	*y*	*x1*	*x2*	*x3*	*y*
1990	-1.40	0.00	0.00	-1.31	-1.41	0.00	0.00	-1.33
1991	-1.31	3.06	0.00	-1.19	-1.33	3.06	0.00	-1.21
1992	-1.19	3.06	3.52	-1.08	-1.21	3.06	3.52	-1.09
1993	-1.08	3.06	3.52	-0.98	-1.09	3.06	3.52	-0.99
1994	-0.98	3.06	3.52	-0.89	-0.99	3.06	3.52	-0.88
1995	-0.89	3.06	5.99	-0.77	-0.88	3.06	5.99	-0.77
1996	-0.77	3.06	5.99	-0.66	-0.77	3.06	5.99	-0.64
1997	-0.66	3.06	12.60	-0.56	-0.64	3.06	12.60	-0.53
1998	-0.56	3.06	12.60	-0.40	-0.53	3.06	12.60	-0.38
1999	-0.40	3.06	12.60	-0.26	-0.38	3.06	12.60	-0.25
2000	-0.26	3.06	15.79	-0.09	-0.25	3.06	15.79	-0.08
2001	-0.09	3.06	15.79	0.08	-0.08	3.06	15.79	0.09
2002	0.08	14.20	15.79	0.32	0.09	14.20	15.79	0.32
2003	0.32	14.20	15.79	0.50	0.32	17.72	15.79	0.50
2004	0.50	14.20	15.79	0.68	0.50	17.72	15.79	0.67
2005	0.68	20.36	15.79	0.83	0.67	27.40	18.98	0.81
2006	0.83	23.88	18.98	1.00	0.81	30.92	22.17	0.98
2007	1.00	27.04	18.98	1.20	0.98	41.86	25.68	1.19
2008	1.20	42.19	38.20	1.39	1.19	64.42	44.90	1.39
2009	1.39	60.82	38.20	1.63	1.39	94.00	52.27	1.64
2010	1.63	71.76	52.46	1.97	1.64	108.46	70.27	1.96

- *Checking Austrian Data with the ANFIS Framework:* The ANFIS framework was re-trained and Austrian data was used for checking the framework. For re-training the model, all generated data sets in Appendix C were used. For checking the model, data presented in Table 6.2 (4 data sets) was used. After setting the training error tolerance to zero and training epochs to 280 (lowest error was achieved on 280 epochs), training error and checking error were obtained as 0.03 and 0.055 respectively, representing a satisfactory outcome for the developed framework, as displayed in Figure 6.2 (ANFIS predicted values were close to the checking data). This result suggests that ANFIS Model can be applied to Austria for developing scenarios and calculate the effect of those scenarios on the innovation output.

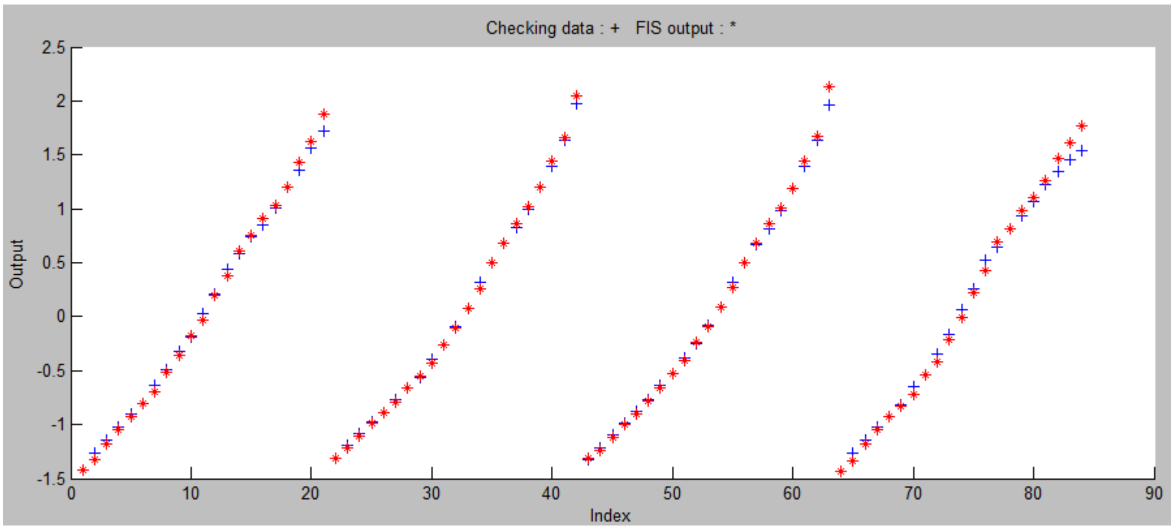

Figure 6.2 Checking Austrian data with ANFIS framework

6.3 Methodology

This study aimed to apply the developed ANFIS framework to Austrian innovation instruments to make suggestions about Austrian future innovation policies for promoting EV technology developments. The methodology involved three stages: designing policy-mixes (scenarios), using those scenarios as inputs for the ANFIS model to calculate the effect of those scenarios on the innovation output and understanding the wider impacts of policy scenarios on a range of cost and benefit components with CBA. By doing so, the aim was to assist EV innovation policy making by assessing the effects of different policy-mixes on the technical change and understanding how policy mix intensity interfaces with ability to fund and the benefit that accrues.

6.3.1 Designing EV Innovation Policy-Mixes

According to Borras [288], designing innovation policy involves three important steps: *"identification of problems in an innovation system, formulation of policy objectives and selection of appropriate innovation policy instruments"*. Thus, the first step of innovation policy design involves identifying problems in an innovation system to formulate policy objectives. As it is not possible to identify problems specifically enough based on theory alone, measurements, analysis or comparative studies are widely used to identify problems [288]. Specifically, innovation indicators [347], benchmarks and best cases and independent expert assessments are frequently used [288]. Although, benchmarks and best cases have become popular in the advanced economies during the past few years, independent expert assessment of innovation policy performance such as evaluation of policies is also used extensively in innovation policy-making these days [288]. Although, as discussed in Chapter 5, patents do not truly represent the technological development of an artefact and the propensity to patent varies significantly across countries and industries, patents are also widely used sources for problem identification in innovation systems and they are accepted as an innovation indicator [347]. Besides, since most patent data are computerised, technical trends in detail [304, 305] technology levels, and commercial values might be understood with patent analysis [306, 307]. Patents are also available in large quantities in long time series allowing comprehensive analyses [298-300]. The innovative output and performance of countries, regions or technological fields might also be understood with patent applications [37, 308, 309]. There are also very few examples of economically significant inventions which have not been patented [310, 311]. Two studies in literature also used patent applications to measure the technology development of EVs [37, 94].

As discussed before, the challenge for Austria is reducing transport emissions as well as increasing the competitiveness of the automotive industry. The Austrian government aims to achieve that by supporting the development of emerging EV industry. In this regard, this study aimed developing innovation scenarios for accelerating the development of EV technologies in Austria and patents were selected as innovation indicators for comparing different scenarios.

The second step of innovation policy design is described as formulation of policy objectives. *"A conventional and general description of public policy instruments is a set of techniques by which governmental authorities wield their power in attempting to* *ensure support and effect (or prevent) change"* [348]. This definition underlines the goal-oriented nature of policy instruments. Policy instruments have a purpose, that is to induce change (or to avoid change) in a specific way, which is believed to stimulate innovation. In that context, the instruments of EV innovation policy are focused on fostering innovation in EV field. However, innovation is rarely a goal in itself, but a way to achieve broader political goals [288]. Table 6.3 summarises the policy objectives of studied regions (United States of America (USA), Japan, EU, Germany, France and UK) in Chapter 5. As can be seen, although all studied regions have aimed to foster the development of EV technologies, they have also intended to achieve other political goals such as protecting environment, restructuring automotive industry, creating jobs and securing energy supply. Thus, EV innovation policy instruments are planned to influence innovation processes, and thereby contribute to fulfilling these ultimate political goals by means of achieving the direct objectives formulated in innovation terms. In the following section, political goals for each scenario will be discussed in more detail.

Table 6.3 Policy objectives of examined regions

Country	*Policy Objective*
EU	European Commission (EC) focuses around three public priorities: security of energy supply, climate protection, and competitiveness. In that context, the EU aims to promote sustainable growth, reduce the EU's dependency on fossil fuels and its emissions resulting from the transport sector [87].
France	The development of EVs is seen as a twofold opportunity in order to fight against climate change, while simultaneously restructuring the automotive sector to ensure the future viability of the domestic automotive industry and to safeguard jobs [87].
Germany	Four targets are aimed by the German government: climate protection, reducing the dependence on oil, strengthening Germany as an industrial and technological location and reducing local emissions [86]. However, although environmental targets exist too, industrial goals play a more significant role since Germany`s economy is highly dependent on its automotive industry and this is endangered by a global transition from traditional internal combustion engine cars towards EVs.
Japan	Japan wants to improve fuel efficiency, decrease CO_2 emissions, diversify the energy mix, and introduce next-generation vehicles to the market on a full-scale basis. The Japanese automobile industry aims to maintain its leadership in high-rate technical capacity on the global market by creating new industry sectors and acquiring new markets. By doing so, the country's economy and employment are aimed to be improved [87].
UK	The UK government aims to decarbonise the transportation sector, support the national economic competitiveness and growth, and improve the life, health and safety [286]. The government also considers such a transition to EVs to be an opportunity for local SMEs to become a more significant part of a future automotive regime by becoming suppliers of alternative technologies [55].
USA	The main motives for the USA government to support the development of electric vehicles (EVs) mainly lie in the energy security of the country. USA also aims at creating jobs, achieving energy security, protecting the environment, and securing the future of the automotive industry [87].

In order to achieve stated political goals, countries follow different trajectories and chose different instrument mixes as there are no "optimal" policy instruments fitting all purposes. This is what Breznitz [349] defines as "micro-level policies" and what Borras [288] describes as "instrument choice". Both of these concepts emphasise the significance of national policy priorities in policy making process. Hence, the last step of the innovation policy design involves selecting the policy instruments based on identified problems and formulated goals. According to Borras [288], selecting policy instruments involves three important steps. Firstly, an initial selection of the most suitable specific instruments among the wide range of different possible instruments. Secondly, the *"concrete design and/or customisation"* of the instruments for the context in which they are supposed to operate. Lastly, the design of an instrument mix, or set of different and complementary policy instruments, to address the problems identified. In previous chapter, related instruments for EV innovation policies were discussed in detail. In the next sections, different instrument mixes for each scenario will be discussed. However, this study does not include the customisation of the instruments as this study aimed to calculate the effect of different scenarios on the technical change in Austria by using the ANFIS framework rather than designing a specific instrument mix for the country.

6.4 Scenario Building

As discussed in the previous section, this study aimed developing innovation scenarios for accelerating the development of EV technologies in Austria. Since different policy priorities would result in different instrument mixes and, hence, would affect the development of EV technologies differently, the question then arises as to which instrument mix affects the technical change mostly? As the developed ANFIS algorithm predicts the technology development of EVs (output parameter) based on national governments` different technology push and pull instruments (input parameters), effects of different instrument mixes on the technical change can be obtained with this framework providing a basis for decision making. In that context, three policy priorities and, thus, instrument mixes were developed to learn the effects of each scenario on the innovation output (number of patent filings). Two of these scenarios were developed by FFG in cooperation with the Austrian Ministry for Transport, Innovation and Technology. The third scenario was developed theoretically based on the results of Chapter 4 which investigated support areas SMEs need to have a role in the possible BEV based automotive value chain re-shaping in Europe [257].

6.4.1 Developed Scenarios by FFG and Austrian Ministry for Transport, Innovation and Technology

Innovation policy aims to influence innovation processes, and thereby achieve other political goals such as protecting environment, restructuring automotive industry and creating jobs. To determine these policy objectives, *"a complex process is required that executive government initiatives, parliamentary discussions, public agencies, the civil society, etc. are involved"* [288]. According to the electromobility (EV) implementation plan of Austria [106] that was drafted after discussions with numerous stakeholders, the country`s EV innovation policy objectives are described as follows:

> *"The targeted development of electromobility in Austria is meant to be vital in making our mobility and transport system more sustainable, more environment-friendly, and more efficient. Electromobility can contribute significantly to the protection of the environment and climate protection as it reduces our dependence on imports of fossil energy sources. Electromobility from Austria is an enormous opportunity, mainly for the technology and business location Austria, so as to successfully position itself, with innovative state-of-the-art technology in, say, the automotive and automotive components industries, and with intelligent energy and mobility services, on international markets. Electromobility, therefore, is now at the centre of research, development and production, so that innovation power and ranking of Austria is enhanced, as well as added value and employment is sustainably secured. Electromobility may finally also establish promising future-oriented options in education and training, as well as job profiles, and also create jobs and new employment opportunities."*

For accelerating the development of EV technologies in Austria and, ultimately, for achieving these political objectives, FFG created two scenarios and, hence, two instrument packages as below:

> *Scenario 1: Promote the development of EV technologies with the prioritised short-term instruments to develop a more sustainable and greener transport system in Austria*
>
> *Scenario 2: Promote the development of EV technologies by implementing all the instruments explained in the Austrian electromobility implementation plan to achieve all goals defined above.*

The corresponding technology-push and technology-pull instrument mixes for these scenarios are summarised in Appendix E. To display instruments selected for each scenario, an "X" meaning that an instrument is chosen in the respective scenario was used. As can be seen, each instrument was evaluated individually based on the evaluation criteria discussed in the ANFIS Model development stages (Chapter 5) to quantitatively assess the each scenario. In the following section, Scenario 3 will be developed based on the results obtained in Chapter 4 [257]. After that, each scenario`s effect on the technical change will be examined by using the ANFIS Model.

6.4.2 Theoretically Developed Scenario for Strategically Supporting SMEs in Austria

An important issue for designing future policies is not designing innovation policy instruments only with the known and established actors in mind, but also to account for actors that do not yet exist or for those that are too small to organize their interests [350]. Policies supporting SME development are especially important since it is expected that there will be change in the established relationships within the automotive supply chain in moving from ICEV to EV [78], and SMEs that are more capable of developing those technologies [28, 37, 78] might have a role in the possible EV based automotive value chain re-shaping. Thus, maximising SME engagement and benefit from the transition to EV is very significant owing to their potential in triggering economic development and innovation via the exploitation of emerging EV business opportunities [257].

The Austrian industry consists mainly of SMEs. Around 298,000 SMEs account for 99,6% of all companies situated in Austria, not taken into account the field of forestry and agriculture [351]. SMEs are a very significant part of the Austrian economy and a crucial driver for economic growth, innovation, employment and social integration in addition to their essential role in innovation and R&D. Hence, a possible transition to EVs might be an opportunity for local SMEs [28, 37, 78] in Austria to become a more significant part of a future automotive regime by becoming suppliers of EV technologies. In fact, as discussed in Chapter 4, European countries might achieve both economic growth and emission reduction targets stated in the Europe 2020 strategy by supporting SME development [257]. One of the aims mentioned in the Austrian electromobility implementation plan [106] also involves pushing electromobility by strategically supporting SMEs. Thus, a theoretical scenario was defined as below:

> *Scenario 3: Promote the development of EV technologies in Austria by strategically supporting SMEs in order to create opportunities for local SMEs to become a more significant part of a future automotive regime*

6.4.2.1 Designing Instrument Mix for Scenario 3

In the real world, the instruments of innovation policy are rarely used standing "alone". On the contrary, innovation policy instruments are combined in specific mixes, using several different instruments in a complementary manner as the solution of specific problems requires complementary approaches to the multi-dimensional aspects of innovation-related problems [288, 352, 353]. For designing instrument mixes, innovation policy instruments are closely related to the different activities of the innovation system [288, 354]. These activities are divided into four groups, as displayed in Table 6.4: provision of knowledge inputs to the innovation process; demand-side activities; provision of constituents and support services for innovating firms. Although activities in those groups are preliminary and hypothetical, they include many determinants mentioned in literature for influencing innovation processes. Therefore, a useful way of designing instrument mixes is to relate instruments to each of the ten activities [288]. In that context, results of Chapter 4 which identified challenges for supporting European SMEs to become a more significant part of a future automotive regime [257] were integrated with the innovation activities mentioned in Table 6.4 to develop a theoretical instrument package in order to support the development of Austrian SMEs in the emerging EV sector, as displayed in Table 6.5. During the selection of instruments for this scenario, it was attempted to relate the instruments with the ones explained in Scenario 2 as this scenario involved all possible instruments defined by the Austrian government.

