Ca' Foscari University of Venice

Master's Degree programme
in Economics and Finance (LM-56)

Final Thesis

Scale Evolution of the Electric Vehicles in the Automotive Market: An Analysis through the System Dynamics Approach

Supervisor
Professor Enrica De Cian

Co-Supervisor
Professor Carlo Giupponi

Graduand
Andrea Polesel
Matriculation number 861815

Academic year
2021/2022

Abstract

Nowadays, cars became a first necessity good, because they allow people to cover long distances in short time. It is possible to observe how the car itself, the overall automotive industry, and the mobility concept, changed over the years. In fact, the modern era is characterized by the debate on diesel- and petrol-powered cars versus electric powered vehicles. This debate is at the centre of the automotive and mobility industry, which is connected to the energy sector in some sense. The main reasons regard emissions and car engines that are energy efficient exploiting full power from the source of energy decreasing emissions as much as possible. European political entities are pushing towards this direction as climate change has become the focus for sustainability policies, and automotive industry needs to change as it is one of the main causes of emissions. Many EU regulations provide target levels to respect by 2030 and car producers are making progresses in trying to reach low emission levels becoming carbon free. Pushed by sustainability and green policies, consumers are trying to change their preferences when they are considering buying an electric car. Consumers make comparisons between electric cars and diesel or petrol cars, (from now conventional vehicles) in order to understand price differences and the main characteristics that differentiate one from the other. To get better insights of consumers' perceptions, a survey was built with this specific objective, and it will be crucial for the model building as it clarifies what the real preferences and expectations of consumers are. In fact, through the model, which follows a system dynamics approach, we are going to simulate if it is possible to see a turning point in the automotive industry, given psychological, economic and demographic aspects. After having provided the above-mentioned premises, the next chapters of this research will break down the study object, the model and the main idea behind it, culminating with a final presentation of the results and some considerations about possible alternatives in mobility and a major push to investigate in such matter.

Contents

1 The Automotive Market Situation: An Introduction to the Study

1.1 Electric VS Conventional Vehicles: the modern era debate

Nowadays, the automotive and mobility industry is characterized by a very important debate that will completely change our daily life. Such debate has arose after all the policies stipulated by the EU Commission are focused on the reduction of CO2 and greenhouse gas (GHG) emissions, aiming at zero emission by 2050. Such objective is the result of many policies, which started in 1997 with the publication of the Kyoto Protocol by the UNFCCC (United Nations Framework Convention on Climate Change), counting 192 participating nations[1]. The nations involved in this policy want to make an effort in reducing the emissions through the adoption of mitigation strategies, that will be discussed later in this section. The Kyoto Protocol has initialized a deeper analysis on emissions produced by each sector for every country, in particular, the four major producers of pollutants are power, industry, agriculture, forestry and land use (AFOLU) and global transport in 2019[2]. As a matter of fact, global transport sector contributed to produce 9 Gt of CO2 and other pollutants, of which, 69% comes from roads and passenger cars[3]. In this sense, the EU Commission has focused on this sector, in order to revise and make automotive and mobility sectors moving towards a "cleaner" and "green" direction, reducing the impact that they have on climate change, and pushing for the implementation of new powertrains such as electric and plug-in hybrid, which should replace the conventional ICE (Internal Combustion Engine) powertrains. Other important contributions regarding the decarbonization of automotive sector coming from the policy environment can be found in the Paris' Agreement setting the objective of carbon neutrality by 2050[4] in Europe. Moreover, European countries are following the carbon neutrality path, in

[1] "What is the Kyoto Protocol?", UNFCCC, 1997

[2] WG III contribution to the Sixth Assessment Report, IPCC, 2021

[3] ibid

[4] Paris Agreement, UNFCCC, December 2015

particular Italy has taken part to the Paris' Agreement thorugh the D.lgs. 204/2016[5], making the effort to reduce emissions thorugh the years. Moreover, Italy is constantly providing new mitigation strategies enlisted in the "Piano Nazionale Integrato per l'Energia e il Clima" (PNIEC)[6] published by the environmental, transport and infrastructure and economic development ministries. Some of the mitigation strategies that the ministry want to adopt regard mainly circular economy, expressed through an efficient use of resources, implying a better input-output ratio, a reduction in the use of carbon-intensive material in the production stage and resource recycling. Moreover, some mitigation strategies were adopted in the mobility sector as well, in particular, the use of electric means such segways and hoverboards to move in the city centre, an incentive encouranging the purchase of less polluting vehicles, the promotion of mobility as a service thorugh electric vehicles and the implementation of biofuels[7], as a cleaner alternative to diesel and petrol fuels, in the logistics sector via trucks, airplanes and other means of transports. Thus, in the context governed by policies which set the emission targets, economists and researchers interrogated themselves on all the possible different aspects regarding electric vehicles and diesel and petrol-powered cars (from now on conventional vehicles). Making such an important decision will influence crucially all the sectors interconnected with the automotive industry, people's lifestyle and the way to organize road trips. In fact, since we are used to petrol and diesel fuels, we can easily organize long road trips, without being worried to plan stops for refuelling, plan the road to take in order to find fuel stations and even plan activities to fill in empty times when refuelling. This is not the case for electric vehicles. Since electric engines technology is at the birth stage, charging stations are very rare to find compared to fuel stations, and the time required to charge batteries depends on two aspects: the type of charging station and the compatibility of the battery with the charging stations. So, choosing between the two

[5]Legge 4 novembre 2016, n. 204, Gazzetta Ufficiale, 2016

[6]"Pubblicato il testo definitivo del Piano Energia e Clima (PNIEC)", Ministero della Transizione Ecologica, 2020

[7]"The contribution of bioenergy to the decarbonization of transport: a multi-model assessment", Muratori et. al, 2020

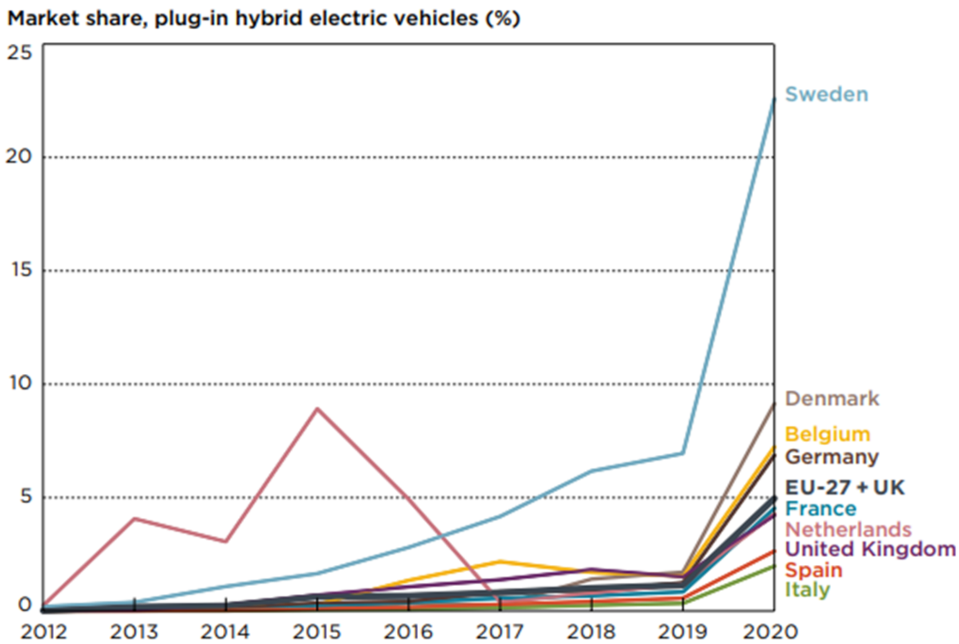
types of drivetrains is not a simple choice, as it involves many aspects, moreover, sustainability, emissions targets and green policies are the focus of EU Commission, since climate change and environmental impact became serious concerns. In fact, automotive industry and mobility sector are the main drivers for CO2 emissions. In this sense, EU Commission has promoted some regulations in order to push towards a cleaner technology, aiming at decreasing constantly CO2 emissions, so reaching the following levels concerning cars:

- 95 gCO2/km during the period 2020-2024;
- a 15% reduction from 2025 on (which should correspond to 80 gCO2/km);
- a 37.5% reduction from 2030 on (corresponding to 50 gCO2/km);
- the final target is to reach a zero level by 2050 (climate neutrality).

The previous target levels were provided the by the regulation (EU) 2019/631 which replaced the regulation (EC) 443/2009[8]. These targets have made a push towards major car producers to innovate and rethink their production lines, in order to meet the above-mentioned targets. Given such context, European countries reacted in different ways, and the different scenarios can be observed by the market share of plug-in hybrid electric vehicles as shown in the graph below:

It can be observed that there are only few countries with a market share of plug-in hybrid vehicles that is above the EU average: Scandinavian countries such as Sweden and Denmark are the leaders in such market. Italy is last in this sort of ranking, as it is struggling to find a good strategy to promote low emissions vehicles, moreover, there are very few fast chargers compared to other European countries.