Table 6.4 Key activities in systems of innovation adapted from [288, 354]

	Key activities in systems of innovation
1	Provision of knowledge inputs to the innovation process
a	Provision of R&D results and, thus, creation of new knowledge
b	Competence building, such as through individual learning (educating and training the labour force for innovation and R&D activities) and organizational learning.
2	Demand-side activities
a	Formation of new product markets.
b	Articulation of new product quality requirements emanating from the demand side.
3	Provision of constituents
a	Creating and changing organizations needed for developing new fields of innovation. Examples include enhancing entrepreneurship to create new firms and intrapreneurship to diversify existing firms, and creating new research organizations, policy organizations, etc.
b	Networking through markets and other mechanisms, including interactive learning among different organizations (potentially) involved in the innovation processes
c	Creating and changing institutions – such as patent laws, tax laws, environment and safety regulations, R&D investment routines, cultural norms, etc. – that influence innovating organizations and innovation processes by providing incentives for and removing obstacles to innovation.
4	Support services for innovating firms
a	Incubation activities such as providing access to facilities and administrative support for innovating efforts.
b	Financing of innovation processes and other activities that may facilitate commercialization of knowledge and its adoption.
c	Provision of consultancy services relevant for innovation processes, e.g., technology transfer, commercial information, and legal advice.

The first group of activities in the systems of innovation include the provision of R&D and competence building (education and training) [288]. As can be seen in Table 6.5, Chapter 4 revealed that the EV sector in Europe attracted SMEs as it was a niche market that SMEs can position their existing expertise and product knowledge [257]. In this regard, supporting the creation of niche markets might increase the number of SMEs operating in this field in Austria. In the long term, Austrian government aims to develop the technology competence for recycling procedures and the recovery of materials in Austria. By selecting an instrument supporting the establishment of business locations focussing on material recovery such as rare earths and other materials in Austria might create market opportunities for SMEs. Similarly, another instrument financially supporting investments, production and new industrial settlement for EVs might also encourage SMEs to involve in this field as the creation of niche markets might be supported with this instrument. Secondly, to support creation of new knowledge and competence building, three education and training instruments were added to the instrument package. Whereas the first instrument might support developing skills for intelligent production technologies and processes for the flexible and competitive production of small, medium and large numbers of EVs and EV infrastructures, the second instrument might support developing new knowledge by establishing practical research trainings and strengthening international cooperation in education and research. The last instrument might also create the awareness regarding EVs among young people and their families.

Table 6.5 Key activities in systems of innovation and European SME responses

	Key activities in systems of innovation and European SME Responses
1	*Provision of knowledge inputs to the innovation process*
a	The EV sector in Europe attracted SMEs since it was a niche market that SMEs can position their existing expertise and product knowledge. SMEs had ability to service new markets and the potential to grow the company
b	People were not found very familiar with the new technology (Lack of skilled people)
2	*Demand-side activities*
a	The demand was low and fluctuated. SMEs identified a risk on how to move to the next level on business where investment is required but the market potential is uncertain. Technical and financial incentives were also found inadequate for private customers. Besides, some SMEs were asked to prove themselves by demonstrating working prototypes
b	Standardisation was seen as one of the main problems for SMEs servicing different markets
3	*Provision of constituents*
a	Niche EV market lowered entry barriers and opened up windows of opportunity for new entrants to enter the market. The emergence of an EV sector provided opportunities for SMEs to become part of a developing supply chain.
b	Establishing relationships between the SME (the newcomer) and the established automotive sector was challenging. Nearly all the SMEs interviewed demonstrated a need for strategic partnerships. Establishing relationships with customers was also seen as a challenge.
c	Although the EV sector was defined as a technology-driven niche market by the interviewed SMEs, they were cautious to exploit EV technologies due to difficulties of protecting intellectual property. The difficulties were claimed to have arisen from high avoidance costs.
4	*Support services for innovating firms*
a	Only a few of the SMEs interviewed used funding programmes often feeling that the system was bureaucratic and the risk that the investment made in pursuing such funding streams was too high given other pressures on the business
b	SMEs were funded through existing margins gained from the sales of the products. This was restrictive as sale revenues were used both to fund existing business and to make new investments. Small amount of funding left for new investments were rarely sufficient to fund up-scaling of production and development to the levels needed to feed into mass production processes at OEM
c	Although there were several regional, national and European level opportunities for SMEs, they needed to be informed about these opportunities. Besides, rules for participation, dissemination, evaluation and implementation were found restrictive.

The second group is demand-side activities [288]. According to Table 6.5, four main challenges were identified by SMEs for demand-side activities: uncertain demand, inadequate technical and financial incentives for private customers, demonstration of working prototypes, and standardisation issues. For overcoming uncertain demand issues, public procurement instrument was added to the instrument package as public agency might place orders for products and services from SMEs and, hence, the necessary demand for SMEs might be created. For providing technical incentives for the private customers of SMEs, an instrument aiming to make the traffic framework conditions attractive for EVs was selected. Similarly, subsidies and tax incentives were also included to the instrument package in order to provide financial incentives for private customers. Additionally, demonstration programmes were selected to provide real life experiences to the customers of SMEs. Finally, two consistent codes and standards instruments were selected to support SMEs operating in the infrastructure businesses as de-facto standards could be developed with those instruments. Besides, an economic and financial instrument was also added to the instrument package to support the installation of necessary infrastructure for EVs. To support standardisation issues, a network management instrument was also added to the instrument package. With this instrument, stakeholders could participate in international panels and committees in the preparation of normative standards. By providing products and services with internationally recognised standards, Austrian SMEs might be more proactive in European and other international markets.

The third group involves activities concerning the provision of constituents [288]. According to Table 6.5, three strategies could be used for supporting Austrian SMEs: creating niche markets to lower entry barriers for new entrants, creating platforms for SMEs that support establishing relationships and reviewing and reforming patent laws for supporting SMEs to protect their technology. Instruments aiming to create niche markets for SMEs were already discussed with the first group of activities. In addition to these instruments, technology roadmaps were also added to the instrument package as they might help show what is needed to take technologies from their current status through to full commercialisation, and to outline the role of SMEs, governments and other stakeholders in achieving various outcomes [292]. Such an instrument might support the continued growth of the EV sector for SMEs and, hence, it might enhance entrepreneurship. For establishing relationships, two network management instruments were selected. While the first one aims to simplify the EV related programmes and procedures by discussing them with SMEs in Austria, the latter aims to support the international cooperation of Austrian institutions. Those instruments might help SMEs to build a capable supply chain and share risks. Besides, a regulatory instrument aiming to review and change the patent regulations to support technology protection of SMEs was also included to the instrument package.

In the final group, support services for SMEs are listed. Table 6.5 summarises these activities as follows: simplifying the rules for funding programmes in order to attract more SMEs to these programmes; informing SMEs about EV market opportunities in Austria and developing financial support for SMEs. Network management instruments discussed in the previous group might also support the first two activities as these instruments aim to simplify the EV related programmes and procedures for SMEs. For supporting SMEs financially, R&D investments were added to the instrument package. According to Verbong and Geels [102], R&D expenditures are one of the major determinants of an industry's sustainability which is a determinant for its ability to innovate and compete in the future. Hence, this instrument might support SMEs for developing EV technologies by providing additional funding.

Overall, a theoretical scenario focusing on strategically supporting SMEs for accelerating the development of EV technologies in Austria was developed by relating results of Chapter 4 [257] to the different activities of the innovation system [288, 354]. The instrument mix influencing the supply and demand sides of EV market is summarised in Appendix F. In the next section, each scenario`s effect on the technical change will be examined by using the ANFIS Model.

6.5 Examining the Effects of Scenarios on the Technical Change by Using ANFIS Model

To accelerate the development of EV technologies in Austria, three different scenarios were developed. Based on these scenarios, Table 6.6 summarising the contribution of each scenario to RPIs of technology push and pull levels of Austrian innovation policies was created. When calculating total RPIs, RPIs for the year 2010 were used since 1990-2011 period was examined in this study owing to the fact that 2011 patent data was the latest reliable patent data at the time of patent search.

Table 6.6 Contribution of each scenario to RPIs of technology push and pull levels of Austrian innovation policies

RPIs in 2010		*Contribution of Each Scenario to RPIs*			*Total RPIs*	
Push	Pull	Scenarios	Additional Push	Additional Pull	Total Push	Total Pull
29.01	21.84	Scenario 1	21.33	22.69	50.34	44.53
29.01	21.84	Scenario 2	35.89	50.67	64.9	72.51
29.01	21.84	Scenario 3	36.85	31.69	65.86	53.53

As can be seen in Table 6.6, the present policy mix within Austria is marginally biased towards technology-push. Although not as divergent as say Japan and Germany, this may indicate that Austria sees the development of e-mobility as being driven by industry. This fits with the stated objectives from Austria of e-mobility being both of benefit to the environment as well as the economic well-being of Austria. For scenario 1, the resultant policy mix moves towards a balance between the technology push and pull, which align with the objective of supporting a more sustainable transport choice, thus requiring greater consumer engagement. Scenario 2 moves policy mix even further to the technology pull side, which somewhat supports the observation that in previous policy mixes the preference has been towards the technology push area. Finally, scenario 3 is aligned to the industry support (the SME sector) and not unsurprisingly is therefore biased towards the technology push area.

Following the data collection and preparation phases the trained ANFIS algorithm was used to understand how these different policy mixes may impact the development of EV technologies in Austria. In that context, total RPIs for each developed scenario in Table 6.6 were used as inputs (input 2 and input 3 based on the used empirical model: $\text{Totalpatents}_{i,t} = \beta_1\text{Totalpatents}_{i,t-1} + \beta_2\text{TechnologyPush}_{i,t-1} + \beta_3\text{TechnologyPull}_{i,t-1} + \varepsilon_{i,t-1}$) for the ANFIS model. By entering the last input which is the standardised value of the latest available cumulative patent data (2011 data: 648 or 1.54 as standardised value), the effect of each scenario on technology development was predicted as standardised cumulative patent applications by ANFIS. These values were then unstandardized and Table 6.7 were created. More information regarding numbers presented in Table 6.7 are given in the next page.

Table 6.7 ANFIS model results for each developed scenario

ANFIS Model Results					
Scenarios	Total patent filings in 2011 Cumulative Standardised (Unstandardized)	Total Push	Total Pull	Predicted Patent Filings Cumulative Standardised (Unstandardized)	Effect of Each Scenario on Patent Filings
Scenario 1	1.54 (648)	50.34	44.53	1.89 (720)	72
Scenario 2	1.54 (648)	64.9	72.51	2.62 (872)	224
Scenario 3	1.54 (648)	65.86	53.53	1.95 (733)	85

For scenario 1, the inputs were 1.54 (or 648 as unstandardized value), 50.34 (total push) and 44.53 (total pull). When these numbers were entered to ANFIS, the output was predicted as 1.89. ANFIS predicts this value as if it belongs to the existing series (the same Standard Deviation (SD). This means that Scenario 1`s outcome was 1.89-1.54= 0.35 SD away from the previous value. The SD of the cumulative patent filings in Austria during 1990-2011 period was calculated as 207. In this respect, the unstandardized patent filings for Scenario 1 was calculated as 648+0.35*207= 720 (Additional 72 patent filings at the end of the implementation phase). The same procedure was followed for other scenarios.

Based on the presented results in Table 6.7, Scenario 2 identifying the implementation of all measures explained in the Austrian electromobility implementation plan resulted in the highest technology development rates. Secondly, although both Scenario 1 that aims the development of EV technologies with the prioritised short-term instruments and Scenario 3 targeting the development of EV technologies by strategically supporting SMEs resulted in similar technology development rates, Scenario 1 caused slightly higher technology development rates. In the next section, CBA will be used to understand the wider impacts of these policy scenarios on a range of cost and benefit components.

6.6 Cost-Benefit Analysis for the Developed Scenarios

Economic analysis is frequently used for policy decisions to determine whether (i) a specific option is cost-effective (justification/feasibility) and (ii) which option yields the greatest overall benefits. Traditionally, the main tool for assessing the welfare benefits of different policy decisions has been CBA, which is based on the Kaldor–Hicks compensation principle of "monetising negative externalities" or "internalising external costs" [355]. According to this efficiency principle, an outcome is found more efficient if those that are made better off could in theory compensate those that are made worse off. It has less stringent criteria compared to Pareto efficiency principle which requires making every party involved better off (or at least no worse off).

CBA is the most widely used ex-ante policy evaluation tool to support the decision making [355, 356]. It provides an integral overview of the estimated costs and benefits of alternative plans and transforms them as much as possible into monetary terms for comparison [355, 357]. By doing so, CBA quantifies social benefits and policy costs [355, 358] and examines the ratio of total benefits regarding total costs, namely the benefit–cost ratio (BCR). A threshold is usually set above a value bigger than 1 for a policy to be considered viable. This provides an easy mechanism for policymakers to decide between different policy options [355].

CBA might play a significant role for assisting policymakers to understand the wider impacts of a policy [355, 358], particularly if total costs and benefits can be identified, quantified and monetised. Yet, because it is not always possible to quantify and convert to a monetary figure impacts associated with a policy intervention, especially the socio-economic or political impacts such as £energy security of supply, quality of life and distribution of inter- and intra-generational inequalities" [355, 358, 359], the analysis is restricted to only monetized aspects [358].

Owing to the restrictions regarding CBA, there are several criticisms in literature. For example, it is argued that CBA has a big disadvantage as it is completely reliant on the impossible attempt to price the priceless values of life, health, nature, and the future [359]. Browne, O'Mahony and Caulfield [355] also claim that "*CBA may not be the ideal tool to measure social or distributional impacts owing to its focus on economic efficiency and allocation of resources"*. Van den Bergh [360] supports these claims by adding that "*an overall quantitative CBA evaluation and comparison of policy options are overly ambitious"*. In his study, Rogers [361] states that *"a quantitative CBA is especially not suitable for complex and emergent programmes as the challenges associated with the use of CBA for these programs go beyond difficulties in quantifying benefits and affect data collection about resources, program procedures, processes and outcomes*", as summarised in Table 6.8.

Table 6.8 Overview of challenges in cost–benefit evaluation of complex, emergent programmes [361]

Component of cost–benefit evaluation	*Characteristic of complex, emergent programmes*	*Implications for cost–benefit evaluation*
Costs (values of resources used)	Unclear boundaries of what constitutes the intervention. Projects encouraged to be opportunistic and build on existing and available resources	May underestimate costs as costs of a precursor or contemporary interventions may not be included
Programme procedures	Non-standardized interventions across projects	Difficult to standardize data collection, analysis and reporting across the funding programme
Psychosocial and other processes	Different processes will be relevant as mediators and moderators to particular projects and for different participants	Difficult to standardize data collection, analysis and reporting across the funding programme
Interim outcomes and long term outcomes	Diverse and emergent outcomes	Difficult to standardize data collection, analysis and reporting across the funding programme. Lack of standardized outcome variables for comparative evaluation of alternatives
	Multiple causation and co-production	May be difficult and not appropriate to attribute the outcomes totally to the intervention, which may need contribution from other factors, including co-production from participants, to achieve the observed outcomes

Therefore, a qualitative empirical analysis, in particular a qualitative trade-off of costs and benefits, namely a sort of qualitative CBA was proposed by Van den Bergh [360], especially for the climate change policies associated with complexity and extreme events. It was argued that *"in the face of extreme uncertainty, a quantitative analysis is often unable to offer more informative insight than a qualitative analysis as the extreme uncertainty does not disappear by adding more quantitative sophistication to the method of analysis"*. Besides, because quantification entails the adoption of several assumptions, it can even result in incorrect insights [360]. Thus, one study introduced "integrative cost benefit matrix approach" to include different costs and benefits, both quantifiable and difficult to quantify [362], as shown in Table 6.9. Their approach had two parts: an integrated cost–benefit matrix, and a participatory process to fill in the matrix. One recent study [361] used this matrix to conduct a completely qualitative CBA. For this aim, the matrix was amended by disaggregating costs into resources used and negative outcomes, and disaggregating benefits into positive outcomes achieved and negative outcomes avoided. Additional rows in the matrix were also added to identify particular groups who incurred the costs or received benefits. Besides, the matrix was expanded to display separately costs and benefits incurred or achieved during the implementation of a strategy, and those that might be reasonably expected in the longer term. The study concluded that *"although the method does not provide an overall BCR or statement of net benefit, nor by itself satisfactorily address causal attribution issues, it does provide a more comprehensive statement of actual and potential costs and benefits, and may provide a useful addition to techniques used for CBA"* [361].

Table 6.9 Integrative cost-benefit matrix [362]

Cost–Benefit Matrix	*Non-financial benefits*	*Financial benefits*	*Non-financial costs*	*Financial costs*
Costs and benefits to individuals				
Costs and benefits to groups				

In this study, a qualitative CBA to assess the developed scenarios for the development of EV technologies in Austria, each assuming a different policy-mix was also implemented. The aim was to find out the scenario providing an attractive balance of economic, technical and environmental points of view. One recent study [287] qualitatively evaluated the policies to promote alternative fuels and technologies as in Table 6.10. As can be seen, costs and benefits were evaluated by considering different dimensions: cost to consumer, cost to exchequer, reduction in GHG emissions and impact on lower socio-economic groups. Although modal shift representing a shift from private car use to public transport, walking or cycling, and impact on rural communities were also included to the study conducted by Browne, O'Mahony and Caulfield [287] owing to their holistic evaluation and for ease of comparison with travel demand management measures, they were considered as de facto "neutral" throughout the evaluation. Hence, in this study, they were not included for CBA. Besides although cost to exchequer of refuelling infrastructure was explained as "neutral" [287], it was evaluated as medium in this study owing to the ongoing investments of some governments in that field. For example, Japan aims to have 5,000 quick chargers and 2 million normal chargers by 2020 according to 'Next Generation Vehicle Strategy" [291, 363]. To reach this aim, the government aims to contribute 100 billion Yen (about €722 Million) to the project [86]. Similarly, under the Grenelle 2 law, the French government declared a plan to encourage the deployment of public charging infrastructure for carbon-free vehicles in 11 French regions in early 2010 [364]. In that context, the State has chosen the Future Investment Programme (Programme Investissements d'Avenir) to provide financial support and 50 million Euros are provided to cover 50% of the equipment and installation costs [86]. Finally, while the developed scenarios also referred to the benefits of improved energy security and higher employment, they were not examined in this study as a gap was found in literature for qualitatively or quantitatively measuring these benefits.

Table 6.10 CBA of policy instruments to promote EV technologies adapted from [287]

Innovation Policy Instruments	*Timeline*	*Cost to consumer*	*Cost to exchequer*	*Reduction in GHG emissions*	*Impact on lower socio-economic groups*
Tax incentives, subsidies	Short-term	Reduction in cost	High	Medium	Positive
Staggered payment schemes	Short-term	Reduction in cost	Neutral	Low	Positive
Traffic Regulations (free parking)	Short-term	Reduction in cost	Medium (cost to local authorities)	Low	Positive
Refuelling infrastructure	Medium-term	Neutral	Medium	Medium	Neutral
Traffic regulations (bus lane access)	Medium-term	Neutral	Low	Low	Neutral
Research and development investments	Long-term	Neutral	High	Medium	Neutral
Patent regulations	Medium-term	Neutral	Neutral	Low	Neutral
Emissions regulations	Medium-term	Increase in cost	Low	Medium	Negative
Mandatory use in public sector fleet	Medium-term	Increase in cost	Medium	Low	Negative
Forced early retirement of older vehicles	Long-term	Increase in cost	Low	Medium	Negative
Purchase of EVs by the government	Medium-term	Increase in cost	Medium	Low	Negative
Consistent codes and standards	Medium-term	Neutral	Low	Low	Neutral
Public-private partnerships, network management	Short-term	Neutral	Low	Low	Neutral
Long term goals and visions, technology roadmaps	Short-term	Neutral	Low	Low	Neutral
Market advertising, awareness campaigns	Medium-term	Neutral	Medium	Medium	Neutral
Education and training	Long-term	Neutral	Medium	Low	Neutral
Eco-labelling of vehicles	Short-term	Neutral	Low	Low	Neutral
Demonstration programmes	Medium-term	Neutral	Medium	Low	Neutral
Targeting niche markets	Medium-term	Neutral	Medium	Low	Neutral

In order to be able to calculate the sum of cost and benefit components and compare the effect of each scenario on these components, relative indexes for each category were created, as displayed in Table 6.11. Next, qualitative evaluations made in Table 6.10 were transformed to quantitative indexes, as exhibited in Table 6.12. After that, CBA for each scenario was conducted by using Table 6.12 as a guide.

Table 6.11 Qualitative CBA indexes for policy instruments to promote EV technologies

Qualitative CBA Indexes	
Cost to consumer	
Reduction in cost	1
Neutral	0
Increase in cost	1
Cost to exchequer	
Neutral	0
Low	1
Medium	2
High	3
Reduction in GHG emissions	
Low	1
Medium	2
Impact on lower socio-economic groups	
Negative	-1
Neutral	0
Positive	1

Table 6.12 Used indexes for the CBA of policies to promote EV technologies

Innovation Policy Instruments	*Cost to consumer*	*Cost to exchequer*	*Reduction in GHG emissions*	*Impact on lower socio-economic groups*
Tax incentives, subsidies	-1	3	2	1
Staggered payment schemes	-1	0	1	1
Traffic regulations (free parking)	-1	2	1	1
Refuelling infrastructure	0	2	2	0
Traffic regulations (bus lane access)	0	1	1	0
Research and development investments	0	3	2	0
Patent regulations	0	0	1	0
Emissions regulations	1	1	2	-1
Mandatory use in public sector fleet	1	2	1	-1
Forced early retirement of older vehicles	1	1	2	-1
Purchase of EVs by the government	1	2	1	-1
Consistent codes and standards	0	1	1	0
Public-private partnerships, network management	0	1	1	0
Long term goals and visions, technology roadmaps	0	1	1	0
Market advertising, awareness campaigns	0	2	2	0
Education and training	0	2	1	0
Eco-labelling of vehicles	0	1	1	0
Demonstration programmes	0	2	1	0
Targeting niche markets	0	2	1	0

Table 6.13 presents the final results of CBA and ANFIS Model. As can be seen, although each scenario`s effect was expected to be the same on cost to consumer and impact on lower socio-economic groups, the effects on cost to exchequer and reduction in GHG emissions differed. For example, although Scenario 2 was expected to have highest effects on the development of EV technologies (in terms of number of patent filings) and on the reduction in GHG emissions, it was also expected to be the most costly alternative. In contrast, while Scenario 1 was expected to have lowest effects on the reduction in GHG emissions, it was also expected to be the least costly alternative. Still, Scenario 1 was expected to result in slightly higher technology development rates compared to Scenario 3. Hence, based on different policy priorities, these results could be used to assist policy making in Austria as CBA is a formal policy evaluation and assessment method which is a guide to good policy [365]. However, the results of CBA should be interpreted with care as assessments of the costs and the benefits of an intervention are never complete and they barely do justice to the complexity of the situation [366]. This is especially relevant for climate change and environmental innovation policies, which are global, diffuse, unequal, long-lived, and uncertain [360]. Besides, the indexes in Table 6.13 were only created to compare the sum of cost and benefit components of each instrument-mix

by assuming that there is a direct relationship between the use of instruments and their effects on costs and benefits although there is a more complicated relationship owing to the complementary/synergetic/contrasting effects of an instrument concerning the specific mix in which it is embedded.

Table 6.13 Final results of CBA and ANFIS model

Scenarios	*CBA Results*				*ANFIS Model Results*
	Cost to Consumer	*Cost to Exchequer*	*Reduction in GHG Emissions*	*Impact on Lower Socio-Economic Groups*	*Impact on EV Technology Development (Number of Patent Filings Predicted by ANFIS)*
Scenario 1	-1	20	16	1	72
Scenario 2	-1	43	31	1	224
Scenario 3	-1	28	20	1	85

6.7 Conclusions

To support national governments in making informed decisions, an ANFIS framework providing an ex-ante impact of various innovation decisions was developed in Chapter 5. In this chapter, the developed ANFIS framework was applied to Austrian innovation instruments to make suggestions about Austrian future innovation policies for supporting EV technology development. This was done with the support of FFG. Key outcomes of this chapter include:

- The re-training of the ANFIS framework with Austrian data showed that ANFIS predicted values were close to the actual Australian data which suggested that ANFIS model could be applied to Austria.
- During the model application process, a dialogue was established with FFG to develop three different scenarios. Two of these scenarios were developed by FFG in cooperation with the Austrian Ministry for Transport, Innovation and Technology. The third scenario was developed theoretically by integrating the results of Chapter 4 which investigated the support areas SMEs need to have a role in the possible BEV based automotive value chain re-shaping in Europe with ten key activities in systems of innovation [288, 354]. This facilitated the selection of instrument-mix for the theoretical scenario.
- Those scenarios were then used as inputs for the ANFIS model to calculate the effect of those scenarios on the innovation output. As expected, an increase in

innovation policy intensity resulted in a higher EV technology output, but what was interesting was that similar EV technology output resulted from quite different policy mixes. This suggests that there are no perfect or ideal policy-mixes that are appropriate for all purposes.

- The successful application of ANFIS Model to different scenarios suggested that the developed framework might play a significant role for assisting EV innovation policy making by assessing the effects of different policy-mixes on the technical change – and hence there is latitude for alternative policy provisions according to national circumstance and preferences.
- Although qualitative CBA produces comparative assessment as opposed to actual quantitative values, it does prove useful in providing comparison between the various options. Nevertheless, it does not provide an overall BCR or statement of net benefit.

CHAPTER 7 - CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

7.1 Introduction

2050 greenhouse gas (GHG) reduction target of the European Union (EU) is an ambitious but also a necessary goal in terms of complying with the Kyoto Protocol of the United Nations Framework Convention on Climate Change`s 2°C target. The literature review demonstrated that, in the automotive industry context, achieving such target requires a technical transition which will not be motivated by single factors. This thesis provided a way of achieving such fundamental changes in the automotive value chain by challenging the factors that limit the new technology in the automotive sector. The research strategy was articulated theoretically by using the transitions theory.

According to transitions theory, a transition from internal combustion engine vehicles (ICEVs) to battery electric vehicles (BEVs) might be possible with an industrial structure which favours the production and consumption of BEVs rather than ICEVs. However, to achieve such architectural change, BEV technologies that are developed in niches by incumbent companies and new entrants need to be further developed and prescriptive policy interventions (target instruments) need to be implemented. The importance of small and medium sized enterprises for the development and dissemination of BEV technologies also makes it critical to understand and support those actors to contribute to technical transition in the automotive industry. In this regard, the strategy of this research to respond the GHG emission reduction challenge of the automotive sector in the EU involved three steps:

- exploring the present industry structure and compatible future structure
- exploring the approach of SMEs to understand and support these actors
- developing and trialling a novel framework enabling the pre-implementation analysis of putative policy measures

This chapter presents the research findings and major conclusions drawn from the studies undertaken. Limitations and recommendations for future research are also presented in this chapter.

7.2 Research Conclusions

Based on the above mentioned strategy, the major conclusions that were found in this PhD research study are summarised and classified into three groups as discussed below.

7.2.1 Exploration of the Present Industry Structure and Compatible Future Structure

- The existing industry structure for BEV production relies on “one: many” relationships. It is expected that the production structure will transition from a “one: many” relationship to a “one: few”. This will be facilitated by growth in demand and higher production numbers which will facilitate the production process to be synchronised and support the establishment of system integrators offering the full electric drivetrain as integrated solutions. In order to be successful during this transition process, stakeholders should be able to exploit economies of scale; make use and expand long-time competencies in electric engineering with automotive know-how; and build up cooperation with experts in the new value chain to facilitate the required transfer of know-how.
- BEVs have a completely different value structure compared to ICEVs. A BEV comes along with approximately 63% higher value added, which is mainly generated at the supplier for the battery cell. However, about 75% of the ICEV drive train production value falls away.
- Such different value structure will have significant implications on make-or-buy decisions of OEMs. For example, an OEM focusing on high quality and high performance might probably choose to produce engine management, integration of batteries and electric systems, thermal and battery management. In contrast, suppliers might develop and produce transmission, battery cells, power electronics, high voltage wiring and comfort/safety/infotainment components.
- The competences for BEV in terms of research and development (R&D), testing and validation and manufacturing are presently available in the region. Although reuse and recycling is also available, it is likely to pose a problem for BEVs if numbers are to increase significantly.
- A benchmark concerning markets and production of BEV in Europe and USA anticipates good chances for European productions, due to competences in vehicle production, engineering and qualified personnel, but also clearly shows the strong position of USA. The strategy for the region for being a leading BEV industry

base globally involves making improvement in production, looking to capture sustainable fields of added value in the automotive industry; and continually innovating through investment and strengthening of links with the R&D sector.

7.2.2 Exploration of the Approach of SMEs to BEV Sector to Understand and Support SMEs

- The role of SMEs in the emergent BEV sector in North-West Europe (NWE) was limited by the confidence in the market and the need for resources. There was also a disconnection between the potential of SMEs to become part of the future BEV supply chain based on technology and based on manufacturing capacity.
- Interviewed SMEs were funded through existing margins gained from the sales of the products. Profits from small volumes of specialist products were rarely sufficient to fund up-scaling of production and development to the levels needed to feed into mass production processes at OEMs.
- SMEs needed strategic partnerships to both build a capable supply chain and share risks. However, it was very challenging to contract with larger organisations.
- SMEs were cautious to exploit BEV technologies due to difficulties of protecting intellectual property.
- For interviewed SMEs, it was also difficult to engage with 7th framework programme since they needed more support for protecting technology, establishing relationships and funding investments. Such kinds of support might further stimulate SMEs to step up to the next level in the possible BEV based supply chain.
- Although Horizon 2020 offers many opportunities for establishing relationships and raising finance for SMEs, they need to be informed about those opportunities. Specific technology protection measures for SMEs are also required.

7.2.3 Development and Trial of a Policy Intervention Evaluation Framework

- There are numerous instruments governments might use for promoting electric vehicle (EV) technologies. The high diversity of instruments together with the increasingly apparent need for urgency in achieving a transition to a more sustainable mobility, means that ex-post analysis is increasingly inadequate to the task of guiding the effective choice of policy interventions. To evaluate various policy measures and enable the pre-implementation analysis of those measures, an "adaptive neuro-fuzzy inference system" (ANFIS) based framework was developed.

- The framework was developed around the innovation policies and EV technology development in the EU, United States, United Kingdom, Japan, Germany and France. The framework was shown to be able to predict the development of EV technologies (in terms of patent filings) based upon national government policy strategies.
- A case study was then conducted by applying the developed ANFIS framework to Austrian innovation instruments to make suggestions about Austrian future innovation policies for supporting EV technology development. This was done with the support of Austrian Research Promotion Agency (FFG). During the model application process, a dialogue was established with FFG to develop three different scenarios. Those scenarios were then used as inputs for the ANFIS model to calculate the effect of those scenarios on the EV technology development rates. As expected, an increase in innovation policy intensity (technology push and pull) results in a higher EV technology output (in terms of patent filings), but what was interesting was that similar electric vehicle technology output resulted from quite different policy mixes.
- The successful application of the ANFIS framework to different scenarios suggests that the developed framework might play a significant role for assisting EV innovation policy-making by assessing the effects of different policy-mixes on the technical change – and hence there is latitude for alternative policy provisions according to national circumstance and preferences. It is an illustration of the ways in which future policy development for socio-technical transitions might also be informed, in the automotive and also in other sectors.
- A qualitative cost-benefit analysis (CBA) was conducted to understand the wider impacts of the policy scenarios on a range of cost and benefit components. It proved useful in providing comparison between the various options although it does not provide an overall benefit–cost ratio (BCR).