[8]European Commission, "Regulation (EU) No. 2019/631", 2019



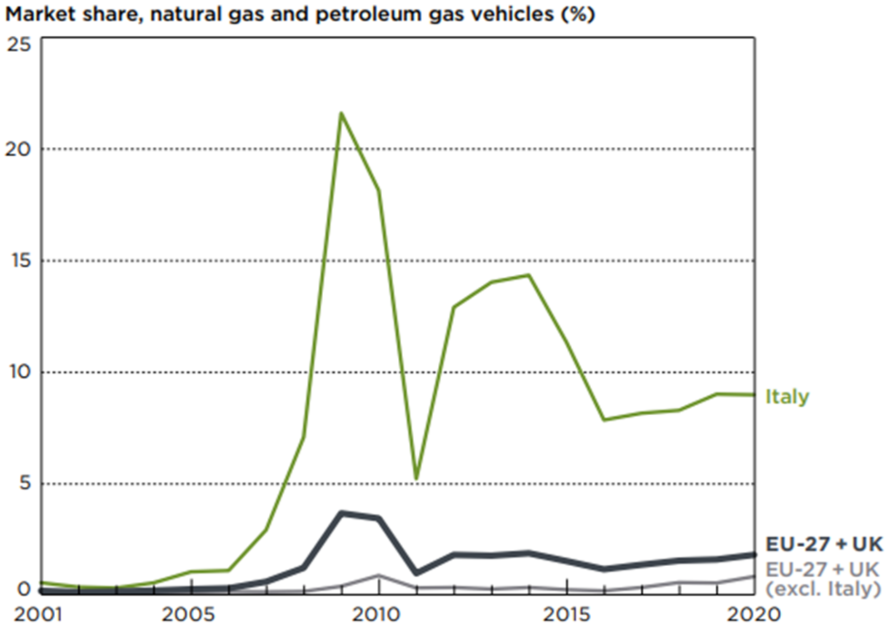
Graph 1.1.1: Market share, plug-in hybrid electric vehicles from 2012 to 2020
Source: ICCT Pocketbook, 2021, https://theicct.org/publication/european-vehicle-market-statistics-2021-2022/

According to the European Automobile Manufacturers' Association (ACEA) figures, Italy has only 9.4% of fast charging points counter parted by 90.6% of normal charging[9] points. The European average for fast chargers is set to be 11.1% of the total charging points, meaning that there is a proportion of one fast charger to nine normal chargers: the European territory is suffering from lack of chargers and very few of these are efficient in terms of time. So, the charging points infrastructure is a problem for the whole EU territory, and Italy in particular, both in terms of availability and time efficiency.

Another figure that characterizes the Italian automotive market regards the choice on LPG (liquified petroleum gas) shown in the graph below:

It can be observed that Italy represents the leading country in LPG vehicles, which can be seen either positively in terms of emissions, as these vehicles have less impact on the environment compared to conventional vehicles, as Italy is implementing LPG as a mitigation strategy, or negatively as this situation represents an obstacle to the

[9] "E-mobility: only 1 in 9 charging points in EU is fast", ACEA, 2021, https://www.acea.auto/press-release/e-mobility-only-1-in-9-charging-points-in-eu-is-fast/

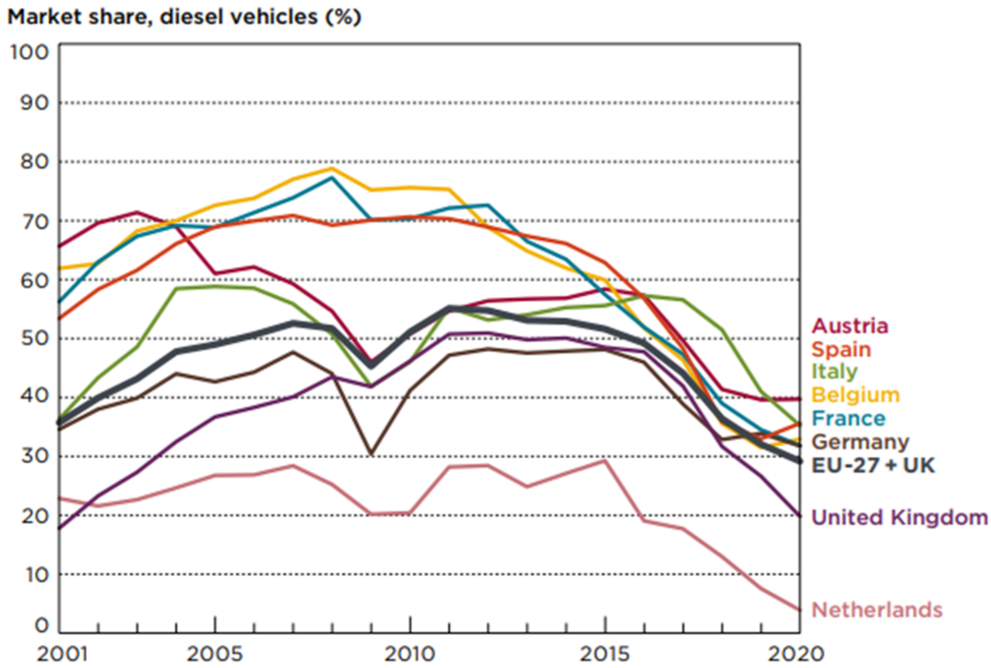


Graph 1.1.2: Market share, natural gas and petroleum gas (LPG) from 2001 to 2020
Source: ICCT Pocketbook, 2021, https://theicct.org/publication/european-vehicle-market-statistics-2021-2022/

implementation of electric vehicles. Even though Italy seems to be moving on the opposite direction with respect to European countries, it has made some improvements in order to meet the emissions targets set by the European Commission. In fact, this can be proved by looking at the market share of diesel vehicles: not only they have decreased, in particular during the period 2017-2020, Italy moved from almost 60% in 2017 to 35% in 2020, meaning that the country made some improvements to promote low emissions vehicles. This is shown in the graph below:

From the graph it is possible to see the different situations among countries in Europe, it is remarkable how Italy was able to reduce the market share of diesel vehicles, giving opportunity to electric vehicles expansion, while reducing CO2 emissions in order to reach the target level set by the European Commission. As a matter of fact, Italy has gone through some important changes in its automotive market, which can be observed even in Stellantis' [10] and Volkswagen Group's [11] long-term strategies: both corporations set the year 2050 to reach carbon neutrality, respecting the Paris

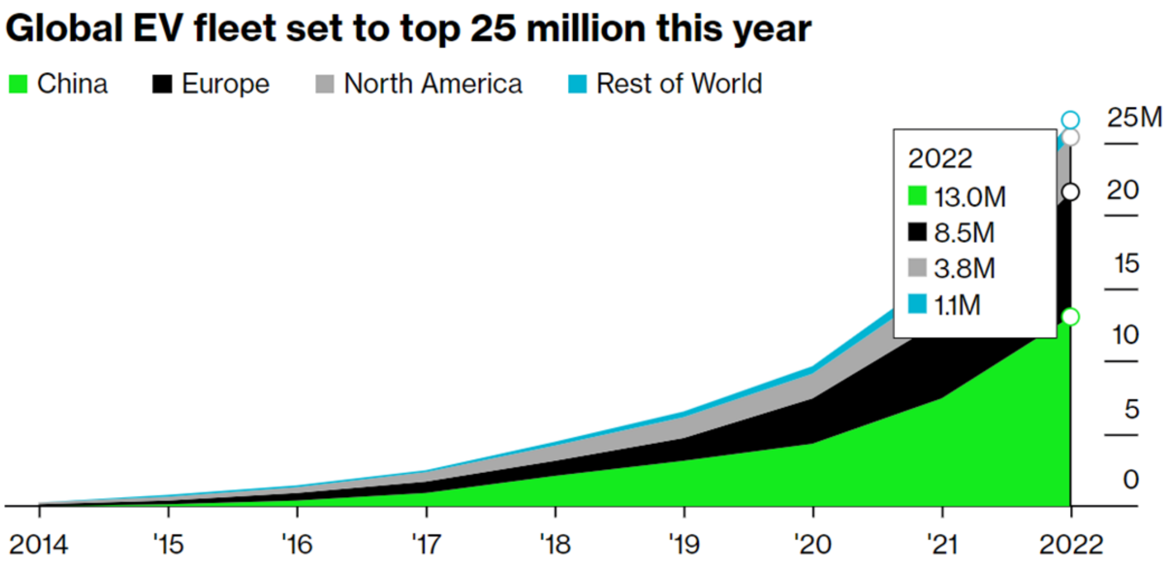
[10] "Annual report 2021 and Form 20-F", Stellantis N.V., 2021
[11] "Annual report 2021", Volkswagen Group, 2021



Graph 1.1.3: Market share, diesel vehicles from 2001 to 2020
Source: ICCT Pocketbook, 2021, https://theicct.org/publication/european-vehicle-market-statistics-2021-2022/

Agreement[12] on climate protection. Since the two corporations have a leading position at the Italian and at the European level, their choices in the long-term strategies and the legal context given by the European regulations and targets about mobility and emissions, changed the direction in the automotive market. To conclude this first introductory paragraph, the real time worldwide situation in the automotive market is very striking: according to Bloomberg's data regarding the European Economic Area and UK, the fleet of electric vehicles has reached 25 million units. This is a remarkable result as there were only one million units of electric vehicles in 2016, and Europe represents the second largest market for electric vehicles behind China. The graph below, represents how the situation looks and will look like:

[12]Paris Agreement, UNFCCC, December 2015



Graph 1.1.4: Global Electric Vehicle fleet real data and forecasts from 2014 to 2022 Source: BloombergNEF, 2022, https://www.bloomberg.com/news/articles/2022-04-08/plug-in-ev-fleet-will-soon-hit-a-20-million-milestone

Moreover, with this figure, Bloomberg is forecasting that electric vehicles will cover 2% of the total automotive market by the end of 2022. All these results are very promising for a possible transition in the automotive sector, so e-mobility could probably become a reality. So, after this brief introduction, it can be observed that the dichotomy Electric vehicles vs Conventional vehicles is very crucial as it does not only affect the automotive sector per se, instead, it does affect all the sectors that are connected to automotive. As a matter of fact, energy and mobility sectors need to respond efficiently in order to meet carbon neutrality objective, as it is the focus of the European Commission and all the sustainability entities, such as the UNFCCC. So, taking the right decisions in order to implement a car that will fit in the sustainability and green context, is a big challenge that car makers are facing, and this will probably change our daily life and the concept of the car itself. In the next paragraph, it will be introduce the study object broken down in all its aspects concerning the reasoning and the main idea behind it.