7.3 Limitations and Future Works

The work carried out in this study has some limitations. These limitations and areas for future investigation are summarised below:

- In the existing BEV production structure, several newcomers are entering to the various parts of the BEV supply chain. New entrants include both SMEs and diversifying established firms moving into BEV markets. This study only focused on SMEs. Therefore, future research might focus on learning what drives and motivates large diversifying established firms to be active in the emerging BEV supply chains. The results of such study together with the results of this study might be used to design more suitable supportive policies by the EU. These policies might attract new large firms together with SMEs to be active in the emerging BEV sector which might better stimulate the existing BEV industry to broaden their activities as the participation of big diversifying firms to BEV niches may bring more resources, and accelerate the development and formation of emerging BEV supply chains.

This research also proposed an ANFIS based framework. However, the developed framework is not without its limitations, and thus future research should contribute to further advancing the framework– mainly along the following four avenues.

- In this study, technology-push and demand-pull policies were chosen as input parameters and patent filings were selected as the output parameter. In literature, there is no recognised procedure for determining if the ‘‘best’’ ANFIS models have been accomplished. Therefore, it is very difficult to find the best mixture of a network topology and parameters. Better performing models might be developed with more successful selection of parameters and architecture. Hence, future research might further investigate the use of ANFIS predictive models in electric vehicle technology development by using other parameters. For example, the effects of EV innovation policies on the CO_2 reduction rates might be modelled by using the ANFIS.
- In order to establish a reliable predictive model for EV technology development, extensive data needs to be collected. Inadequate data might render the most promising predictive model inefficient. In this study, six regions were analysed for collecting data regarding input parameters. During the analyses of policies in those regions, only instruments for promoting innovation in EV field that were explained in Chapter 5 (Table 5.2) were considered. Policy development in other areas that may ultimately impact upon electric mobility were not examined. Thus, strict bounds were placed on what was considered as an EV innovation policy.

For collecting information regarding output parameter, B60L international patent classification (IPC) code was used. However, this was also limited as many patents in linked areas might not appear in patent search when using the B60L code. Besides, technological developments can happen outside the patent arena and propensity to patent might vary among countries. Thus, to improve the effectiveness of the model, future research might gather additional data by considering other EV related policy areas and patents. The collection of data for other countries such as Norway, China, South Korea and Netherlands would also make a significant contribution to the model by refining the learning rules and membership functions.

- When evaluating the effects of policy instruments, the person assessing the instruments as well as the method used by the assessor is very significant. For evaluating the effect of policy instruments on EV technology development, studies in literature were reviewed. However, a gap was found in literature for integrated and quantitative evaluation of policy-mixes. Existing evaluations in literature only provide limited information on the performance of different policy instruments and they are inclined to focus on the results of policy implementation. Besides, only a few evaluations provide information on how policy instruments might affect the technology development. Yet, they are based on specific characteristics of the evaluated instruments and are not part of an integrated evaluation process. A large share of those studies also focus on single policy instrument although innovation policies usually involve the mix of several instruments. For EV technologies, there is also a lack of research for evaluating the policy instruments. Hence, development of integrated and quantitative instrument evaluation methods would significantly increase the reliability of the model
- Qualitative CBA is limited since it does not provide an overall BCR or a statement of net benefit. Besides, this study used the results of a recent study [287] which qualitatively evaluated the policies to promote alternative fuels and technologies for qualitative CBA. During the analysis, relative indexes for each cost and benefit category were created to calculate the sum of cost and benefit components and compare the effect of each scenario on these components. This kind of analysis was also limited as it assumed that there is a direct relationship between the use of instruments and their effects on costs and benefits although there is a more

complicated relationship owing to the synergetic and contrasting effects of an instrument concerning the specific mix in which it is embedded. Hence, further research might focus on the development of qualitative CBA considering the synergetic and contrasting effects of an instrument concerning the particular policy-mix in which it is embedded.

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APPENDIX

APPENDIX A - Electric Vehicle (EV) Innovation Policies of Selected Regions

APPENDIX A.1 EV Policy Review of United States of America (USA)

APPENDIX A.2 EV Policy Review of Japan

APPENDIX A.3 EV Policy Review of the European Union

APPENDIX A.4 EV Policy Review of France

APPENDIX A.5 EV Policy Review of the United Kingdom (UK)

APPENDIX A.6 EV Policy Review of Germany

APPENDIX B - SQL Code Used for Gathering Patent Filings in Selected Regions

APPENDIX C - All Generated Data Sets for ANFIS

APPENDIX D - Austrian Innovation Policies for EV Technologies

APPENDIX E - Technology Push and Pull Instruments for Scenarios 1 and 2

APPENDIX F - Technology Push and Pull Instruments for Scenario

Appendix A EV Innovation Policies of Selected Regions

Appendix A.1 EV Policy Review of USA

Aim: The USA government mainly aims to support the development of electric vehicles (EVs) for energy security of the country. USA also aims at creating jobs, achieving energy security, protecting the environment, and securing the future of the automotive industry [87].

Key stakeholders: Due to the high subsidy level, the USA market for EVs is highly dependent on political decisions. Therefore, the most important stakeholder is the government and the USA Department of Energy's (DOE) Vehicle Technologies Office. Other important stakeholders are the growing battery industry and the car manufactures including new specialized companies such as Tesla Motors Inc. [86].

Overall strategy: The USA government has created a number of tax incentives mainly to ensure the future viability of the domestic automotive industry. The country aims to become market leading in the area of automotive batteries [86].

Technology-push policies for the development of EV technologies in USA are summarised in the following pages. As can be seen, the USA government mainly focused on establishing public-private partnerships (PPPs), creating roadmaps and investing for research and development (R&D). However, with Energy Independence and Security Act (EISA) in 2007 and American Recovery and Reinvestment Act (ARRA) in 2009, the government increasingly played a venture capitalist role in the automotive industry [30].

Technology Push Policies for EV Technologies in United States of America			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Public-private partnerships	Electric Drive Transportation Association (EDTA) was founded for electric drive R&D and demonstration [367].	1989
Regulatory instruments	Emissions regulations	California Air Resources Board`s (CARB) Zero Emission Vehicle (ZEV) mandate was introduced. ZEV mandate required seven major automobile manufacturers in terms of California sales to introduce BEVs for an increasing part of their vehicle sales: 2% in 1998, 5% in 2001, and 10% in 2003. In 1996, the ZEV guidelines were revised and requirements for 1998 were eliminated in exchange for 10 percent ZEV sales in 2003. Memorandum of agreements (MOA) were also signed with the seven automakers. In 1998, ZEV`s flexibility increased. The revised standards allowed hybrid, natural gas and “low speed vehicles” which are closely related to golf carts. In 2003, ZEV mandate was adjusted to allow ZEV credits for non-ZEVs and development of new technology ZEVs. The policy revisions also included a point system for increased flexibility in compliance that manufacturers could choose technology options to meet the ZEV requirement [339].	1990-1998
Soft instruments	Public-private partnerships	The USA Advanced Battery Consortium (USABC) was established in 1991. In 1993, New Generation of Vehicles (PNGV) replaced USABC to combine all programmes to one public-private partnership and FreedomCAR and Fuel Partnership replaced PNGV in 2002 as there was no statutory basis for it. In 2011, Driving Research and Innovation for Vehicle efficiency and Energy sustainability (US DRIVE) initiative replaced FreedomCAR and Fuel Partnership and added the Electric Power Research Institute (EPRI) and Tesla Motors to the initiative [368].	1991
Economic and financial instruments	R&D investments	USABC allocated $189 million (€138.1 million) in contracts to battery companies [369].	1991-1996
Soft instruments	Public-private partnerships	The Energy Policy Act (EPAct) directed Department of Energy (DOE) to develop a R&D and demonstration project for FCEVs and BEVs [369].	1992
Economic and financial instruments	R&D investments	The USA federal government invested $626 million (€458 million) to accelerate the development of EV technologies in response to ”Clean Air Act” in 1990 and EPAct in 1992 [94].	1993-1998
Soft instruments	Public-private partnerships	The California Fuel Cell Partnership was launched to promote the commercialization of FCEVs [370].	1999
Economic and financial instruments	R&D investments	EUR 53 million were spent by the federal government to develop battery technologies	2001-2003
Soft instruments	Long term goals and visions	DOE published a national vision of America's transition to a hydrogen economy: 2030 and beyond. National Hydrogen Energy Roadmap was also published to explore the wide range of activities required to realize hydrogen’s potential in solving USA`s energy security, diversity, and environmental needs [371].	2002
Economic and financial instruments	R&D investments	The FreedomCAR and Fuel Partnership allocated $1.2 billion (€877 million) for R&D and demonstration for developing hydrogen fuel cells [372].	2003-2008
Regulatory instruments	Emissions regulations	EISA called for a 40 percent increase in fleet-wide fuel economy in new vehicles between 2010 and 2020 raising the combined fleet average from 25 miles per gallon (mpg) to 35 mpg for the 2017 model year by 2020 [368].	2007

Technology Push Policies for EV Technologies in United States of America			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Economic and financial instruments	R&D investments	Advanced Technology Vehicles Manufacturing (ATVM) loan programme provided \$2.4 billion (€1.75 billion) loans to Nissan, Tesla Motors and Fisker to develop EV technologies [291].	2008
Economic and financial instruments	R&D investments	EISA established a Near-Term Transportation Sector Electrification Programme and authorized \$95 million (€69.5 million) grants per year [368].	2008-2013
Economic and financial instruments	R&D investments	EISA further authorized DOE to disperse \$90 million (€66 million) grants per year with the Plug-in Electric Drive Vehicle Programme [368].	2008-2012
Soft instruments	Public-private partnerships	USA-China Electric Vehicles Initiative was launched to accelerate the development of EV technologies	2009
Soft instruments	Public-private partnerships	Japan and USA signed "Memorandum of Understandings" to develop EV technologies	2009
Economic and financial instruments	R&D investments	ARRA provided \$2.0 billion (€1.46 billion) with advanced battery and electric drive component manufacturing grants program to support 30 factories producing EV components [368].	2009
Soft instruments	Long term goals and visions	The government aimed to put one million EVs on the road by 2015 [86].	2009
Economic and financial instruments	R&D investments	DOE committed \$307 million (€224 million) for Fuel Cell Technologies [291].	2010
Regulatory instruments	Emissions regulations	The federal government and a number of major carmakers reached an agreement on a fleet-wide average 54.4 mpg target by 2025 [76].	2011

Technology-pull policies in USA are summarised in the following page. As can be seen, the government mainly used economic and financial instruments involving tax incentives and infrastructure investments in recent years to increase the demand for EVs.

Technology Pull Policies for EV Technologies in United States of America			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Eco-labelling of vehicles	Fuel economy/consumption labelling programme started [76].	1976
Economic and financial instruments	Infrastructure investments	400 public charging stations in California were installed owing to CARB mandate. They were funded by the government and electric utilities [368].	1990-2000
Soft instruments	Public-private partnerships	National Electric Transportation Infrastructure Working Council was established to formulate recommendations for a standard EV infrastructure [367].	1991
Regulatory instruments	Mandatory use in public sector fleet	EPAct required that 75% of new light duty vehicles acquired by certain federal fleets must be alternative fuel vehicles [373].	1992
Soft instruments	Public-private partnerships	“Clean Cities” partnership was founded to deploy alternative fuel vehicles and the fuelling stations and help accelerating the entry of EVs into the marketplace [368].	1993
Soft instruments	Eco-labelling of vehicles	Federal law required auto dealers to have copies of gas mileage guides available on the showroom floor. The DOE also maintains fuel economy and green vehicle guides (www.fueleconomy.gov/ and www.epa.gov/greenvehicles/) [76].	2000
Economic and financial instruments	Tax incentives	EPAct of 2005 offered a tax credit up to $2400 (€1465) for HEVs based on an individual model’s fuel efficiency and fuel savings. The credit was designed to be phased out after a manufacturer sold 60.000 qualified vehicles [76].	2005
Economic and financial instruments	Infrastructure subsidies	ARRA supported the deployment of more than 22 000 charging points for EVs in more than 20 cities across the country [76]. ARRA subsidised the expenditures for installing alternative fuelling equipment. The credit amount went up to 50% of the equipment costs (not to exceed $50,000 (€36,600)). Private consumers also received a tax credit of $2000 (€1465) [87].	2009
Economic and financial instruments	Tax incentives	ARRA provided the qualified plug-in electric drive motor vehicle tax credit. It contributes between $2500 (€1830) and $7500 (€5400) to the purchase of a new qualified EVs depending on the battery capacity and the gross vehicle weight. It was aimed to be phased out after 200,000 vehicles from qualified manufacturers [87]	2009
Economic and financial instruments	Purchase of EVs by the government or stakeholders	ARRA supported fuel-efficient vehicles in the federal fleet. $3 billion (€2.20 billion) were allocated for the acquisition of more fuel efficient vehicles for the federal fleet [87].	2009-2011
Soft instruments	Public-private partnerships	The Electric Vehicles Standards Panel was formed to foster coordination and collaboration on standardization matters [367].	2011
Soft instruments	Eco-labelling of vehicles	Fuel economy label was updated listing more information for the customers [76].	2011

Appendix A.2 EV Policy Review of Japan

Aim: Japan wants to improve fuel efficiency, decrease CO_2 emissions, diversify the energy mix, and introduce next-generation vehicles to the market on a full-scale basis. The Japanese automobile industry aims to maintain its leadership in high-rate technical capacity on the global market by creating new industry sectors and acquiring new markets. By doing so, the country's economy and employment are aimed to be improved [87].

Key stakeholders: The Japanese vehicle manufacturers play a key role for the market penetration of EVs. In addition to their high expenditure on R&D, they are also involved in the development of the charging infrastructure [86]. New Energy and Industrial Technology Development Organization (NEDO) and the Ministry of International Trade and Industry (MITI) which funds NEDO are other major stakeholders. In 2001, MTI`s role was taken over by the Ministry of Economy, Trade and Industry (METI). NEDO has created R&D plans that individual private enterprises are not capable of implementing on their own [374].

Overall strategy: MITI identified EVs as a long-term target for vehicle development. The government aimed to influence the direction of technology development by setting long-term goals and issuing ambitious market development plans. MITI funded programmes were usually long (longer than 10 years) and divided into three phases: (i) R&D on basic technologies, (ii) demonstration and prototype and (iii) production and early deployment [375]. As the Japanese automotive industry is technology leading in the area of EVs and MITI recognises the lack of charging facilities as one of the most serious challenges for the widespread diffusion of BEVs in Japan, the government has focused on developing charging infrastructure recently [86].

Technology-push policies in Japan are summarised in the next pages.

Technology Push Policies for EV Technologies in Japan			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Public-private partnerships	Japanese Electric Vehicle Association was established for a coordinated effort [375]	1976
Soft instruments	Long term goals and visions	MITI aimed to have 200,000 BEVs on the road until 2000. This was a de-facto technology strategy for BEVs. In 1997, the plan was revised to include not only BEVs, but also HEVs, compressed natural gas vehicles, methanol-fuelled vehicles and FCEVs under the definition of Clean-Energy Vehicles [375]	1991-2000
Economic and financial instruments	R&D investments	The government spent 1,850 million Yen (€13.4 Million) on polymer electrolyte fuel cells with new sunshine programme [376]	1992-1998
Economic and financial instruments	R&D investments	R&D for lithium batteries was conducted through the “Lithium Battery Energy Storage Technology Research Association” with a total budget of 14 billion Yen (€101 Million) [375]	1992-2001
Economic and financial instruments	R&D investments	World energy network (WENET) programme conducted hydrogen research for hydrogen storage and hydrogen production, and carried out field tests for hydrogen energy solutions. The government spent EUR 51 Million for basic R&D [374].	1993-1998
Soft instruments	Public-private partnerships	MITI has included other ministries in the process as a consequence of the administrative reform and ‘‘diversified interest in society’’. Thus, an interministerial action programme was formed and included government actors outside of the office of MITI more in the strategic process of planning for new visions [375]	1996
Economic and financial instruments	R&D investments	600 million Yen (€4.33 Million) were spent with the objective of developing different high-energy efficient HEVs with "Advanced Clean Energy Vehicle Programme" [375].	1997-2003
Regulatory instruments	Emissions regulations	Japan included motor vehicles in its Top Runner Programme. Top runner standards are based on best performing vehicles in the national market and on a range of other factors. These standards set efficiency levels to be reached by gasoline and diesel powered light commercial vehicles by 2010. It ensures flexibility and technology neutrality, as the requirements based on energy performance give automobile manufacturers the freedom to develop their own solutions. In 2007, the government published updated Top Runner light commercial vehicles for light duty vehicles to reach in 2015. These are based on establishing the most fuel efficient vehicles in each of 16 different weight classes [76].	1998
Soft instruments	Demonstration programmes	The government spent EUR 81 Million for WENET demonstration programme [374]	1999-2003
Soft instruments	Long term goals and visions	The Policy Study Group for FCEVs organised by METI aimed to have 50.000 FCEVs between 2005 and 2010. The target for the year 2020 is 5,000,000 sold FCEVs [375]	2000
Soft instruments	Long term goals and visions	MITI`s plan drafted in 1991 failed. New targets were set: 110,000 BEVs, 2,110,000 FCEVs and HEVs in the country by the year 2010.	2001
Soft instruments	Public-private partnerships	JEVA and Japanese Automotive Research Institute (JARI) were integrated to JARI [375]	2003
Regulatory instruments	Emissions regulations	Under the terms of the Kyoto Protocol enforced in 2005, Japan is to reduce its total annual volume of GHG emissions to 6% below the 1990 level by 2008-2012 [76].	2005

Technology Push Policies for EV Technologies in Japan			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Public-private partnerships	The Japanese government announced the "Next-Generation Vehicle and Fuel Initiative" which established diffusion targets for alternative-energy/next generation vehicles [291]	2007
Economic and financial instruments	R&D investments	Development of high-performance battery system for next-generation vehicles project run with the aim of battery module for PHEVs. The project allocated EUR 17.9 Million [377]	2007-2011
Soft instruments	Public-private partnerships	Japan and USA signed "Memorandum of Understandings" to develop EV technologies	2009
Economic and financial instruments	R&D investments	With R&D initiative for scientific innovation of new generation batteries (RISING), the government allocated 3 billion Yen (€21.7 Million). The main targets have been the analysis of battery reaction mechanism, guideline to develop new material for li-ion batteries and new materials for post li-ion batteries [377]	2009-2015
Soft instruments	Technology roadmaps	With 'Next Generation Vehicle Strategy", Japan has developed roadmaps in six areas: overall, batteries, natural resources, infrastructure, system integration, and international standards [363]	2010
Soft instruments	Public-private partnerships	The Japan Smart Community Alliance (JSCA) was established. JSCA acts as an umbrella programme for many of Japan's electric mobility demonstration projects [291]	2010
Soft instruments	Public-private partnerships	JARI, Japan Society of Automobile Engineers and the German Society of Automobile Manufacturers agreed for establishing a common framework. Hence, NEDO and the German Ministry of Education and Research signed a research agreement to cooperate on batteries, rapid chargers, EVs and on the policy measures to promote them	2010
Soft instruments	Long term goals and visions	"Next Generation Vehicle Strategy" was released. This was a technology neutral strategy aimed to support new vehicle technologies simultaneously until 2030. The aim was achieving EV percentage of 20–50% of new vehicles by 2020 and 50–70% of newly sold vehicles by 2030. The plan also aims a full-scale diffusion of HEVs by the year 2050 [87]	2010
Economic and financial instruments	R&D investments	Under next generation vehicle strategy, speedy innovation of li-ion and next generation battery material's evaluation R&D programme allocated 250 million Yen (€1.8 Million). Electric energy storage system for grid-connection programme also allocated 2 billion Yen (€14.4 Million) [377]	2010-2014

Technology-pull policies in Japan are also summarised in the next page.

Technology Pull Policies for EV Technologies in Japan

Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Economic and financial instruments	Infrastructure investments	The ECO-Station Project was introduced to establish 2000 fuelling stations for clean energy vehicles until 2000. Approximately 50% of these were planned as BEV charging stations. 14 billion Yen (€101 Million) was allocated for the project. The ECO-Station Project failed to meet the targets as there were only 36 stations for BEVs in 2000 [376].	1993-2000
Economic and financial instruments	Purchase of EVs by the government	Under the Environment Conservation Programme, the government aimed to replace 10% of their public vehicles with LEVs by 2000. Yet, the programme failed and only a few BEVs were actually in use in 2000 [376].	1995-2000
Economic and financial instruments	Subsidies	The first EV incentive programme was introduced under the Environment Conservation Programme. It provided a purchase subsidy of up to 50% of the incremental costs of a BEV as compared with the price of a conventional engine vehicle. As a result, 117 BEVs were sold between 1996 and 1997 with a total cost of 380 million Yen (€2.74 Million) [376].	1996-1997
Economic and financial instruments	Subsidies	The subsidy programme was integrated to the “Clean Energy Vehicles Introduction Programme”. The budget was 9 billion Yen (€65 Million) in 1998 and 10 billion Yen (€72 Million) in 1999 and 2000. HEVs were included to the programme. During 1998–2000 periods, 276 BEVs and 12,242 HEVs were subsidized. The programme was extended until 2003 [376].	1998-2003
Regulatory instruments	Consistent codes and standards	Within the framework of the Millennium Project, JARI and NEDO conducted a standardisation project especially targeting FCEVs. The budget was 4,180 billion Yen (€30.2 Million) between 2000 and 2002. The programme ended in 2005 [376].	2000-2005
Economic and financial instruments	Purchase of EVs by the government	The government took a new initiative to replace all vehicles used by government with LEVs by the year 2004. Of these vehicles, 60% was expected to be HEVs which corresponds to roughly 4000 vehicles. The rest would mainly be replaced by compressed natural gas vehicles and some BEVs [376].	2001-2004
Soft instruments	Eco-labelling of vehicles	Japan introduced a Fuel efficiency labelling system in connection with the Top Runner Programme. The system was updated in 2006. The labelling scheme allowed to identify if the vehicle is "fully compliant", "plus 5%", "plus 10%" or "plus 20%" higher than the fuel economy standard [76].	2004
Economic and financial instruments	Subsidies	The government supported EVs by paying half of the price gap between EV and corresponding ICE vehicles, up to up to 1 million Yen (€7218) per vehicle. Additionally, 250,000 Yen (EUR 1805) were provided as scrapping bonus for the replacement of at least 13 years old cars. The government allocated approximately 370 billion Yen (€2.67 Billion) for the incentives programme, which could lead to the sale of up to 690,000 vehicles [87].	2009
Soft instruments	Public-private partnerships	"Association for the Promotion of Electric Vehicles" was established to diffuse EVs and to conduct information campaigns	2010
Soft instruments	Long term goals and visions	Japan aimed to have 5,000 quick chargers and 2 million normal chargers by 2020 according to "Next Generation Vehicle Strategy" [291, 363]	2010
Soft instruments	Public-private partnerships	Toyota, Nissan, Mitsubishi, Fuji Heavy Industries and Tokyo Electric Power Company established the association CHAdeMo (Charge Move), in order to install standardized, rapid charging points and equipment [378]	2010
Economic and financial instruments	Infrastructure investments	The government has aimed to contribute 100 billion Yen (€ 722 Million) for funding a nation-wide charging infrastructure. It will be powered by renewable energy and will be installed in cooperation with CHAdeMo association. The charging infrastructure climbed from 60 public charging stations in 2010 to 1381 public quick-charge stations in December 2012, representing the largest deployment of fast chargers in the world [86].	2010-2020

Appendix A.3 EV Policy Review of the EU

Aim: European Commission (EC) focuses around three public priorities: security of energy supply, climate protection, and competitiveness. In that context, the EU aims to promote sustainable growth, reduce the EU's dependency on fossil fuels and its emissions resulting from the transport sector [87].

Key Stakeholders: The EC coordinates activities at a European level, and supports the introduction of alternative transportation technologies. After the establishment of the European Green Vehicles Initiative (EGVI) in 2008, most measures on EU-level for electric mobility are bundled in the EGVI.

Overall Strategy: Although, initially, the EC focused on the supply side activities, recently, the EC declared to become market leader and technological champion for EVs by setting up "Green vehicles: a European strategy" including both technology-push and technology-pull measures

Technology-push policies in EU are displayed below.

Technology Push Policies for EV Technologies in the European Union

Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Economic and financial instruments	R&D investments	During the fourth framework programme (FP4), €9 million were spent to understand the technological alternatives and evaluate the effects of different technological solutions in order to contribute to the development, integration and management of a more efficient, safer and environmentally friendly transport system [379].	1994-1998
Regulatory instruments	Emissions regulations - Voluntary	EU set voluntary targets agreed with the European Automobile Manufacturers' Association (ACEA). These targets were designed such that through technological adjustments, the average emissions of all new cars sold in the EU would be no more than 140g CO_2/km by 2008 and through non-technological measures (taxation/labelling) would reach 120g CO_2/km by 2012 [29].	1998
Economic and financial instruments	R&D investments	FP5 funded R&D activities for EVs with 2 thematic programmes: competitive and sustainable growth, and energy, environment and sustainable development. Approximately €90 million public funding were allocated for 16 collaborative projects (2 Biofuel, 7 HCEVs, 6 FCEVs and 1 BEV) [379].	1998-2002
Economic and financial instruments	R&D investments	FP6 supported the development of EV technologies with sustainable development, global change and ecosystems thematic programme. Approximately €301 million were allocated to 50 collaborative projects (15 Biofuel, 34 FCEVs and 1 BEV) [379].	2002-2006
Soft instruments	Public-private partnerships	European Road Transport Research Advisory Council (ERTRAC) was established. ERTRAC developed a shared vision and ensured a timely, coordinated and efficient implementation of transport research in Europe	2003
Soft instruments	Public-private partnerships	European Hydrogen and Fuel Cells Platform was established in December 2003	2004
Soft instruments	Technology Roadmaps	The European Hydrogen and Fuel Cell Technology Platform adopted a research agenda for accelerating the development and market introduction of fuel cell and hydrogen technologies within the European Community	2005

Technology Push Policies for EV Technologies in the European Union

Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Economic and financial instruments	R&D investments	FP7 highlighted the importance of EV technologies and approximately allocated €410 million for 86 projects (16 Biofuel, 1 Hybrid, 34 FCEVs and 65 BEVs) [379].	2007-2013
Soft instruments	Demonstration programmes	Several demonstration programmes have been launched. Demonstration projects covering the period from 2007 to 2015 add up to total of €470 million [380].	2007-2015
Soft instruments	Public-private partnerships	EGVI was launched. After the establishment of EGVI, most measures on EU-level for electric mobility are bundled in the EGVI [381].	2008
Soft instruments	Public-private partnerships	The "Joint Technology Initiative on Fuel Cells and Hydrogen" was launched on 14 October 2008 during the General Assembly of Fuel Cells and Hydrogen Stakeholders. It was aimed to reduce time to market for hydrogen and fuel cell technologies by between 2 and 5 years	2008
Economic and financial instruments	R&D investments	€4 billion loan were provided for the support of R&D on technologies and infrastructures by EGVI. Projects related to fully electric and HEVs were aimed to be supported [381].	2008-2011
Economic and financial instruments	R&D investments	Fuel Cells and Hydrogen Joint Undertaking provided €940 million (including 50% industry cost share) to accelerate the development and market deployment of FCEVs through the 2015-2020 timeframe [380].	2008-2013
Regulatory instruments	Emissions regulations	In 2009, the EU adopted a regulation which established a CO_2 emission target of 130 g/km for the average of new cars sold by 2015. This regulation was amended in 2014 to establish a CO_2 emission target of 95 g/km by 2020 [29].	2009
Soft instruments	Technology Roadmaps	EU published European Roadmap for Electrification of Road Transport. This roadmap is dedicated to fully electrified or Plug-in-Hybrid passenger cars. The document identified three milestones for EVs: introduction (adapting and converting existing vehicles) in 2012, intermediate (2nd generation EV updated powertrain) in 2016 and mass production in 2020. It also set EV deployment targets: 200,000 (PH)EVs by 2012; 1 million EVs/PHEVs by 2016 and 5 million EVs/PHEVs by 2018 [382].	2009
Soft instruments	Long term goals and visions	EU declared to become market leader and technological champion for EVs by setting up "Green" vehicles: a European strategy.	2010
Soft instruments	Technology Roadmaps	European Roadmap for Electrification of Road Transport was updated. Updated multi-annual roadmap comprised three pillars: electrification of road transport, long distance transport, and logistics and co-modality and defined R&D objectives [52]	2011

Technology-pull policies in the EU are also summarised in the next page.

Technology Pull Policies for EV Technologies in the European Union			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Eco-labelling of vehicles	Directive 1999/94/EC has required dealers in new passenger cars to provide potential buyers with information on vehicle consumption and CO_2 emissions. The fuel economy label must be attached to the windscreen of all new passenger cars at the point of sale [76].	2000
Economic and financial instruments	Tax incentives	Most of the countries within the EU have introduced CO_2-based car taxes favouring EVs starting with FP7 (especially after 2009). In 2010, 17 of the 27 European Union member states provided tax incentives for EVs [76].	2007
Economic and financial instruments	Subsidies	Green vehicles: a European strategy detailed an action plan composed of over 40 concrete and ambitious measures. One significant measure was that the EC planned to present guidelines on financial incentives to consumers to buy green vehicles in order to encourage coordination of demand-side measures adopted in Member States.	2010
Regulatory instruments	Consistent codes and standards	The Communication (based on Green vehicles: a European strategy) highlighted several actions required to establish a regulatory framework for EV technology. Through working together with international partners at the United Nations Economic Commission for Europe, the EC aimed to propose technical rules relating to electric safety for vehicle type-approval. The EC also mandated the European standardisation bodies to adopt a European harmonised approach for the charging system of batteries used in EVs so that this system is compatible with and can recharge all types of batteries of EVs and it can operate in all EU States.	2010
Economic and financial instruments	Infrastructure investments	Member states started developing infrastructure development plans owing to the new emission regulations and the Commission`s Green Vehicle Strategy	2010
Soft instruments	Technology Roadmaps	The Roadmap on Regulation and Standards for EVs were published in December 2010. It defined follow-up activities aimed at creating the necessary conditions for market deployment of EVs in Europe [380].	2011

Appendix A.4 EV Policy Review of France

Aim: The development of EVs is seen as a twofold opportunity in order to fight against climate change, while simultaneously restructuring the automotive sector to ensure the future viability of the domestic automotive industry and to safeguard jobs [87].

Key stakeholders: Due to the high subsidy level, the French market for EVs is highly dependent on political decisions, making the French Government the most important stakeholder. The French State also holds 15% of the shares in Renault. Other important stakeholders are the automobile manufacturers particularly Renault and PSA Peugeot Citroën [86].

Overall strategy: The focus of French EV initiatives is primarily monetary, focusing on familiarising potential users of EVs with the vehicles, and making sure that the necessary charging infrastructure is in place. Cooperation between the public and private sectors is created under the leadership of the government. Since 2009, the government aims that supply and demand of EVs goes hand in hand for increasing the public profile of EVs and making their production commercially viable [364].

Technology-push policies used in France are summarised in the next page.