1.2 Study object: the main idea and the research reasonings

After having described how the automotive sector is characterized and all the changes that need to be implemented in order to meet the emission targets, such sector has to face uncertainty and difficulties: finding the right strategies to promote clean cars while fitting the best engine technology to reduce GHG emissions is a tough challenge. Car producers as Mercedes, Volkswagen and Fiat (to quote some of them) have completely revised their strategies and their production lines, where sustainability, carbon neutrality and electric mobility represent the focus. Another important fact, regarding car makers brands, is that they aim to make partnerships with energy sourcing organizations: FCA (Fiat Chrysler Automobiles) corporation has made an important deal with Enel-X and Engie[13] to acquire the know-how processes to build electric engines. This move brought important improvements in the production line of all the brands associated to FCA (now part of the Stellantis group), in particular, Fiat which was the first Italian brand to present its brand new "500 la prima"[14], entering de facto in the electric powertrain segment. Before Fiat, Volkswagen made a similar strategic move, the group cooperated with Bosch[15] to develop a mobility scheme with the purpose to test electric and automated cars, as part of the long-term strategy TOGETHER2025+. On one hand, it can be observed that car makers are concentrated in making deals with specialized firms in the production of electric engines and automated systems, on the other, they are trying to answer the problem of battery disposal, either through an internalization of the battery recycling process or through cooperation with third parties specialized in such task. Taking for example Fiat, the brand is cooperating with the COBAT association which is specialized in battery recycling and giving a second life to batteries. COBAT support to Fiat was crucial to present and introduce the new Fiat 500 "la prima" back in June 2020[16], pointing out their mission to develop a cost-efficient and competitive zero emission

[13] "Fca, al via partnership con Enel-X ed Engie per le auto elettriche", IlSole24Ore, 2019
[14] "Fiat Nuova 500, debutta la prima auto nata full electric di Fca", IlSole24Ore, 2020
[15] "Volkswagen and Bosch team up to develop self-driving software", FleetEurope, 2022
[16] "Fiat 500 elettrica", COBAT, 2020

technology that can be applied to city cars in general, aiming at reaching a 400 kilometres range benchmark. So, FCA is trying to find a good strategy to answer the problem of batteries second life, and at the same developing a zero-emission technology. On the same line, Volkswagen tried another way to answer the long-term problem of battery disposal, through an acquisition of a battery-recycling site settled in Salzgitter[17]: the group thinks that through the new know-how acquired, they will be able to improve battery efficiency while giving them second life, enforcing their sustainability goal. The above-mentioned strategies and plans should give an example of how firms and main automotive groups reacted to the Commission's regulations in order to meet emissions and sustainability targets. In fact, Fiat and Volkswagen, which cover leading roles in Italy and Europe respectively, are making radical changes to their production lines and their production processes. These changes require time to be fully applied, as the automotive sector is one of the most complicated economic sectors, where effort, research and development departments and skilled workforce make the difference. This represents one side of the whole research, as firms and legal entities need to cooperate to reach the desired goal, on the other side the product should be addressed to satisfy consumers' needs, which are changing following the sustainability trend as well. In this sense, firms are facing another challenge, which is to understand the main factors that can make an electric car more attractive to consumers, while making it competitive with respect to their diesel and petrol counterparts. In fact, finding the right strategy to promote electric powertrains is not simple, as the common mean of transport is represented by diesel or petrol fuelled car. A possible scenario, that firms want to avoid, is that some cars may remain unsold if the electric powertrains long-term project[18] could represent a failure for creating a clean mean of transportation. This would cause a big loss in terms of revenues for car producers, and a complete revision of the production processes and the production lines: basically, a 360-degree reorganization aiming at finding another type

[17] "Giving raw materials a second life", Volkswagen, 2021
[18] "Ambitious Electric Car Sales Targets May Fall Short And Reprieve ICE Power", Forbes, 2022

of clean technology. So, to represent the object of the study, many different methods could be used, such as the agent-based models (ABMs), the integrated assessment models (IAMs) or system dynamics, but all the three methods have different applications. Concerning integrated assessment models, such class models was applied to investigate the technologic and economic feasibility of the possible pathways in order to reach climate goals, holding global warming, as pointed in the Paris Agreement[19]. In the study provided by Climate Analytics by Bill Hare, Robert Brecha and Michiel Schaeffer they demonstrated that thorugh IAMs it is possible to fulfill the objective of limiting global warming to 1.5°C above pre-industrial levels[20]. Integrated assessment models are based on the combination of three different worlds: energy system models, economic system modelling and climate science models as these represent the main fields of application. In particular, recent studies applying IAMs in global warming, find that time-averaged discounted reductions in global GDP associated with mitigation measures in the 1.5°C scenario should result in three times bigger losses with respect to the second scenario of reaching 2°C in the long term. Anyway, the losses in GDP are outweighed by the projected overall GDP growth in pursuing the 1.5°C objective[21]. Yet, IAMs proved that the 1.5°C scenario could be feasible thorugh the addition of carbon capture and storage to fossil fuels power plants, since in IAMs a new technology is scaled up easily if it is very similar to known technologies, so turning out to be a more logical and cost effective strategy than considering new technologies such as utility scale photovoltaics. Integrated assessment models turned to be very sensible to this aspect, in fact in such models the rapid and fast technological advances are not captured, and this could be observed both in the energy sector, as such models do not consider renewable energies as a feasible solution, as well as in the transport sector, electric vehicles were not taken into account, as such powertrain ex-

[19]"Integrated Assessment Models: what are they and how do they arrive at their conclusions?", Climate Analytics, 2018

[20]ibid

[21]"Scenarios towards limiting global mean temperature increase below 1.5°C", Rogelj et al., 2018

perienced a very fast growth[22]. As a matter of fact, IAMs show some issues in keeping up with changes in the real economy, the possible change from conventional vehicles to electric vehicles and the rapid advances in the deployment of solar photovoltaics and the decreasing costs of renewable energies are an example[23]. In this sense, IAMs tend to show a more conservative view of the potential for transformational change, as such models are more representative for gradual changes of existing technologies, instead of rapid technological advances. For what concerns the second class type of models, agent-based models (ABM) are mainly used to evaluate agents' interactions, which compose the mix of stochastic and deterministic actions of all agents, should result in some emergent behaviour across the entire population. In particular, such models wre used to explore the impacts of charging habits of the agents for electric vehicles to capture relevant information about electricity needs[24]. Researchers wanted to investigate the impact of agents' behaviour and routines in charging time schedule to understand the improvements that could be brought in the power system demands. They used the agent-based model to replicate real use of electric vehicles, including road trips and charging strategies of car owners, in order to compare the simulated results with trials results taken from the "My Electric Avenue" (MEA) initiative[25], started in the UK in 2012. The assumptions of the model were stated in the flow diagram of the agent drive cycle, which comprises all the actions that an individual would take at the start, while driving on the road and at the end of the journey about when the car requires to be charged[26]. When the researchers compared the simulated results with real data taken from the MEA initiative, they demonstrated that agent-based simulation of electric vehicle use and charging demands can render a good approximation to real-world power system demands, moreover, electric vehicles battery size can have a significant impact on domestic peak demand as well as on

[22] "Integrated Assessment Models: what are they and how do they arrive at their conclusions?", Climate Analytics, 2018

[23] ibid

[24] "Validation and application of agent-based electric vehicle charging model", Rachel Lee, Saadallah Yazbeck, Solomon Brown, 2020

[25] "My Electric Avenue", EA Technology, 2017

[26] ibid

total household energy supplied[27]. In another research paper, an agent-based model is designed to understand the impact of time-of-use pricing schemes in the Chicago area for drivers of battery-electric vehicles[28]. The four experts build a behavioural heuristic such that battery-electric vehicle drivers have to survey the area once at their destination and pick the station which maximizes their utility (i.e. the closest station, if there is one within a one-mile radius)[29], then a combination of range anxiety and lowerthan-normal prices can lead to a desire to charge proactively. They discovered that if drivers obey this heuristic, it generally results in lower rates of unmet charging demand for drivers below their comfortable battery state-of-charge. However, the use of public chargers increases dramatically in this scenario. Despite the lower unmet demand, such higher public charging station utilization can cause congestion, indicating a need for more investment in charging infrastructure[30]. As a matter of fact this agent-based model was used to gain insights of potential outcomes, such that, under reasonable assumptions, it is possible to guide decision-making processes in a plausible future scenario. Finally, concerning system dynamics, particular studies have been performed using such class of models, where the prediction of a possible transition in the automotive market from conventional to electric vehicles was the focus. The investigation of the connections between different sectors and the causal-effect relations between variables should replicate the functioning of a complex real system, that should bring results near to reality[31]. The researchers studied through a system dynamic approach the factors that could impact and speed up the process of scale of the electric vehicles, providing a possible year of transition in the powertrain, in the Chinese market. They concluded that electric vehicles will substitute conventional vehicles once the technology applied to electric cars is produced on large-scale, while in the early stage of development, because of the low level of technology and imper-

[27]ibid

[28]"Agent-based modeling of electric vehicles with time-of-use electricity rates", Spencer Aeschliman, Yan Zhou, Charles Macal, Zhi Zhou, 2020