Technology Push Policies for EV Technologies in France

Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Public-private partnerships	French Environment and Energy Agency (ADEME) was launched to increase efforts in developing BEV technologies [181].	1991
Economic and financial instruments	R&D investments	During PREDIT 3 (Programme de recherché et d'innovation dans les transports terrestres 3), initiatives were launched such as the plan for a clean and economical vehicle in 2003 (Plan Véhicules Propres et Economes). Overall, €145 million were spent for 165 research projects for EVs [181].	2002-2006
Soft instruments	Public-private partnerships	iDforCAR, Pôle Véhicule du Futur (Solutions for Future Vehicles & Mobility) and Lyon Urban Truck and Bus clusters were launched. These pole organisations aimed to strengthen the competitiveness of the sector and sustainable mobility through innovation and collaboration. In 2006, Mov'eo (private cars and public transport safe for man and his environment) cluster was also established. Mov'eo forecasts developments in clean technologies, decarbonised vehicles and life cycle assessment [181].	2005
Soft instruments	Technology Roadmaps	ADEME published a road map to 2050 for the private vehicle – fuel combinations in order to determine R&D priority topics. The roadmap identified three families of topics, which then formed the subject of R&D "prioritisation": motor propulsion system, reduced vehicle energy demand and vehicle pool and usage segmentation	2007
Regulatory instruments	Emissions regulations	"First Grenelle Act" aimed to reduce CO_2 emissions by 75% until 2050 as compared to 1990 levels	2008
Economic and financial instruments	R&D investments	Based on the Environment Round Table (Grenelle) strategy, €137 million R&D budget was agreed for the projects which were near commercialisation. By including PREDIT 4 funds and R&D expenditures by pole organisations, this figure added up to €400 Million [181].	2008-2012
Economic and financial instruments	R&D investments	The 'Automobile Pact' allocated €250 million loan for the industrialisation of decarbonised vehicles [87].	2009
Soft instruments	Technology Roadmaps	ADEME published technology roadmap for Low-Carbon Vehicles. The roadmap aimed two interdependent objectives: powertrain electrification which is partial (hybrid and rechargeable hybrid) or total (electric vehicles), and development and deployment of new concepts, effective components for engines and dedicated auxiliaries, and related services	2009
Regulatory instruments	Emissions regulations	France is bounded with the EU regulation that has been adopted in December 2008 enforces member states to decrease their CO_2 emissions	2009
Soft instruments	Long term goals and visions	"Low-carbon vehicle plan" was published. The plan set targets for the market share of EVs of newly sold vehicles: 7% until 2015 (16% in 2020, 27% in 2025) and 450.000 vehicles shall have been deployed (2 million by 2020, 4.5 million by 2025) [364].	2009
Economic and financial instruments	R&D investments	The "Grand Emprunt" announced in December 2009 allocated €750 million loan for the development of EVs. Specific funding was also made available for the construction and development of a battery production factory with a capacity of up to 350,000 batteries. The eco-conception of batteries and their recycling were defined as research priorities [87].	2010

Technology-pull policies used in France are described below.

Technology Pull Policies for EV Technologies in France

Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Economic and financial instruments	Infrastructure investments	A protocol was signed between government and the industry. Whereas automobile companies would manufacture thousands of BEVs, Electricite de France (EDF) would build the appropriate charging infrastructure by 1995 [339].	1992-1995
Soft instruments	Long term goals and visions	100,000 BEVs goal was set by the year 2000. The state launched an agreement with Renault and PSA, and EDF on recharging infrastructure aiming at the use of 100,000 BEVs by 2000 through state organisations and local authorities. Yet, only 7,059 EVs were in use in 2000 [339].	1995-2000
Soft instruments	Public-private partnerships	The association Espace Mobilités Electriques (EME) was set up by EDF, the French electricity utility company, and the City of Paris, in order to provide information about all types of EVs [339].	1997
Soft instruments	Eco-labelling of vehicles	The EU Parliament introduced legislation requiring that information on fuel economy and CO_2 emissions must be provided to consumers for all new passenger cars [76].	2000
Soft instruments	Eco-labelling of vehicles	A labelling system for new vehicles based on their CO_2 emissions (7 categories symbolised by labels ranging from dark green to red) has been implemented	2006
Economic and financial instruments	Subsidies	"Bonus-Malus" scheme was introduced. This one-time purchase tax (subsidy) levies a Malus ranging between €200 and € 3600 for the owners of the cars emitting more than 160g CO_2/km, or provides a Bonus ranging between €300 and €5000 to the owners of the cars emitting less than 130g of CO_2/km. During 2008 and 2010, the cost of the system was €1.25 billion [76]. Although this system aimed reducing CO_2 emissions, it was criticised for favouring diesel cars due to their comparatively low consumption compared to gasoline engines. The share of diesel-driven new cars rose to more than 70% in 2012 [181].	2008
Economic and financial instruments	Subsidies	There was also a “super bonus” of €200 which consists of an additional premium paid in case of the disposal of an old vehicle (more than 15 years old) and the purchase of a new green car. During 2008 and 2010, the cost of the system was €1.2 billion [76].	2008
Economic and financial instruments	Infrastructure investments	Under the Grenelle 2 law, the government declared a plan to encourage the deployment of public charging infrastructure for EVs in 11 French regions. With the Future Investment Programme (Programme Investissements d’Avenir), €50 million were provided to cover 50% of the equipment and installation costs. €60 million was also made available for the installation of 1250 public recharging points around 20 agglomerations until 2012 [86].	2010-2012
Regulatory instruments	Consistent codes and standards	Every new building was obliged to be equipped with parking units to connect these to electricity supply by 2012 in order to assure the supply of appropriate recharging infrastructure. Car parks at work places had to be equipped with electricity connections by 2015 [86].	2010-2015
Soft instruments	Long term goals and visions	A recharging infrastructure of 9.9 million points has also been aimed to be established until 2025 (thereof 9 million private points, 750,000 public normal charging and 150,000 public rapid charging points).	2010
Economic and financial instruments	Purchase of EVs by the government	A purchase group of 20 industry partners was formed and an agreement was signed in 2010 setting up EV pilot schemes in 12 municipalities that guaranteed a demand of 50.000 BEVs by 2015. First orders were placed in October 2011. Renault received an order of 15,637 utility vehicles over the duration of 4 years mainly to equip the vehicle fleet of La Poste (French Postal Service). PSA also received an order of 3074 vehicles of its Peugeot Ion model [87].	2011-2015

Appendix A.5 EV Policy Review of UK

Objective: The UK government aims to decarbonise the transportation sector, support the national economic competitiveness and growth, and improve the life, health and safety [286]. The government also considers such a transition to EVs to be an opportunity for local SMEs to become a more significant part of a future automotive regime by becoming suppliers of alternative technologies [55].

Key stakeholders: Due to the high subsidy level, the UK market for EVs is highly dependent on political decisions. In this regard, the most important stakeholder is the government of UK. Other important stakeholders are the vehicle manufacturers, component suppliers and banks [86].

Overall strategy: Supported by the three key government departments (the “Department for Transport” (DfT), the “Department for Business, Innovations and Skills” (BIS) and the “Department of Energy and Climate Change” (DECC)), research councils and the automotive industry, an interconnected set of organisations have implemented a strategic innovation strategy aimed at developing the EV sector in the UK. A key priority for both DfT and BIS has been the revitalisation of the domestic automotive sector by exploring the potential for EV production (both component and assembly) to become a core activity within the UK automotive sector [192]. Hence, the UK government has created a number of funding programmes to achieve such aim.

Technology-push policies used in UK are described in the next page.

Technology Push Policies for EV Technologies in United Kingdom			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Public-private partnerships	The Low Carbon Vehicle Partnership was established to accelerate a sustainable shift to lower carbon vehicles and fuels and create opportunities for UK businesses	2003
Soft instruments	Public-private partnerships	The Centre of Excellence for Low Carbon and Fuel Cell Technologies (CENEX) was established to promote UK market development in low carbon and fuel cell technologies for transport applications, principally by focusing on market transformation projects linking technology providers and end users [55].	2005
Soft instruments	Public-private partnerships	The Technology Strategy Board (TSB) was established to promote innovation and the adoption of new technologies. It supports collaborative R&D through Knowledge Transfer Networks, the Low Carbon Vehicles Innovation Platform (LCVIP) and CENEX. TSB also plays an active role in developing national policy related to EVs [55].	2007
Economic and Financial instruments	R&D investments	£250 million (€300 million) of joint government and industry investments were provided for a range of R&D projects associated with EV technologies by the TSB under LCVIP. Several R&D competitions were launched to accelerate the development of EV technologies [292].	2007-2012
Soft instruments	Network Management	The New Automotive Innovation and Growth Team (NAIGT) was formed to develop strategies for UK automotive industry and provide the key components for policy planning for EV sector [192].	2008
Regulatory instruments	Emissions regulations	UK government legislated the "Climate Change Act" which is a binding GHG emission reduction target of 80% by 2050 relative to 1990 levels	2008
Soft instruments	Technology Roadmaps	NAIGT have agreed a roadmap (product development roadmap for HEVs, BEVs, FCEVs and R&D roadmap) from 2009 to 2050	2009
Soft instruments	Technology Roadmaps	Integrated Delivery Programme was created to maximize the benefit to UK-based businesses of the rapidly-developing low carbon vehicles market and to help accelerate the adoption of low carbon vehicles in UK [55].	2009
Regulatory instruments	Emissions regulations	UK committed itself to the "European Energy and Climate Policy Package" setting a CO_2 emission reduction target of 20% by 2020	2009
Economic and Financial instruments	R&D investments	Office for Low Emission Vehicles (OLEV) allocated £80 million (€100.5 million) for supporting R&D activities [292].	2009
Soft instruments	Demonstration programmes	The Ultra-low Carbon Vehicle Demonstrator Programme operated by the TSB made £25million (€30 million) of funding available to several stakeholders. The programme was recognised to be Europe's largest real world trial of low carbon vehicles [87].	2009-2012
Soft instruments	Public-private partnerships	The Automotive Council was formed to further develop the technology roadmaps for low carbon vehicles and fuels, and exploit opportunities to promote UK as a strong candidate to develop EV technologies [350].	2010

Technology-pull policies used in UK are described in the next page.

Technology Pull Policies for EV Technologies in United Kingdom

Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Eco-labelling of vehicles	The EU Parliament introduced legislation requiring that information on fuel economy and CO_2 emissions must be provided to consumers for all new passenger cars [76].	2000
Soft instruments	Eco-labelling of vehicles	A new "Green Label" started to appear in car showrooms across UK to let the consumer know about the environmental impact of the cars	2005
Economic and Financial instruments	Purchase of EVs by the government	Low Carbon Vehicle Public Procurement Programme (LCVPP) was set up as an initiative by CENEX. LCVPP provided £20 million (€30 million) to support the trial of over 200 electric and low emission vans in a range of public fleets [55].	2007
Soft instruments	Public-private partnerships	OLEV was established to encourage the adoption and widespread use of low emission vehicles. OLEV released a policy paper on ‘Ultra-Low Carbon Vehicles in the UK’ in 2009, which mainly referred to BEVs [55].	2009
Economic and Financial instruments	Subsidies	Scrappage incentive scheme was introduced offering £2000 (€2512) cash incentive to trade in old car for new low carbon vehicle	2009-2010
Economic and Financial instruments	Tax incentives	Vehicles below 100 g CO_2/km were exempted from annual circulation tax. EVs also received a five-year exemption from company car tax (until 2015) [87].	2010
Economic and Financial instruments	Purchase of EVs by the government	A funding of up to £1.7 million (€2 million) was made available for any public fleet buyers to purchase a further 500 low carbon vans from the procurement framework by the LCVPP [55].	2011
Economic and Financial instruments	Tax incentives	Low emission vehicles were exempted from congestion charges in London [87].	2011
Economic and Financial instruments	Subsidies	OLEV provided a plug-in car grant with a total budget of £300 million (€370 million). It was equivalent to 25% of the car price (up to a limit of £5000 (€6200)). Motorists were also entitled to 25% (up to £5,000 (EUR 6283)) off the list price of an eligible car. Cars with tailpipe emissions of 75g CO_2/km or less, including BEVs, FCEVs and HEVs were all potentially eligible for the subsidy [86].	2011
Economic and Financial instruments	Infrastructure investments	The government launched Plugged-in Places programme with £30 million (€37 million) funding [55]. The programme aimed to create a critical mass of infrastructure for 8 pilot projects and install 8.500 charge points	2011

Appendix A.6 EV Policy Review of Germany

Aim: Four targets are aimed by the German government: climate protection, reducing the dependence on oil, strengthening Germany as an industrial and technological location and reducing local emissions [86]. However, although environmental targets exist too, industrial goals play a more significant role since Germany`s economy is highly dependent on its automotive industry and this is endangered by a global transition from traditional internal combustion engine cars towards EVs.

Key stakeholders: Due to the relative low subsidy level, the German automotive industry is the main driving force when it comes to the organisation and financing of R&D activities. Nevertheless, the automotive industry can revert to a comprehensive research network including technical and non-technical university as well as private and public research institutes. The German government encourages and supports these efforts through the promotion of selected research projects [86].

Overall strategy: The German government aims to create suitable framework conditions for a coordinated research on electric drive technologies. Since the automotive industry itself is the main investor and driver of the market introduction of electric driving, only a moderate public funding-level is provided. Policymakers also create only adequate pressure to incentivise German industry to direct the industry towards electric mobility without destabilizing it [55].

Technology-push policies used in Germany are summarised in the following page.

Appendix A EV Innovation Policies of Selected Regions

Technology Push Policies for EV Technologies in Germany			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Economic and financial instruments	R&D investments	Ministry of Education & Research invested €30 million for electric power and drive train [55].	2005-2010
Economic and financial instruments	R&D investments	The National Innovation Programme provides €1.4 billion (including €700 million in industry funds) to prepare the market for hydrogen and fuel cell technologies [383].	2006-2016
Soft instruments	Long term goals and visions	The German Federal Government aimed to put one million EVs on the road by 2020 and five million EVs on the road by 2030 in accordance with its integrated energy and climate programme [55].	2007
Soft instruments	Public-private partnerships	Lithium Ionen Batterie 2015 – BMBF Innovationsallianz (Lithium-Ion Battery 2015 – BMBF Innovation Alliance) consortium was founded by the companies including BASF, BOSCH, EVONIK, LiTec and Volkswagen [384].	2007
Economic and financial instruments	R&D investments	German Alliance for Automotive Electronics invested €500 million for vehicle electronics in which Ministry of Education & Research contributed €100 million [55].	2007-2012
Regulatory instruments	Emissions regulations - Voluntary	German cabinet adopted climate package setting an ambitious target of achieving 40% reductions on 1990 CO_2 emission levels by 2020. However, it was a voluntary agreement [55].	2008
Regulatory instruments	Emissions regulations	Germany is bounded with the EU regulation. The aforementioned regulation enforces member states to decrease their CO_2 emissions	2009
Economic and financial instruments	R&D investments	One out of 14 resolutions of the Konjunkturpaket II ("Economic Stimulus Package II") specifically addressed electric mobility and allocated €500 million for investments in R&D in the general benefit of electric mobility under the National Electromobility Programme [86].	2009-2011
Economic and financial instruments	R&D investments	Ministry of Economics and Technology also committed to contribute €35 million to BMBF Innovation Alliance for lithium-ion battery research [55].	2009-2012
Economic and financial instruments	R&D investments	In 2007, BMBF Innovation Alliance made a commitment to invest €360 million in lithium-ion battery research between 2009 and 2015, and Ministry of Education & Research contributed €60 million [55].	2009-2015
Soft instruments	Public-private partnerships	The Electric Mobility Summit held in Berlin led to the establishment of National Electric Mobility Platform (NPE), bringing together all the relevant stakeholders from government, industry and society. Seven high-level working groups were created to discuss major issues relating to electric mobility [87].	2010
Soft instruments	Public-private partnerships	The BMWi set up a dedicated electromobility coordination office with the BMVBS (Bundesministerium für Verkehr und digitale Infrastruktur - the federal ministry of transport and digital infrastructure) in the guise of the Joint Agency for Electric Mobility (GGEMO). GGEMO were specially created to bundle and coordinate the federal government's electromobility tasks. It also supports the federal government and NPE [384].	2010
Soft instruments	Technology Roadmaps	NPE`s seven working groups created technology roadmaps for the realization of the objectives laid out in the National Electromobility Development Plan. NPE defined interdisciplinary lighthouses and thematic clusters to encourage linkages in the field of electromobility based on the technology roadmaps [384].	2010
Soft instruments	Long term goals and visions	NPE`s interim report proposed increasing R&D funding to €4 billion between 2012 and 2020	2010
Soft instruments	Public-private partnerships	JARI, Japan Society of Automobile Engineers and the German Society of Automobile Manufacturers agreed upon to establish a common framework. Hence, NEDO and the German Ministry of Education and Research signed a research agreement to cooperate on batteries, rapid chargers, EVs and on the policy measures to promote them	2010

Technology-pull policies used in Germany are described below.

Technology Pull Policies for EV Technologies in Germany			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Eco-labelling of vehicles	The EU Parliament introduced legislation requiring that information on fuel economy and CO_2 emissions must be provided to consumers for all new passenger cars [76].	2000
Economic and financial instruments	Tax incentives	Completely electric vehicles (BEVs and FCEVs) were exempted from motor vehicle tax [384].	2009
Soft instruments	Long term goals and visions	Germany aimed to adopt a holistic approach to electromobility; covering everything from the vehicle itself through to a charging network, traffic management system and smart grid power supply with NPE in order to achieve one million EV goal by 2020 [384].	2010
Soft instruments	Technology Roadmaps	German Commission for Electrical, Electronic & Information Technologies created standardization roadmap for electromobility [384].	2010

Appendix B SQL Code Used for Gathering Patent Filings in Selected Regions

Sample SQL Code for B60L IPC Coded Patents that were filed in USA

```
SELECT appln_id, appln_filing_year, nb_citations, appln_auth, appln_nr, COUNT(*)
FROM tls201_appln a
WHERE
 EXISTS
 (SELECT i.appln_id
 FROM tls209_appln_ipc i
 WHERE i.appln_id = a.appln_id
 AND ipc_class_symbol LIKE 'B60L%')
 and appln_filing_year >= 1990
AND appln_auth = 'US'
group by appln_filing_year
order by appln_filing_ye
```

Appendix C All Generated Data Sets for ANFIS

Year	UK				France				Germany				EU				USA				Japan			
	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y
1990	-1.40	0.00	0.00	-1.40	-1.30	0.00	0.00	-1.20	-1.40	0.00	0.00	-1.30	-1.10	0.00	0.00	-1.10	-1.20	7.44	7.45	-1.10	-1.30	3.55	0.00	-1.20
1991	-1.40	0.00	0.00	-1.20	-1.20	3.06	0.00	-1.10	-1.30	0.00	0.00	-1.20	-1.10	0.00	0.00	-1.00	-1.10	15.09	10.87	-1.10	-1.20	6.71	0.00	-1.10
1992	-1.20	0.00	0.00	-1.10	-1.10	3.06	3.52	-1.00	-1.20	0.00	0.00	-1.10	-1.00	0.00	0.00	-1.00	-1.10	18.64	14.35	-1.00	-1.10	15.23	0.00	-1.00
1993	-1.10	0.00	0.00	-1.00	-1.00	3.06	3.52	-0.90	-1.10	0.00	0.00	-1.00	-1.00	0.00	0.00	-0.90	-1.00	22.90	17.87	-0.90	-1.00	19.49	4.26	-0.90
1994	-1.00	0.00	0.00	-0.80	-0.90	3.06	3.52	-0.80	-1.00	0.00	0.00	-0.90	-0.90	4.24	0.00	-0.90	-0.90	22.90	17.87	-0.90	-0.90	19.49	4.26	-0.80
1995	-0.80	0.00	0.00	-0.70	-0.80	3.06	5.99	-0.70	-0.90	0.00	0.00	-0.80	-0.90	4.24	0.00	-0.80	-0.90	22.90	17.87	-0.80	-0.80	19.49	7.90	-0.70
1996	-0.70	0.00	0.00	-0.60	-0.70	3.06	5.99	-0.60	-0.80	0.00	0.00	-0.60	-0.80	4.24	0.00	-0.70	-0.80	22.90	17.87	-0.70	-0.70	23.04	11.62	-0.60
1997	-0.60	0.00	0.00	-0.40	-0.60	3.06	9.41	-0.50	-0.60	0.00	0.00	-0.50	-0.70	4.24	0.00	-0.60	-0.70	22.90	17.87	-0.60	-0.60	27.30	11.62	-0.50
1998	-0.40	0.00	0.00	-0.30	-0.50	3.06	9.41	-0.40	-0.50	0.00	0.00	-0.40	-0.60	11.72	0.00	-0.50	-0.60	22.90	17.87	-0.50	-0.50	31.19	15.36	-0.40
1999	-0.30	0.00	0.00	-0.20	-0.40	3.06	9.41	-0.30	-0.40	0.00	0.00	-0.20	-0.50	11.72	0.00	-0.30	-0.50	26.42	17.87	-0.40	-0.40	34.85	15.36	-0.30
2000	-0.20	0.00	3.19	0.00	-0.30	3.06	12.60	-0.20	-0.20	0.00	3.19	0.00	-0.30	11.72	3.19	-0.20	-0.40	26.42	21.06	-0.20	-0.30	38.01	18.50	-0.10
2001	0.00	0.00	3.19	0.10	-0.20	3.06	12.60	0.00	0.00	0.00	3.19	0.20	-0.20	11.72	3.19	0.00	-0.20	30.66	21.06	-0.10	-0.10	41.17	22.12	0.00
2002	0.10	0.00	3.19	0.30	0.00	7.30	12.60	0.20	0.20	0.00	3.19	0.40	0.00	15.96	3.19	0.20	-0.10	33.82	21.06	0.10	0.00	41.17	22.12	0.20
2003	0.30	3.52	3.19	0.50	0.20	7.30	12.60	0.40	0.40	0.00	3.19	0.60	0.20	19.61	3.19	0.30	0.10	37.95	21.06	0.40	0.20	44.69	22.12	0.30
2004	0.50	3.52	3.19	0.60	0.40	7.30	12.60	0.60	0.60	0.00	3.19	0.70	0.30	23.26	3.19	0.50	0.40	37.95	21.06	0.60	0.30	44.69	25.31	0.50
2005	0.60	7.04	6.38	0.70	0.60	10.82	12.60	0.70	0.70	4.26	3.19	0.80	0.50	26.42	3.19	0.60	0.60	37.95	24.80	0.80	0.50	48.58	25.31	0.70
2006	0.70	7.04	6.38	0.90	0.70	10.82	15.79	0.90	0.80	8.39	3.19	1.00	0.60	26.42	3.19	0.90	0.80	37.95	24.80	1.10	0.70	48.58	25.31	0.90
2007	0.90	14.82	9.89	1.10	0.90	13.98	15.79	1.10	1.00	19.20	3.19	1.10	0.90	34.10	6.93	1.10	1.10	41.84	24.80	1.30	0.90	56.34	25.31	1.20
2008	1.10	22.23	9.89	1.30	1.10	22.11	23.27	1.40	1.10	22.57	3.19	1.30	1.10	49.38	6.93	1.40	1.30	54.56	24.80	1.50	1.20	56.34	25.31	1.40
2009	1.30	36.97	17.26	1.60	1.40	36.48	23.27	1.70	1.30	38.84	6.93	1.50	1.40	56.43	6.93	1.80	1.50	69.02	35.90	1.70	1.40	64.12	29.05	1.70
2010	1.60	40.49	21.00	1.90	1.70	40.74	33.81	2.20	1.50	55.49	13.25	1.80	1.80	59.59	17.91	2.40	1.70	73.28	35.90	1.90	1.70	81.72	43.38	2.10

Year	USA+Japan				USA+Germany				USA+EU				Japan+Germany				Japan+EU				UK+France			
	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y
1990	-1.31	10.99	7.45	-1.23	-1.29	7.44	7.45	-1.24	-1.17	7.44	7.45	-1.13	-1.36	3.55	0	-1.28	-1.32	3.55	0	-1.23	-1.35	0	0	-1.28
1991	-1.23	21.80	10.87	-1.14	-1.24	15.1	10.9	-1.17	-1.13	15.1	10.9	-1.08	-1.28	6.71	0	-1.17	-1.23	6.71	0	-1.13	-1.28	3.06	0	-1.18
1992	-1.14	33.87	14.35	-1.04	-1.17	18.6	14.4	-1.09	-1.08	18.6	14.4	-1.02	-1.17	15.23	0	-1.06	-1.13	15.23	0	-1.03	-1.18	3.06	3.52	-1.07
1993	-1.04	42.39	22.13	-0.95	-1.09	22.9	17.9	-0.99	-1.02	22.9	17.9	-0.95	-1.06	19.49	4.26	-0.96	-1.03	19.49	4.26	-0.94	-1.07	3.06	3.52	-0.97
1994	-0.95	42.39	22.13	-0.85	-0.99	22.9	17.9	-0.90	-0.95	27.1	17.9	-0.88	-0.96	19.49	4.26	-0.86	-0.94	23.73	4.26	-0.85	-0.97	3.06	3.52	-0.85
1995	-0.85	42.39	25.77	-0.76	-0.90	22.9	17.9	-0.80	-0.88	27.1	17.9	-0.80	-0.86	19.49	7.9	-0.76	-0.85	23.73	7.9	-0.76	-0.85	3.06	5.99	-0.74
1996	-0.76	45.94	29.49	-0.66	-0.80	22.9	17.9	-0.69	-0.80	27.1	17.9	-0.71	-0.76	23.04	11.6	-0.65	-0.76	27.28	11.6	-0.65	-0.74	3.06	5.99	-0.64
1997	-0.66	50.20	29.49	-0.54	-0.69	22.9	17.9	-0.58	-0.71	27.1	17.9	-0.61	-0.65	27.3	11.6	-0.52	-0.65	31.54	11.6	-0.53	-0.64	3.06	9.41	-0.52
1998	-0.54	54.09	33.23	-0.43	-0.58	22.9	17.9	-0.46	-0.61	34.6	17.9	-0.51	-0.52	31.19	15.4	-0.39	-0.53	42.91	15.4	-0.41	-0.52	3.06	9.41	-0.38
1999	-0.43	61.27	33.23	-0.30	-0.46	26.4	17.9	-0.30	-0.51	38.1	17.9	-0.38	-0.39	34.85	15.4	-0.26	-0.41	46.57	15.4	-0.29	-0.38	3.06	9.41	-0.29
2000	-0.30	64.43	39.56	-0.16	-0.30	26.4	24.3	-0.13	-0.38	38.1	24.3	-0.22	-0.26	38.01	21.7	-0.11	-0.29	49.73	21.7	-0.14	-0.29	3.06	12.6	-0.13
2001	-0.16	71.83	43.18	-0.01	-0.13	30.7	24.3	0.06	-0.22	42.4	24.3	-0.04	-0.11	41.17	25.3	0.04	-0.14	52.89	25.3	0.00	-0.13	3.06	12.6	0.02
2002	-0.01	74.99	43.18	0.17	0.06	33.8	24.3	0.26	-0.04	49.8	24.3	0.15	0.04	41.17	25.3	0.22	0.00	57.13	25.3	0.17	0.02	7.3	12.6	0.24
2003	0.17	82.64	43.18	0.35	0.26	38	24.3	0.46	0.15	57.6	24.3	0.35	0.22	44.69	25.3	0.39	0.17	64.3	25.3	0.34	0.24	10.82	12.6	0.43
2004	0.35	82.64	46.37	0.55	0.46	38	24.3	0.67	0.35	61.2	24.3	0.57	0.39	44.69	28.5	0.56	0.34	67.95	28.5	0.51	0.43	10.82	12.6	0.61
2005	0.55	86.53	50.11	0.75	0.67	42.2	28	0.86	0.57	64.4	28	0.79	0.56	52.84	28.5	0.74	0.51	75	28.5	0.71	0.61	17.86	15.79	0.75
2006	0.75	86.53	50.11	0.98	0.86	46.3	28	1.05	0.79	64.4	28	1.02	0.74	56.97	28.5	0.95	0.71	75	28.5	0.94	0.75	17.86	18.98	0.94
2007	0.98	98.18	50.11	1.23	1.05	61	28	1.24	1.02	75.9	31.7	1.24	0.95	75.54	28.5	1.20	0.94	90.44	32.2	1.20	0.94	28.8	22.49	1.16
2008	1.23	110.90	50.11	1.48	1.24	77.1	28	1.41	1.24	104	31.7	1.47	1.20	78.91	28.5	1.45	1.20	105.7	32.2	1.47	1.16	44.34	29.97	1.41
2009	1.48	129.62	64.95	1.77	1.41	108	42.8	1.66	1.47	125	42.8	1.77	1.45	102.96	36	1.74	1.47	120.6	36	1.78	1.41	69.66	37.34	1.71
2010	1.77	147.96	79.28	2.09	1.66	129	49.2	1.95	1.77	133	53.8	2.14	1.74	130.17	56.6	2.08	1.78	141.3	61.3	2.16	1.71	77.44	51.62	2.14

Year	EU+Germany				USA+Germany+Japan				USA+EU+Japan				EU+Japan+Germany				EU+USA+Germany				EU+USA+Germany+Japan			
	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y	x1	x2	x3	y
1990	-1.31	0	0	-1.25	-1.33	11	7.45	-1.25	-1.29	11	7.45	-1.22	-1.34	3.55	0.00	-1.25	-1.26	7.44	7.45	-1.21	-1.31	10.99	7.45	-1.24
1991	-1.25	0	0	-1.18	-1.25	21.8	10.9	-1.16	-1.22	21.8	10.9	-1.13	-1.25	6.71	0.00	-1.16	-1.21	15.09	10.87	-1.14	-1.24	21.80	10.87	-1.15
1992	-1.18	0	0	-1.09	-1.16	33.9	14.4	-1.06	-1.13	33.9	14.4	-1.03	-1.16	15.23	0.00	-1.05	-1.14	18.64	14.35	-1.07	-1.15	33.87	14.35	-1.05
1993	-1.09	0	0	-0.99	-1.06	42.4	22.1	-0.96	-1.03	42.4	22.1	-0.94	-1.05	19.49	4.26	-0.96	-1.07	22.90	17.87	-0.98	-1.05	42.39	22.13	-0.96
1994	-0.99	4.24	0	-0.91	-0.96	42.4	22.1	-0.86	-0.94	46.6	22.1	-0.85	-0.96	23.73	4.26	-0.86	-0.98	27.14	17.87	-0.90	-0.96	46.63	22.13	-0.87
1995	-0.91	4.24	0	-0.80	-0.86	42.4	25.8	-0.77	-0.85	46.6	25.8	-0.76	-0.86	23.73	7.90	-0.76	-0.90	27.14	17.87	-0.80	-0.87	46.63	25.77	-0.77
1996	-0.80	4.24	0	-0.68	-0.77	45.9	29.5	-0.66	-0.76	50.2	29.5	-0.66	-0.76	27.28	11.62	-0.65	-0.80	27.14	17.87	-0.69	-0.77	50.18	29.49	-0.66
1997	-0.68	4.24	0	-0.56	-0.66	50.2	29.5	-0.54	-0.66	54.4	29.5	-0.55	-0.65	31.54	11.62	-0.53	-0.69	27.14	17.87	-0.59	-0.66	54.44	29.49	-0.54
1998	-0.56	11.72	0	-0.42	-0.54	54.1	33.2	-0.42	-0.55	65.8	33.2	-0.43	-0.53	42.91	15.36	-0.40	-0.59	34.62	17.87	-0.47	-0.54	65.81	33.23	-0.42
1999	-0.42	11.72	0	-0.25	-0.42	61.3	33.2	-0.28	-0.43	73	33.2	-0.31	-0.40	46.57	15.36	-0.27	-0.47	38.14	17.87	-0.31	-0.42	72.99	33.23	-0.29
2000	-0.25	11.72	3.19	-0.07	-0.28	64.4	42.8	-0.14	-0.31	76.2	42.8	-0.16	-0.27	49.73	21.69	-0.12	-0.31	38.14	24.25	-0.14	-0.29	76.15	42.75	-0.14
2001	-0.07	11.72	3.19	0.12	-0.14	71.8	46.4	0.02	-0.16	83.6	46.4	-0.01	-0.12	52.89	25.31	0.03	-0.14	42.38	24.25	0.04	-0.14	83.55	46.37	0.02
2002	0.12	15.96	3.19	0.31	0.02	75	46.4	0.20	-0.01	91	46.4	0.17	0.03	57.13	25.31	0.21	0.04	49.78	24.25	0.23	0.02	90.95	46.37	0.20
2003	0.31	19.61	3.19	0.46	0.20	82.6	46.4	0.38	0.17	102	46.4	0.34	0.21	64.30	25.31	0.38	0.23	57.56	24.25	0.42	0.20	102.25	46.37	0.38
2004	0.46	23.26	3.19	0.61	0.38	82.6	49.6	0.57	0.34	106	49.6	0.54	0.38	67.95	28.50	0.54	0.42	61.21	24.25	0.62	0.38	105.90	49.56	0.56
2005	0.61	30.68	3.19	0.77	0.57	90.8	53.3	0.77	0.54	113	53.3	0.74	0.54	79.26	28.50	0.73	0.62	68.63	27.99	0.81	0.56	117.21	53.30	0.76
2006	0.77	34.81	3.19	0.95	0.77	94.9	53.3	0.98	0.74	113	53.3	0.97	0.73	83.39	28.50	0.95	0.81	72.76	27.99	1.01	0.76	121.34	53.30	0.97
2007	0.95	53.3	6.93	1.14	0.98	117	53.3	1.22	0.97	132	57	1.22	0.95	109.64	32.24	1.19	1.01	95.14	31.73	1.22	0.97	151.48	57.04	1.21
2008	1.14	71.95	6.93	1.35	1.22	133	53.3	1.46	1.22	160	57	1.48	1.19	128.29	32.24	1.44	1.22	126.51	31.73	1.42	1.21	182.85	57.04	1.45
2009	1.35	91.48	10.7	1.68	1.46	168	71.9	1.74	1.48	190	71.9	1.77	1.44	155.60	39.72	1.75	1.42	160.50	46.57	1.70	1.45	221.10	75.62	1.75
2010	1.68	111.29	28	2.13	1.74	203	92.5	2.06	1.77	211	97.2	2.13	1.75	189.49	71.35	2.12	1.70	181.05	63.87	2.07	1.75	255.73	107.25	2.10

Appendix D Austrian Innovation Policies for EV Technologies

Technology push policies for EV Technologies in Austria are summarised below.