[29]ibid

[30]ibid

[31]"Scale Evolution of Electric Vehicles: A System Dynamics Approach", Yue Xiang et al., 2017

fect infrastructure construction, the evolution of such vehicles will be restricted[32]. As a matter of fact, system dynamics turned out to be the most versatile approach among the three, as we can investigate the relations that surround the market, while considering also the psychological aspect driven by consumers' perceptions, and we could study scenarios that could be plausible in the real world. Thus, the objective of the thesis is to illustrate what are the challenges that firms need to face in order to promote electric cars respecting the emission targets dictated by the Commission while satisfying consumers' needs, allowing a better understanding of which factors could make electric mobility our new transportation reality. In this research, we will be trying to go beyond an analysis of firms' strategies and the regulations impact on such sector. The main idea is to build a model which should represent the Italian automotive market and its main variables, observe the cause-effect relations with the economic and demographic variables, and, finally, calibrating the model psychological aspect through a survey analysis, which should resemble the consumers' potential purchase of an electric car. The psychological aspect represents a key part to understand which factors firms should focus on, in order to register an increase in electric vehicles sales and observe a transition in the vehicles' powertrains. Providing a model that can replicate all the cause-effect relations and the links between variables that should simulate the behaviour of the Italian automotive market is not an easy task. Using simple models without considering a survey should bring poor and inconsistent results, as variables could be characterized by more links, instead of being a one-to-one cause-effect relation. Moreover, causal loops should give a better understanding of the model as whole, since variables regarding different sectors are interconnected with other variables regarding other dynamics. To give an example, the total vehicle demand characterizes both the automotive market and GDP and population dynamics. Economic variables and demographics give us an idea about how many cars are needed respecting a target of vehicles per thousand people ratio, while producers keep track of how many cars have to be produced ensuring an increasing number of

[32] ibid

electric vehicles on the roads, reaching a complete transition to such vehicles. So, it can be observed that the automotive world is very complex, and it involves many other sectors. In such scenario, and given the level of complexity, the best model that will fit the best such study object is represented by the class of system dynamics, through which it will provide a simulation of the Italian automotive market regarding the scale of electric vehicles. To conclude this paragraph, the final objective of the simulation is to predict how many years it will take to reach a complete transition from conventional vehicles to electric vehicles, explaining some theoretical elements of this class of models, which will be the focus of the next paragraph.

1.3 Main elements of the approach applied: some basis of system dynamics

As it can be observed in the previous section, the feedback system regarding the automotive sector is a complex system as it is interconnected with economic, legal, social, and environmental aspects, that can imply important changes in the lifestyle and habits regarding car mobility. In fact, the whole system is composed of multiple subsystems, as the automotive sector cannot be taken on its own, as we need to investigate the full net of interconnections between the various factors, in order to understand how the feedback works. As a matter of fact, the main idea of system dynamics methodology is to understand the complexity[33] of such systems and provide a well-functioning strategy elaborated through simulations of possible scenarios. Usually, feedback can be intended as the response of a particular sample under investigation to the system implemented; in system dynamics, such concept goes deeper. Feedback represents the causal loop of all the variables involved[34], where it is supposed that a variable X affects another variable Y, then, closing the loop through a chain of causes and effects from Y to X. Given such image of feedback, which is what we experience in our daily life, system dynamics are the most used class of models to represent the complexity of the reality that is part of all the economic systems. In fact, one of the challenges that is constantly faced by system dynamics regards policy resistance, which is the tendency to remain in the status quo as the response of the system defeats the possibility to implement interventions[35]. A typical example of policy resistance can be represented by all the road building programs: the expected result is to lower traffic congestions and ensuring faster ways to connect one city to another, but the side effects, such as increased traffic and pollution due to the higher number of circulating cars represent big obstacles to implement such programs[36]. In order to fight and overcome policy resistance, researchers need to

[33]"System Dynamics Modelling: tools for learning in a complex world", John D. Sterman, 2002
[34]Ibid
[35]Ibid
[36]Ibid

know how and where this phenomenon comes from, and they need to understand the complexity regarding both systems and mental models. People's mental models are limited, internally inconsistent and they do not investigate the nature of complexity surrounding the entire automotive sector, and this can be extended to other sectors. In general, such decision moving models are short-term oriented, and so, people appreciate more short-term results, without considering the possible negative impacts of their decisions in the long term. For what concerns complexity, it can be intended as the number of components that take part in a system or the number of possibilities one must consider when making a decision[37]. In some cases, the complexity in a particular system lies in finding the best solution among an infinite number of possible solutions, usually referred as combinatorial complexity[38]. An example of high combinatorial complexity could be the interpretation of the FIA Formula One regulation: teams have an infinite number of possible car designs considering chassis, powertrains, aerodynamics and durability. Given these four aspects, the teams have to develop the best possible car aiming to achieve best performance and best adaptability to circuits during the whole season. There exist infinite possibilities to create a car, but only one best solution which is in the hands of engineers specialized in each area of development. Anyway, combinatorial complexity is not the only source of policy resistance, instead, most cases derive from dynamic complexity, where it is observed how the unpredicted behaviour of complex system arises from the interactions of the agents over time[39]. The more agents take part in a system and the more they interact themselves implementing different strategies, the more the system responds in an unpredictable way, and the more it becomes complex. As a matter of fact, systems are characterized by dynamic complexity because they are:

- <u>interconnected</u>: agents tend to interact with other agents and with the surrounding environment, increasing the unpredictability of the system;

[37]Ibid
[38]Ibid
[39]Ibid

- governed by feedback: the decisions we make alter the state of the world, bringing changes to the environment and triggering other agents to react, so giving rise to new scenarios which influences our next decisions and so on;
- constantly changing: time is a crucial component in a complex system; even though some phenomena seem to remain unvaried, instead they could vary over a long term horizon;
- adaptive: agents' desires, needs and decision rules change over time following the dynamic patterns guided by the system. Adaptation occurs as people learn from experience, so that they can achieve their goals overcoming obstacles and barriers;
- nonlinear: effects, in general, tend not to be linear, as this can be experienced in many economic concepts. For example, learning curves require time to learn a new process, and once the worker has acquired the skills, he is able to produce more and faster. It is very rare to observe effects that are proportional to causes.

The list above briefly summarizes feedback, time delays, and stocks and flows and nonlinearity that are the crucial elements characterizing dynamic complexity in a system dynamics model, and they will be described deeply later in this paragraph. Starting from the first element, feedback takes place in all real systems when we react to our interventions or when a strategy is implemented[40]. Feedback works as a program guiding tool where the results of our actions define the situation we face in the future. This in turn will affect the assessment of the problem and the solutions we will provide for the future, moreover, side effects will be triggered by our decision, as other agents will aim to something different or restore the status quo situation, in order to seek their objectives. In such scenario, policy resistance arises because strategy planners were not able to anticipate such side effects and they did not understand the complexity describing the full range of feedbacks operating in the

[40]Ibid

system. This is what it is described as the "Feedback view of the world"[41], which will be shown in the figure below:

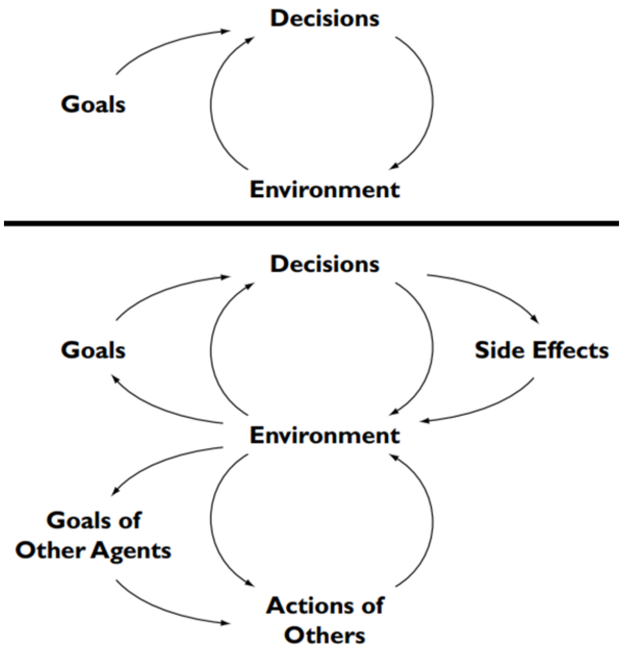


Figure 1.3.1: Feedback view (Loop view) of the world in a real system
Source: John D. Sterman, Business Dynamics, 2000

Our decisions affect the environment leading to new decisions, but at the same time, side effects play a role since other agents could have different goals from the original ones, so these feedbacks could lead to ineffective policies bringing very negative results. This explains why we should take care of all the possible agents that play a role in the system, so that we can develop a strategy that will seek the desired results. The second aspect characterizing system dynamics is time delays. In any real system, time is a key component, which give us the possibility to evaluate if the strategy implemented was successful in reaching the goal we wanted[42]. On this line, time delays are very common in feedback loops, and they could generate instability and troubles in real systems. In fact, when a strategy is implemented, we cannot observe the immediate results of our decisions and the effect caused, instead they are delayed. As a matter of fact, time delays create discrepancies between the desired

[41] Ibid
[42] Ibid

and the actual state of the system, so decision makers and strategy planners continuously intervene, in order to restore equilibrium in the system. This makes clear that time delays increase the instability of real systems and should always be considered otherwise, strategies will be ineffectively implemented. The last two components of system dynamics, stocks and flows and nonlinearity, can be seen as moving in the same direction. Generally, stocks and flows define the accumulation and usage processes of resources[43]; these are the focus in system dynamics as from analysing their performances, we can evaluate the modifications that we can take, in order to guide our strategy in the direction of the desired results. The concept of stock was limited to just tangible assets of a firm, such as plant, equipment, cash and thanks to the resource-based view, such concept has evolved in considering even intangible assets, such as employee skills, technology and production methods. In fact, nonlinearity is what characterizes stocks and flows since it takes place in most of accumulation and production processes. If we take employee skills as an example applied to automotive, it is possible to observe that engineers and mechanics need to learn the technology, make trials, and then move to production. As we can imagine, the workforce requires time to learn the whole process and acquire the necessary skills, and obviously this should lead to very few units produced. Once they mastered the process, the employees can now replicate the whole process faster leading to more units produced in less time: learning curves describe such situation and represent a clear case of nonlinearity. So, it can be observed that nonlinearity is a basic aspect in complex systems, as it is more common to find relations that are nonlinear, instead of linear ones[44]. Understand complex systems and the above-mentioned aspects is not an easy task, so, we need to use tools that are capable of capturing the feedback processes, stocks and flows and time delays which are the main sources of dynamic complexity. The main tools used in system dynamics are causal mapping, model sketching, model equations and simulation modelling[45]. Starting from causal mapping, these maps

[43]Ibid
[44]Ibid
[45]Ibid

represent a crucial part in system dynamics modelling as they describe the feedback processes that determine the dynamics of a real system. Such feedback processes can take place in two types of loops: self-enforcing and balancing causal loops[46]. The first ones are loops that generate their own growth, in which, the relations among variables lead to amplify what is happening in the system. For example, price wars can represent such situation: if one firm decides to lower its prices to gain market share, then its competitors will respond consequently, and so the first firm responds again to lower its price even more[47]. In fact, the decision of price decreasing lead to other firms lowering their prices, in order to increase market share and attract potential customers as final goal. On the other hand, negative loops tend to restore or counteract the change, and so they could be used to reinstate equilibrium at the status quo situation. Keeping the example of gaining market share previously showed, if a firm has a dominant position on the market and the more it wants to increase market share, the more the role of antitrust entities will come out in order to limit monopolistic power[48]. As a matter of fact, antitrust bodies serve the purpose to keep balance and equilibrium in the market, as explained in the previous example, creating a negative loop. After we have understood the difference between the two types of causal loops, we can now sketch the model defining the interactions between variables and which effect they create to stocks and flows. Thus, the sketch should give us a better understanding of causality between variables in the whole system: this allows us to quantify correlations between factors. The following legend will be used to build the model:

[46] Ibid
[47] Ibid
[48] Ibid

SYMBOLS	DEFINITION
A + B	A moves in the same direction of change B
A - B	A moves in the opposite direction of change B
+	Self enforcing loop
-	Balancing loop

Table 1.3.1: Legend used in system dynamics modelling

Such type of causal mapping will be shown in the next chapter when the model will be introduced. Once we have sketched the model and we provide all the causal relations, we can now proceed to develop the mathematical structure of the system: simple equations will help us in completing such step. As for the sketch of the model, the equations regarding the model will be presented later on in the next chapter. Finally, we can proceed to simulate the models. Simulations should not be taken as predictions of future events, instead, they should serve the purpose of presenting different microworlds, in which decision makers test different approaches to reach the desired results[49]. For example, he or she can make an hypothesis on different subsidies strategies to introduce and increase the selling of electric vehicles. For example, if the decision maker assumes to adopt low subsidies strategy to promote electric vehicles, starting with a very high reduction in the price, concluding with an exponential decrease in the final phase of this strategy, he should observe a completely different result with other types of subsidy strategies. This part concludes the whole chapter dedicated at the introduction of the study object, with a deeper understanding of the automotive sector, the main reasoning behind such study and the approach used to present the results of this research. The next chapter will show the model in all its details regarding the equations and the cause-effect relations, the Italian situation

[49]Ibid

in front of electric mobility and concluding with the presentation and review of the final results.

2 The Model, The Survey and The Final Results

2.1 Presentation of the system dynamics model

After having described how the Italian situations is appearing through the results of the survey, now we will proceed to present the model, in order to see an application of what was described theoretically in paragraph 1.3. The main tools used to build such analysis are the causality relationship diagram, which describes briefly the positive/negative loops characterizing the model, the stock-flow diagram which gives the complete view to each single branch composing the model and, finally, the equations which describe the direct relations between the variables. All these tools were presented in the final paragraph of chapter one, and now they will be applied in this study research. Starting from the model and the variables selected, it should reflect the behaviour of the automotive industry from three different perspectives: the demand of vehicles, describing the impact of economic variables with respect to the automotive sector, the development of vehicles, describing the variables affecting the scale and the production of vehicles, finally, the evolution of vehicles guided by an investigation on consumers' perceptions with respect to electric vehicles. All these three single branches will compose the whole model and will be presented one by one in this paragraph. First of all, we will start with the causality relationship diagram, which will give the idea of the interconnections between the three branches and the relationships linking the variables between each other. The focus of the system dynamic approach will be to study the feedback processes, presented in the causality relationship diagram, that occur between the internal variables, as the dynamics characterizing them must be closely associated with the internal structure of some identifiable system[50]. Thus, it is implicitly assumed that the external environment does not influence the system, as the behaviour of the system is mainly determined by the internal causality interactions between variables. Moreover, the model could be expanded considering the impact that the energy sector could have on the automotive

[50]"System Dynamics: Systemic Feedback Modeling for Policy Analysis", Y. Barlas, 2009

industry, as finding sources of renewable energy is crucial to develop clean cars as well as decreasing the CO2 emissions. This could suggest for a further deeper analysis in the future, so a push to continue investigating such matter. Now, we will proceed to show the causality relationship diagram, in order to have the main causal relations among variables in the whole model and for each branch. All the three branches will be presented one by one in the next figures:

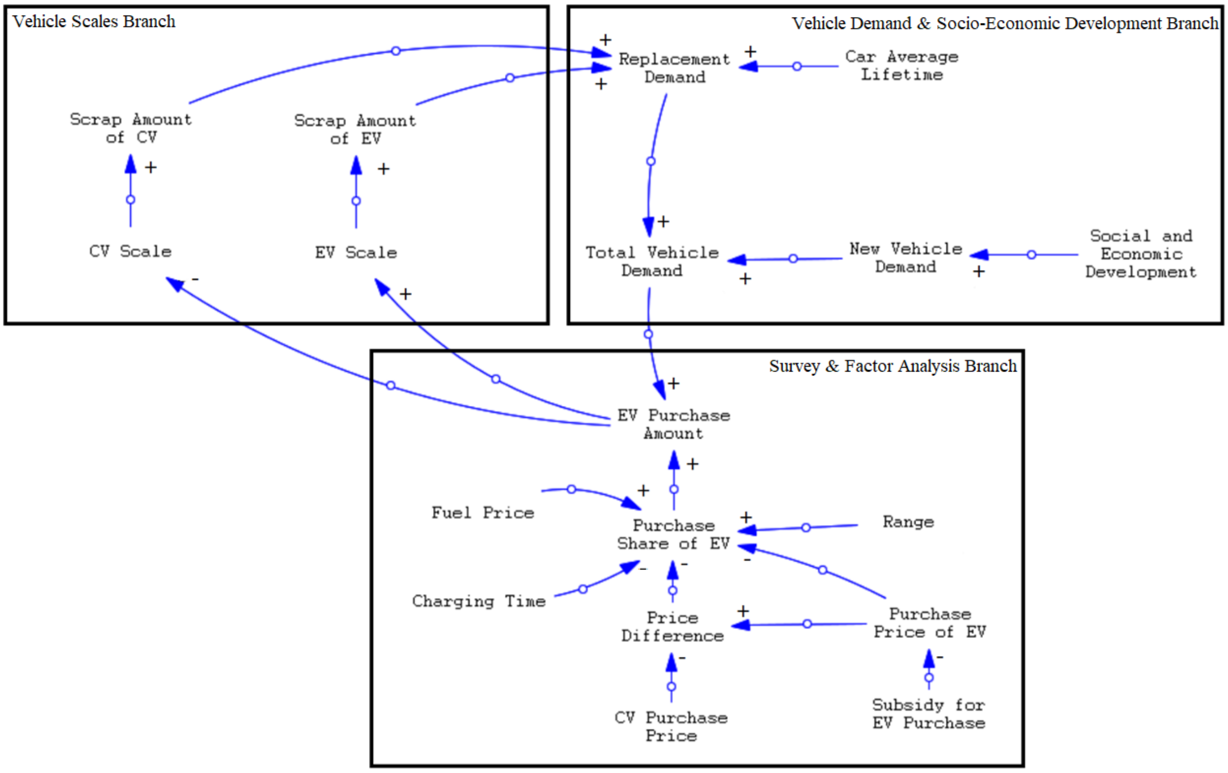


Figure 2.1.1: Causality relationship map presenting the links between variables

Figure 2.2.1 shows the model in its entirety, and it can be decomposed in three parts, in order to have a better understanding of the causality surrounding the matter under research. Most aspects of the model have been reworked and adapted to the study object from previous models: the sub-model regarding the demand of vehicles has been taken from Earth3 model, which has been hypothesized by the Stockholm Resilience Center in 2018[51], while the complementary parts have been taken from

[51]"Transformation is feasible: How to achieve the Sustainable Development Goals within Planetary Boundaries", Stockholm Resilience Center, 2018

a reasearch paper elaborated from the university of Sichuan[52] and adapted to the Italian framework. We will start from the vehicle scales branch, as it represents the starting point in the automotive sector, from which we could investigate how the socio-econominic development and some psychological factors could guide an evolution in the automotive industry, with the possibility to reach a transition in the cars' powertrain. In such branch, it is possible to observe the relations guiding the scale of vehicles (for both powertrains), and the functionality (in a very naïve way) of the production processes, as this branch should reflect firms' behaviour. It can be observed that EV scale positively affects the scrap amount of electric cars, since, the more cars are produced, the more such cars will be scrapped once the lifetime of the battery comes to the end; the same reasoning applies to conventional vehicles. Moreover, after the car is scrapped, for conventional vehicles the process is less complicated, as each mechanic component can be reused, if the parts are in good conditions, while for electric vehicles such process could become a bit complicated. The main problem is represented by the battery, as it is the most difficult component to be disposed, since lithium ions can be very polluting, so, some car manufacturers are trying to find ways to recycle batteries and give them a second life, as described earlier in paragraph 1.2. As a matter of fact, once the production process for electric vehicles is mastered and made feasible, this should allow a faster scale for such vehicles, so it implies that conventional vehicles should decrease both in terms of production and in terms of circulating cars. Thus, it could be expected that a possible transition might happen regarding powertrains. Then, moving to the second branch, the vehicle demand and socio-economic development branch, it is observed how the economic, social development, meaningly the expansion or accumulation of GDP and the demographic growth, and the average car lifetime affect the demand of vehicles. So, analysing the interactions between the variables in this branch, it is straightforward to think that if the GDP is expected to increase, meaning that the country has created value and it has become richer, and the populations has grown across time, meaning that births