Technology Push Policies for EV Technologies in Austria			
Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Long term goals and visions - Voluntary	Austrian Government formulated a strategy to achieve the Kyoto goals. The goal was limiting emissions each year in the transport sector with maximum limit of 16.3 million ton. However, the goal was voluntary not mandatory	2002
Economic and financial instruments	R&D investments	Austrian government spent approximately €60 million for R&D projects in the field of alternative propulsion systems	2002-2014
Soft instruments	Public-private partnerships	"Austrian Agency for Alternative Propulsion Systems" (A3PS) which is a PPP of enterprises, research institutions and federal ministries was founded to develop and coordinate activities concerning alternative propulsion systems	2006
Soft instruments	Public-private partnerships	VIRTUAL VEHICLE competence centre for virtual development and optimisation of vehicles started implementing EV projects. The centre is an international platform which is co-funded by the government and about 120 companies and scientific partners	2008
Soft instruments	Public-private partnerships	"eConnected Austria" was set up. In several working groups comprising representatives form industry, research institutions, governmental organisations and non-governmental organisations, the status quo and the necessities for electric mobility development were defined.	2008-2010
Regulatory instruments	Emissions regulations	Austria is bounded with the EU regulation that was adopted in 2009. It enforces member states to decrease their CO_2 emissions	2009
Economic and financial instruments	R&D investments	"Austrian Electric Mobility Flagship Projects" providing funding for R&D projects focussed on the whole electric vehicle mobility system (vehicle, infrastructure, users) started. The Budget was approximately €35 million	2009-2014
Soft instruments	Long term goals and visions	Austrian government set EV goals: 130.000 to 150.000 BEVs and 900.000 PHEVs on Austrian roads by 2020	2010
Soft instruments	Public-private partnerships	Austrian government supported transnational engagement of Austrian enterprises in international projects (e.g. VIBRATE, HUBJECT, etc.)	2010-2014
Soft instruments	Technology roadmaps	An implementation plan for electric mobility, elaborated by a working group consisting of representatives of the Ministry of Innovation, the Ministry of Environmental Affairs and The Ministry of Economic was prepared.	2012
Regulatory instruments	Emissions regulations	"Austrian Climate Protection Act" passed. Maximum emissions of road transport sector for each year for the period 2013 – 2020 was limited to 21 million ton	2013

Technology pull policies for EV Technologies in Austria are described below.

Technology Pull Policies for EV Technologies in Austria

Instrument Typology	*Instrument*	*Activities*	*Key Dates*
Soft instruments	Awareness campaigns	Pilot communities to establish green tourism were supported. For example, Werfenweng could only be visited without cars or only with EVs.	1997-2014
Soft instruments	Eco-labelling of vehicles	The EU Parliament introduced legislation requiring that information on fuel economy and CO_2 emissions must be provided to consumers for all new passenger cars	2000
Economic and financial instruments	Infrastructure investments	"Electric Mobility Models Regions" started. With this programme, developed solutions were tested by end users. The purchase of charging stations and EVs, the provision of renewable energy and the development of new business models and mobility were the core content of the programme. Total budget was €150 million	2008-2014
Economic and financial instruments	Subsidies	Klimaaktiv mobil (Climate: active mobil) programme started. It supported the procurement of EVs. Funding was only available for enterprises and communities.	2008-2014
Economic and financial instruments	Tax incentives	EVs were exempted from the insurance tax and Austrian registration tax	2008-2014
Economic and financial instruments	Subsidies	Funding for the procurement of EVs for private customers were provided	2010-2014
Economic and financial instruments	Purchase of EVs by the government	Several enterprises, owned by the federal government such as federal post, federal railways started a fleet conversion (Conventional vehicles were replaced by EVs)	2012
Economic and financial instruments	Free parking	Free reserved parking space with charging infrastructure for EVs were provided in several cities	2012
Regulatory instruments	Consistent codes and standards	Austrian government and companies engaged in standardisation processes on international level such as charging plug, communication protocols etc. to ensure standardisation and interoperability for EVs	2012
Soft instruments	Awareness campaigns	Education programmes for electric mobility were started. Courses were held to train mechanics and fire brigades	2012

Appendix E Technology Push and Pull Instruments for Scenarios 1 and 2

Technology push policies for EV Technologies in Austria for Scenarios 1 and 2 are detailed below.

Technology-Push Policies for EV Technologies in Austria			*Scenarios*	
Typology	*Instrument*	*Activities*	*Scenario 1*	*Scenario 2*
Soft instruments	Demonstration programmes	Awareness-raising campaigns for electromobility are initiated simultaneously. An important aspect of this is designing new demonstration programmes for EVs	X	X
Soft instruments	Technology Roadmaps	A joint communication strategy to foster electromobility step by step is prepared. The Austrian electromobility roadmap is also regularly updated in cooperation with the domestic research institutions and the automotive industry		X
Soft instruments	Long term goals and visions	Long-term potential of hydrogen for Austria is analysed by identifying obstacles related to eco-efficient hydrogen production and hydrogen infrastructure and defining any potentials of added value for Austria.	X	X
Economic and financial instruments	R&D Investments	New R&D investments are provided to develop hybrid, battery electric and fuel-cell electric vehicles. Research between universities and non-university research institutions with the industry is also supported	X	X
Soft instruments	Network Management	Setting up a coordination group of ministries and research funding agencies for the technical orientation, optimisation and simplification of electromobility-related programmes and procedures. Here, information gained by experience so far is exchanged and future developments of the electromobility-relevant stakeholders are discussed.	X	X
Economic and financial instruments	Creation of niche markets	Development of technology competence for recycling procedures and the recovery of materials in Austria and extending competence for substitution technologies and appropriate organisational concepts. For this aim, the establishment of business locations focussing on material recovery such as rare earths and other materials in Austria is supported.		X
Economic and financial instruments	Creation of niche markets	Supporting investments, production and new industrial settlement in the field of electromobility from Austria		X
Soft instruments	Network Management	Supporting the international cooperation of Austrian institutions and enterprises in the fields of R&D as well as the enhanced integration of electromobility activities and projects in European and international demonstrations	X	X
Soft instruments	Education and Training	Designing education and training programmes to develop skills for intelligent production technologies and processes, especially for the flexible and competitive production of small, medium and large numbers of EVs and EV infrastructures. A training module “e-vehicle” in the apprenticeship automobile technology is aimed to be implemented. Implementation of a course system is also aimed to promote trainers to create a sufficient number of apprentice jobs.	X	X
Soft instruments	Education and Training	Establishing practical research trainings for young researchers in the field of electromobility. Strengthening international cooperation in education and research with leading universities and research institutions in Europe, USA, and Asia.		X

Technology pull policies for EV Technologies in Austria for Scenarios 1 and 2 are described below.

Technology-Pull Policies for EV Technologies in Austria			*Scenarios*	
Typology	*Instrument*	*Activities*	*Scenario 1*	*Scenario 2*
Regulatory instruments	Consistent codes and standards (Set-up and operation of charging stations)	Drafting a catalogue specifying relative necessary minimum standards for safety regulations of the charging infrastructure. Drafting of recommendations and directives for the set-up of public and semi-public charging stations including fast charging stations. Drafting recommendations for the harmonisation of the framework conditions and procedures for the set-up and the operation of charging stations jointly with all federal provinces.	X	X
Regulatory instruments	Consistent codes and standards (Parking facilities)	Drafting of national recommendations and planning basics for garages on the basis of technical requirements specifying the adaptation of construction and design regulations for user-friendly parking facilities with regard to access, authorisation, and billing systems for EVs	X	X
Economic and financial instruments	Infrastructure investments	Further development of the support of charging stations following the criteria catalogue specifying charging infrastructure requirements, focussing especially on enhanced system effects		X
Economic and financial instruments	Subsidies	Direct support for the purchase of EVs is examined, further developed and continued. New vehicle classes such as REEV and PHEV are included in the support measures		X
Economic and financial instruments	Tax incentives	If feasible, retaining the exemption of the standard fuel-based vehicle consumption tax (NoVA) and the engine power-related vehicle insurance tax for EVs	X	X
Economic and financial instruments	Purchase of EVs by the government	Existing structures for the purchase of EVs by the public sector with Austrian federal procurement agency are used increasingly (Extending efforts)		X
Soft instruments	Awareness campaigns	Integration of electromobility to tourism strategies. For example, tourism communities can rent EVs for users so that they can be tested	X	X
Soft instruments	Network management	Participating in international panels and committees designed for the preparation of normative standards for the construction, measurement and registration regulations for EVs	X	X
Soft instruments	Eco-labelling of vehicles	Examination of options for the provision of information and labelling of the positive effects on the environment and climate before and when vehicles are purchased. To quantify and monitor the effects of electromobility on the environment, the necessary basic data is compiled. The information on EVs available on the market is also enhanced by using existing structures such as the internet platform (www.autoverbrauch.at)	X	X
Regulatory instruments	Traffic regulations (Bus lane access etc.)	Drafting requirements and recommendations of electromobility for the traffic and area planning and making the traffic framework conditions attractive for EVs. Here, review and adaptation of federal matters such as Road Traffic Code, Motor Vehicles Act and other respective regulations are aimed.		X

Appendix E Technology Push and Pull Instruments for Scenarios 1 and 2

Technology-Pull Policies for EV Technologies in Austria			*Scenarios*	
Typology	*Instrument*	*Activities*	*Scenario 1*	*Scenario 2*
Soft instruments	Awareness campaigns	Raising awareness of engineers and technicians for attractive career options ("technical career ladder") for electromobility. Raising awareness for EVs by making changes within the framework of traffic education of children		X
Soft instruments	Education and Training	Adaptation and upgrading of existing curricula, as well as education and training of teacher teams in electromobility at schools to establish the electromobility subject. Besides, drafting a "train-the-trainer" concept for the qualification of teachers in schools.		X
Soft instruments	Education and Training	Setting up training programmes for the staff in trading and selling, operation and maintenance of EVs to make them familiar with the requirements of electromobility.		X
Soft instruments	Education and Training	Integrating EVs to driving schools. For this, appropriate training programmes are developed for driving instructors, and teaching materials and test catalogues for driving licence tests are updated.		X
Soft instruments	Technology roadmaps	Collating and drafting of national positions vis-à-vis the energy and charging infrastructure by the ÖVE (Austrian Electrotechnical Association)/ASI (Austrian Standards Institute) joint working group to design step by step infrastructure development and deployment strategies	X	X

Appendix F Technology Push and Pull Instruments for Scenario 3

Technology push policies for EV Technologies in Austria for Scenario 3 are displayed below.

Technology-Push Policies for EV Technologies in Austria for Scenario 3

Typology	*Instrument*	*Activities*
Soft instruments	Demonstration programmes	Designing new demonstration programmes with the objective of supporting micro, small and medium sized enterprises (SMEs)
Soft instruments	Technology Roadmaps	Working out a joint communication strategy with SMEs to foster electromobility in and from Austria in time, and, step by step. The Austrian electromobility roadmap is also regularly updated in cooperation with all relevant stakeholders
Economic and financial instruments	R&D Investments	New R&D investments are provided to develop hybrid, battery electric and fuel-cell electric vehicles. Research between universities and non-university research institutions with the industry is also supported
Soft instruments	Network Management	Setting up a coordination group of the ministries and the research funding agencies for the technical orientation, optimisation, and simplification of electromobility-related programmes and procedures for SMEs.
Economic and financial instruments	Creation of niche markets	Development of technology competence for recycling procedures and the recovery of materials in Austria and extending competence for substitution technologies and appropriate organisational concepts by supporting SMEs in these areas
Economic and financial instruments	Creation of niche markets	Supporting investments, production and new industrial settlement in the field of electromobility with the focus on SMEs.
Soft instruments	Network Management	Supporting the international cooperation of Austrian SMEs in the fields of R&D, as well as the enhanced integration of any electromobility activities and projects in European and international demonstrations
Soft instruments	Education and Training	Supporting SMEs to develop skills for intelligent production technologies and processes, especially for the flexible and competitive production of small, medium and large numbers of EVs and EV infrastructures. A training module “e-vehicle” in the apprenticeship automobile technology is aimed to be implemented. Implementation of a course system is also aimed to promote trainers to create a sufficient number of apprentice jobs.
Soft instruments	Education and Training	Establishing practical research trainings for young researchers in the field of electromobility. Strengthening international cooperation in education and research with leading universities and research institutions in Europe, USA, and Asia.
Regulatory Instruments	Patent Regulations	Patent regulations are reviewed and specific SME technology protection measures are designed

Technology Pull Policies for EV Technologies in Austria for Scenario 3 are outlined below.

Technology-Pull Policies for EV Technologies in Austriafor Scenario 3

Typology	*Instrument*	*Activities*
Regulatory instruments	Consistent codes and standards	Developing standards for the set-up and operation of charging stations in Austria
Regulatory instruments	Consistent codes and standards	Developing standards for the parking facilities of EVs
Economic and financial instruments	Subsidies	Direct support is to be examined, further developed, and continued for EVs
Economic and financial instruments	Tax incentives	Exempting EVs from the standard fuel-based vehicle consumption tax (NoVA) and the engine power-related vehicle insurance tax
Soft instruments	Network Management	Participation in international panels and committees in the preparation of normative standards for the construction, measuring, and registration regulations for EVs
Economic and financial instruments	Infrastructure investments	Further development of the infrastructure investments for installing the necessary charging facilities for EVs
Soft instruments	Education and Training	Adaptation and upgrading the existing curricula, as well as education and training of teacher teams in electromobility at schools to establish the electromobility subject and create awareness
Regulatory instruments	Traffic regulations (Bus Lane Access)	Making the traffic framework conditions attractive for EV users. Thus, federal matters such as Road Traffic Code, Motor Vehicles Act and other respective regulations are reviewed and changed
Economic and financial instruments	Purchase of EVs by the government	Supporting SMEs by purchasing innovative products of SMEs with Austrian federal procurement agency