[52]"Scale Evolution of Electric Vehicles: A System Dynamics Approach", Yue Xiang et al., 2017

exceeded deaths, the demand for new vehicles increases as well. On the other side, the average car lifetime, which will be set in between 10-11 years as obtained from estimates computed by the ACI (Automobile Club Italia), is related to replacement demand, which describes the quantity of electric vehicles which should substitute conventional vehicles. What we should expect is that, if electric vehicles are characterized by a longer lifetime compared to diesel and petrol fuelled vehicles, the latter should decrease in terms of sales and circulating vehicles, so the decrease in such vehicles should be compensated by an increasing number of electric vehicles. Thus, this describes why the car average lifetime is positively related with replacement demand, as this reflects the increments that electric vehicles have produced compensating the lower amount of registered conventional cars. Finally, it is consequential the reason why new vehicle demand and replacement demand are positively linked to total vehicle demand: the more electric cars will substitute conventional ones, and the more new vehicles are introduced in the market, the more the entire car fleet and the total vehicle demand will increase. Finally, to close the whole model and the whole causal loop, the third branch will describe the consumers' perception in relation to the most important factors characterizing an electric car. This branch should give a useful guideline for car constructors, as they can understand on which factor, they should focus on to improve the production process allowing a faster transition to electric powertrains. The main factors which influence the purchase of an electric car are the ones listed in the questions of the survey, which are pointed out in table 2.1.1: range, charging time, price difference, purchase price and fuel price. Analysing each causal relation one by one, it is possible to observe that fuel price is positively related to the purchase share of electric vehicles, as if the prices for diesel and petrol are higher than "electric fuel" price, the less they are willing to buy electric vehicles, so the purchase share should decrease. For what concerns the charging time factor, this describes the time required to fully recharge the battery of an electric vehicle. The charging time factor reflect the points of charge infrastructure, so the more it is developed, the less time is required to charge the battery, and so, this will produce an increase in the purchase share of electric vehicles; conversely, the more time is required to charge the electric car, the less the such cars will be purchased. Then, the price difference is obtained as the difference between the purchase price of electric vehicles, after the eco-bonuses are applied, and the purchase price of conventional vehicles. As it can be observed, the prices of the two different types of vehicles have an opposite causal effect, since the less the conventional cars will cost, the more the price difference gap could represent an obstacle for consumers, that will not find any advantage in spending more for the same car, but with different powertrain. Nevertheless, if electric vehicles are characterized by a decreasing price across time, consumers may perceive the price difference gap as something that is feasible, in which the electric car requires an extra amount of money, that could represent a small percentage increase of its conventional counterpart. Therefore, this is directly related to the purchase share of electric vehicles, since, if the price difference gap is unfeasible and it requires an amount of money that is not justified, consumers are not willing to pay that extra amount, and so, the share of electric vehicles will decrease. Thus, the negative causal relation linking electric vehicles purchase price and the share of these ones is straightforward: the more they cost, the less such cars are sold. Finally, for what concerns range, this factor's value depends on the technology improvements applied to the batteries, basically on the capacity of these batteries, representing one of the main components of electric cars. The most famous car brands are investing many resources in R&D departments, to continuously improve the production process of batteries, ensuring that the car can cover higher distances, thank to an improved battery capacity. So, this explains why the range factor is positively related to the share of electric vehicles, since the more the batteries show important improvements, the more range the car can exhibit, the more cars are sold, so this should close the loop, aiming at the scale of electric cars. To conclude, the causality relationship map served the purpose to briefly show how the variables are related between each other, and to present the working system dynamics model as a whole. Then, the stock-flow diagram, which is the next tool used in this research, shows a much deeper analysis of the interactions between variables broken down in their components. This should give a complete view of the system as for each branch will be shown all the equations taking place in the business models, which define each of the three branches. To simplify the comprehension of the system, the business model's equations will be presented describing the cause-effect relations for each branch.

"Vehicle scales" branch represents the starting point of the model, as we can observe evolutions in the automotive industry, once cars are introduced, we can investigate the reaction in the economic and social framework of a country (Italy in this case), which should be, then, transferred to the analysis of the psychological factors that could drive a transition in the mobility sector. The first branch should picture the improvements that car manufacturers should implement, in order to reach scale production of electric vehicles. Thus, it will be investigated the interactions between demand increments and demand replacement, which are determined by the increments in vehicle scale and in the amount of scrapped cars respectively. Since electric and conventional cars are produced by the constructor, the two powertrains could be seen as a disruptive synergy, as both of them will compete to gain market share in the automotive industry. Such scenario cannot be avoided by manufacturers, as the powertrains have different purposes, and it is reasonable to think that electric vehicles could steal market share from conventional vehicles, which could bring in big losses for car makers. The figure below will represent the detailed version of such branch, which has already been presented through the causality relationship map:

Most of the significant relations have already been described in the causality relationship diagram, although it can be observed that an initial level of electric and conventional vehicles should be considered, since the automotive market is not starting at a zero level, and considering as reference the year 2015, we can analyse how the electric vehicle implementation has evolved. Moreover, the total vehicle demand here affects the purchase amounts of both powertrains, it is shown as a shadow variable, since it is stricly correlated with economic and social variables. So, the demand drives how much car manufacturers have to produce, and here we can

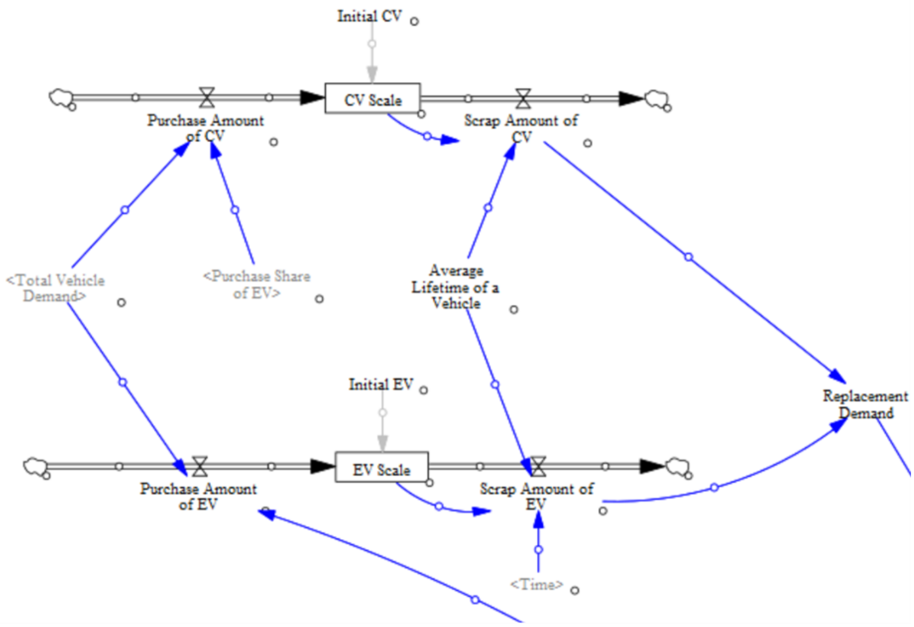


Figure 2.1.2: Vehicle Scales Branch

start to observe if the transition is happening, as the more electric cars are bought, the more such cars gain market share and the less conventional vehicles are sold. To describe such relations in mathematical way, the following equations should describe the business model of this branch:

$$SCALE_{i,t} = \sum_{t=0}^{T=300} (B_{i,t} - D_{i,t}) + SCALE_{i,0} \tag{1}$$

$$D_{CV,t} = \frac{SCALE_{CV,t}}{ALV} \tag{2}$$

$$D_{EV,t} = \begin{cases} \frac{SCALE_{EV,t}}{ALV} & \text{if } t \geq delay \\ 0 & \text{if } t < delay \end{cases} \tag{3}$$

$$B_{EV} = TD_t * EV_{\%share} \tag{4}$$

$$B_{CV} = TD_t * (1 - EV_{\%share}) \tag{5}$$

Equation (1) describe the scale evolution of both conventional and electric vehicles, where the purchase (B_i, for i=EV, CV) and scrap (D_i, for i=EV, CV) amounts are the main determinants. Consequently, the scrap amounts are defined as something similar to an average, since they are obtained as the division of the scale of vehicles (for each powertrain) by the average lifetime of vehicles (ALV), which is a figure provided by the ACI. This is described in equations (2) and (3), moreover, in equation (3) a delay should be considered, since to "produce" scrap amounts will take time, since electric vehicles are still in the early stage of their lifecycle, and it should be lagged for 48 months (which is equal to 4 years). Finally, to close the loop, the purchase amounts are defined as the portion of the total vehicle demand (TD_t) times the share related to each powertrain, which will be $EV_{\% \text{ share}}$ for electric vehicles, and (1 - $EV_{\% \text{ share}}$) for conventional vehicles, since it represents the complementary part, which are equations (4) and (5).

Then, after the "vehicle scales" we move to the "vehicle demand and socio-economic development" branch, in which the population dynamics, the economic (basically the GDP) dynamics and the automotive market dynamics are analysed. GDP and population dynamics can be thought as social and economic development, and they are key components regarding this part of the model, as they are some of the main drivers of demand, so an increase in the demand of vehicles can represent an important push towards the promotion of the growth of electric vehicles scale. The following figure will show in detail the relations characterizing such branch, which were described previously through the causality relationship diagram:

As shown in the above figure, the causal loop regarding the population has been expanded considering the death and birth rates estimates, in order to have a better representation of the real world. For what concerns the GDP dynamics, here it is considered the accumulation function, as a crucial aspect to understand whether the economy of a country is growing or is shriking. Such components tend to be strictly correlated with demand movements, since if they are growing, this is translated in a growing demand for vehicles. At the same, assuming a growing social and economic

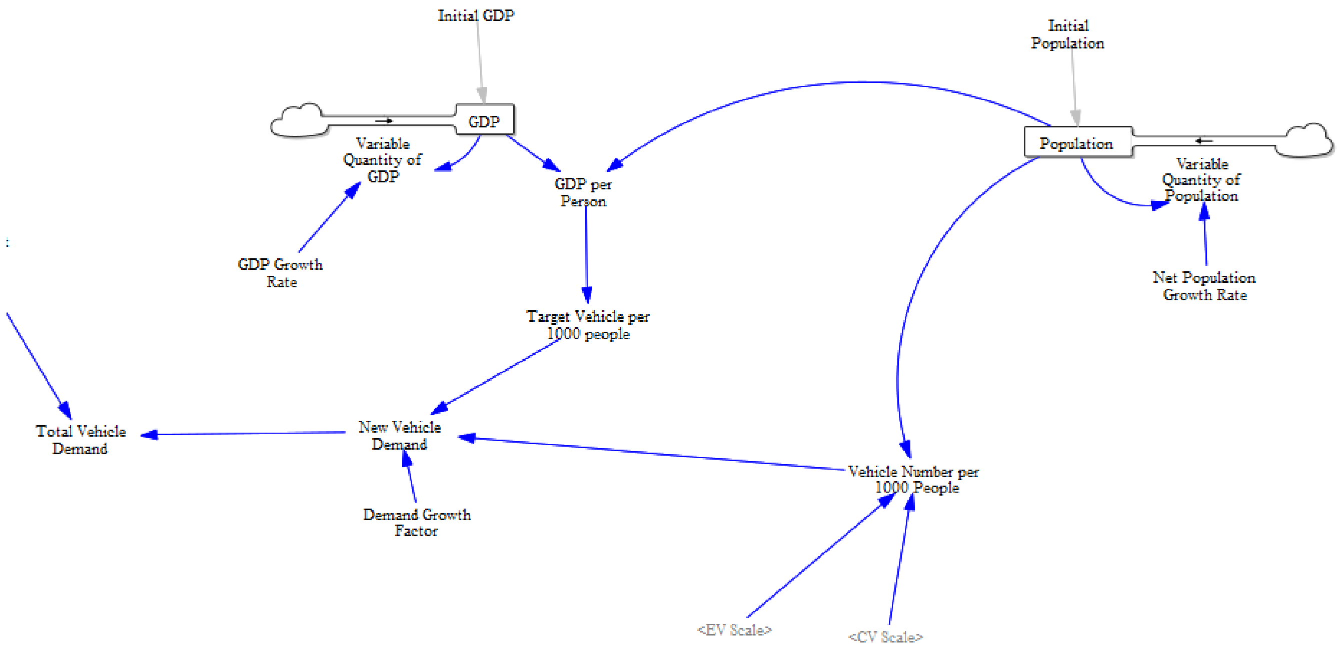


Figure 2.1.3: Vehicle Demand & Socio-Economic Development Branch

development, so an increase in the number of circulating vehicles, governments co-operating with organizations regulating transports want to keep a viable mobility, avoiding traffic congestions, while fulfilling the emission targets provided by the EU regulations. In order to do so, a target of vehicles per 1000 people is needed with the purpose to keep track of mobility and even emission targets. To conclude this branch, the following equations should describe the relations characterizing the variables of this business model:

$$POP_t = \sum_{t=0}^{T=300} PV_t + POP_{t_0} \tag{6}$$

$$PV_t = POP_t * r_{POP,t} \tag{7}$$

$$GDP_{TOT,t} = \sum_{t=0}^{T=300} X_{GDP,t} + GDP_{TOT,t_0} \tag{8}$$

$$X_{GDP,t} = GDP_{TOT,t} * r_{GDP,t} \tag{9}$$

$$VP_t = \frac{SCALE_{EV,t} + SCALE_{CV,t}}{POP_t} \tag{10}$$

$$NVD_t = (VPT - VP_t) * \alpha \tag{11}$$

$$VD_{TOT,t} = D_{EV,t} + D_{CV,t} + NVD_t \tag{12}$$

Equations (6) and (7) describe the population dynamics, as total population, at time t, is defined by variable quantity of population plus population at time t=0, which is the initial population level that depends on which year we use as reference. Equations (8) and (9) describe the GDP dynamics, so the accumulation of capital across time. The closing equations, which are (10), (11) and (12) describe the automotive market dynamics, so, the vehicle increments can be computed by the ratio relation between the demand factor (α) and the differential of the vehicle number per 1000 people and the target of vehicle number per 1000 people, thus the total demand can be quantified. All these equations describe the determinants of the average number of vehicles per 1000 people ($\mathrm{VP_t}$), the new vehicle demand ($\mathrm{NVD_t}$) and total vehicle demand ($\mathrm{VD_{TOT,t}}$).

The closing brach, which will close the model as well, is the "survey and factor analysis" branch that describes the factors influencing the purchase share of electric vehicles and, consequently, the scale of such vehicles. The factors that cover a special role in this branch are the ones pointed out in each question of the survey: "range factor", "charging time factor", "price factor", "fuel factor" and the "price difference factor". The following figure will present the causal relations of this closing part of the model:

As shown in figure 2.2.4, the factors chosen have a direct effect relation in the purchase share of electric vehicles, as these can contribute to the adoption of electric vehicles, favouring a change to "green" powertrains. Nevertheless, it should be noted

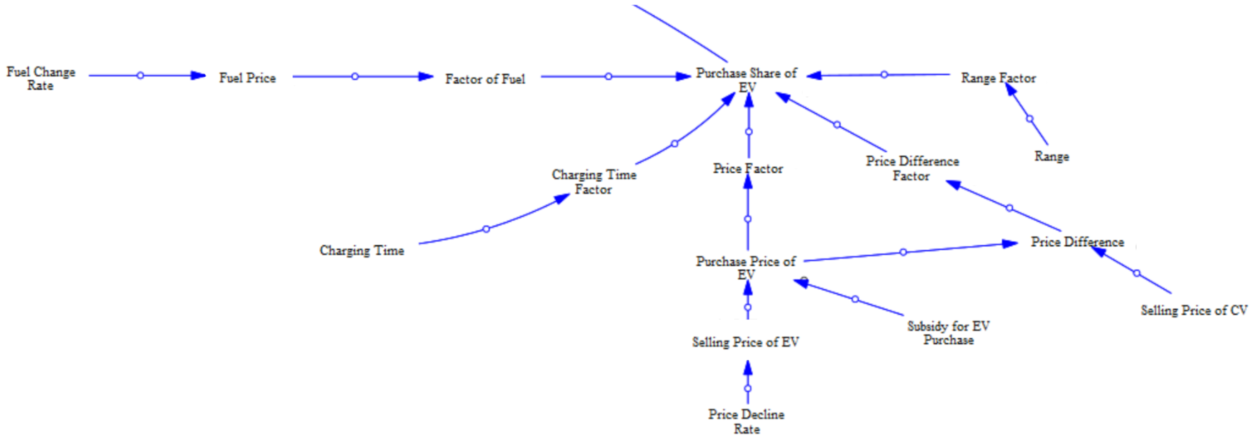


Figure 2.1.4: Survey & Factor Analysis Branch

that the five factors chosen are not the only ones that influence the share of electric vehicles, yet, they should represent the most considered factors in the purchase of an electric car for potential consumers. The main equations characterizing such branch are the following:

$$P_{Buy} = P_{Sell} - P_{Sub} \tag{13}$$

$$EV_{\%share,t} = EV_{R,t}^{\beta_1} * EV_{CT,t}^{\beta_2} * P_{EV,t}^{\beta_3} * P_{Fuel,t}^{\beta_4} * P_{PD,t}^{\beta_5} \tag{14}$$

Equation (13) points out that the purchase price for electric is obtained as the subtraction between the selling price and the subsidies perceived; then, the purchase price is used to compute the price difference between electric and conventional cars. Equation (14) describes the relation between the factors and the share of electric vehicles, where $EV_{R,t}$, $EV_{CT,t}$, $P_{EV,t}$, $P_{Fuel,t}$, $P_{PD,\,t}$ represent the above mentioned factors, and β_i represent the weight parameters for each factors computed using the following average criteria:

$$\beta_m = \frac{\sum_j n_{j,m} * rank_j}{\sum_{j,m} n_{j,m} * rank_j} \tag{15}$$

where $\beta_{m=1,2,3,4,5}$ indicates the weight factor and $n_{j,k}$ represents the number of respondents evaluating the m^{th} factor with j^{th} rank. Basically, if we consider the range factor, the numerator is calculated as the sum of how many people selected range as being the first factor times the value of the rank (rank#1 will have value 5, and so on) repeated for all the consequent ranks. Then, this is done for all the remaining factors, and the sum of all numerators will represent the denominator, which is a total sum. The next tables will show, the answers distributed in terms of ranking and factors:

Ranking Value	Range	Charging Time	Buying Price	Price Difference	Diesel/Petrol Price
Rank #1	239	79	73	30	79
Rank #2	115	196	85	77	27
Rank #3	67	110	125	139	59
Rank #4	35	86	142	179	58
Rank #5	44	29	75	75	277

Table 2.1.1: Absolute frequencies registered in sixth question of the survey

Ratio	Range	Charging Time	Buying Price	Price Difference	Diesel/Petrol Price
Numerator	1970	1710	1439	1308	1073
Denominator	7500	7500	7500	7500	7500
Weight	0,263	0,228	0,192	0,174	0,143

Table 2.1.2: Weight parameters calculated using equation (15)

To clarify the role the economic relation that characterize each factor, such as the range factor for example, we used a cumulative distribution function (CDF) that should describe respondents' reactions to changes in the initial values set for the range, for the charging time and for all the other factors. The following piece-wise function defines the cumulative distribution for the range factor:

$$EV_{R,t} = \begin{cases} 0.006 & \text{if } EV_{R,t} < 80 \\ 0.092 & \text{if } 80 \leq EV_{R,t} < 160 \\ 0.304 & \text{if } 160 \leq EV_{R,t} < 320 \\ 0.740 & \text{if } 320 \leq EV_{R,t} < 480 \\ 1 & \text{if } 480 \leq EV_{R,t} \leq 640 \\ 1 & \text{if } EV_{R,t} > 640 \end{cases} \tag{16}$$

All the probability mass defined by this piecewise function are calculated through an analysis of the choice ratio for each question and its correspondent factor, which is described in the table 2.2.1, that will be presented in the next subsection. We can notice that most of the probability mass can be found for higher values of range, in particular considering the interval between 320 and 480 kilometers. So, we can conclude that for our 500 repsondents' sample, the most preferred choice was a car which is able to cover a distance of at least 320 kilometers. Then, assuming different values for this factor, we can observe how it could affect the share of electric vehicles when we want to simulate the model; the same reasoning and procedure can be applied to the remaining factors. To conclude, the analysis could go much deeper considering the relations between the energy sector and the charging infrastructure, in particular, analysing the costs that individuals have to incur, like the installation of a domestic point of charge, the increase in the electric fees and the general price fluctuations reflected in the electricity demand, fuel costs and availability of generation sources, which will be discussed in the next chapter. It could be investigated the awareness of people in relation to the awareness of the availability of generation sources, where

Europe is still depending from fossil fuels as main source of energy. In fact, in the EU, fossil fuels account for almost 36% of sourcing in the electricity production, with Italy reaching almost 57% in 2020 [53]. This means that, to produce electric cars, fossil fuels are still required, and this can be seen as a negative impact for electric vehicles adoption, as the more consumers are aware of such figure, the less likely they consider to buy electric cars as a cleaner transport alternative to conventional vehicles. In the next paragraph, the survey's results will be presented and discussed.

[53] "What is the source of the electricity we consume?", Eurostat, 2020

2.2 The Italian situation: a short view to survey's results

In this chapter, we will go through the presentation of the system dynamics model describing the Italian automotive market broken down in all its causal loops and equations characterizing them. Before proceeding to the presentation of the model, a look to the results of the survey is necessary, in order to have a starting idea about the consumers' perspective on electric vehicles. This will be very useful to present the model, as it will give us the points to focus on guiding us to a faster implementation of electric cars, and a possible transition from conventional vehicles to electric ones in the long term. So, a detailed analysis of the survey will suggest us the possible strategies to adopt, in order to find the best possible real scenario when dealing with simulation on the model. First of all, we will go through the characteristics of the dataset. The survey registered 500 replies where the portion of females and males is almost split in equal parts: males represent 53% of the sample, while the complementary portion is represented by females. In general, the sample average age classes are between 21 and 30 years old and between 31 and 40 years old for both females and males. So, the two age classes can be assumed to be interested in such topic, as the purchase and ownership of a car is important for people in both age classes. Moreover, consumers could still be studying or have just started working in a workplace and choosing between conventional vehicles and electric vehicles is a decision that, certainly, characterizes such age class. On one side, students could have the critical thinking to suppose if electric cars are implemented in a way, such that, sustainability, green policies and emission targets are met, so, the purchase and the ownership of an electric car could make a step ahead facing climate change. On the other side, workers could find in electric vehicles new possibilities in changing lifestyle as they need to plan road trips, taking account of car range and the location of charging stations, while it could turn out to be a smart investment, since it could save money in the long term. For example, electric cars require less maintenance costs[54] compared to conventional vehicles, as the battery and engine form a unique block

[54]"Pay Less for Vehicle Maintenance With an EV", Consumer Reports, 2020

oppositely from internal combustion engines. Moreover, electric cars do not require oil or any other fluids, which are one of the main causes of mechanical problems and, so requires regular maintenance. So, after a descriptive analysis of the sample, here below it will be presented the results of the survey showing the most chosen answer for each question and the ranking of factors, which characterize electric vehicles, ordered by importance by respondents which will be presented later on in this paragraph.

QUESTIONS	POSSIBLE ANSWERS	CHOICE IN ABSOLUTE FREQUENCIES	% CHOICE RATIO
What is the minimum range (km) that an EV (electric vehicle) should have in order to be considered by you as a customer?	0-80 km	3	0,60%
	80-160 km	43	8,60%
	160-320 km	106	21,20%
	320-480 km	218	43,60%
	480-640 km	130	26,00%
Considering your expected vehicle use, how much time (hours) would you expect to fully recharge the battery of your vehicle, when you are considering to buy an EV?	less than 1/2 hour	153	30,60%
	between 1 and 2 hours	178	35,60%
	between 2 and 4 hours	111	22,20%
	between 4 and 8 hours	45	9,00%
	more than 8 hours	13	2,60%
How much more would you pay for an EV compared to conventional vehicles (intended as percentages of purchase price of conventional vehicles)?	less than 10%	96	19,20%
	between 10% and 20%	167	33,40%
	between 20% and 30%	149	29,80%
	between 30% and 40%	74	14,80%
	more than 40%	14	2,80%
If you were considering buying an EV, in which of the following price ranges will you expect it to lie (x10^3 euro)?	less than 18 (thousand)	51	10,20%
	between 18 and 28 (thousand)	130	26,00%
	between 28 and 38 (thousand)	163	32,60%
	between 38 and 48 (thousand)	106	21,20%
	more than 48 (thousand)	50	10,00%
At what price for gasoline/diesel would you be more likely to consider buying an EV?	less than 1.45 euro/liter	97	19,40%
	between 1.45 and 1.55 euro/liter	77	15,40%
	between 1.55 and 1.65 euro/liter	98	19,60%
	between 1.65 and 1.75 euro/liter	109	21,80%
	more than 1.75 euro/liter	119	23,80%

Table 2.2.1: Results from the survey (Reference: Italy)

It can be observed that Italians, in general, prefer to have a mid-long range car that is compatible with fast chargers, so that the charging time taking between 1 and 2 hours is satisfied. On average, the range of an electric car is given by the capacity of its battery: it is required a capacity of 45-58 kWh (kilowatt-hour) to have a range of 320-480 kilometres[55], according to WTLP (Worldwide Harmonised Light-Duty Vehicles Test Procedure) range standards[56]. Anyway, these standards are

[55] "Quanti chilometri posso percorrere?", Volkswagen, 2022
[56] "Electric car range figures: WLTP and real-world range", green.car, 2021

very optimistic, as they try to replicate the behaviour of the car in most common situations, even though some figures may not represent real case situations. Real world range[57] figures gave the most realistic values for range, but these are obtained under very specific circumstances like cold weather, heavy traffic and extra passengers, which could represent real scenario but not common. Still, WTLP produces good estimates, which could be taken as an average value or as another reference. Given range and charging time preferred choices, Italians seem to prefer to spend a good amount of money on electric vehicles, as most of the answers lie in the 28-38 thousand euro class price. Some examples of cars that an average consumer can afford, taking the previous factors as reference, could be the following:

- Volkswagen ID.3: this car represents a good compromise between a comfortable city car and a car for mid length trips. It is a valid option, since it offers a good range value depending on the battery capacity, which could be 330 kilometres with a 45 kWh battery capacity, and the base price starts at 35 thousand euro[58];

- Nissan Leaf: this car is another example of a car thought to cover mid-long distances, it is equipped with a 62 kWh battery, and its base price starts at 33 thousand euro. Anyway, this car suffers of many problems related to electrical and brake issues, as pointed out in many consumers reports[59];

- Fiat 500 Icon: historically, the Fiat 500 represents one of the most important cars in the Italian market; it is not a case that Fiat decided to make it the first car to mark the starting point for electric vehicles to be produced in Italy. This car represents the classic version of the city car, thought to cover short distances, very easy to drive: a good daily car. It is equipped with 42 kWh battery and the base price starts at 31 thousand euro[60];

[57]"Electric car range figures: WLTP and real-world range", Green.Car, 2021

[58]Volkswagen, "ID.3", 2019, https://www.volkswagen.it/it/modelli/id3.html

[59]Nissan, "Everyday Electric Car Nissan Leaf", 2021, https://www.nissan.it/veicoli/veicoli-nuovi/leaf.html

[60]Fiat, "Nuova 500 Icon", 2021, https://www.fiat.it/500-elettrica/nuova-500-berlina-icon

- Volkswagen e-up!: this car represents a possible alternative in the city or daily car segment, as it is cheaper compared to all other vehicles in this list, and a direct competitor to the Fiat 500. This could be the right car, if a typical consumer focuses on the purchase price, starting at 25 thousand euro, while having a good battery capacity of 36.8 kWh[61];
- Peugeot e-208: this car is another example of versatility as city car and for mid long road trips, it is equipped with a 50 kWh battery capacity which can reach 340 kilometres as maximum range, according to WTLP figures. One con regarding this car is certainly the base price, which starts at almost 34 thousand euro, which is the highest price regarding this list, and one of the most expensive cars in the compact car segment[62].

This list reports some examples of possible electric cars that should be in line with the choices of Italian consumers, in fact the Fiat 500 and the Volkswagen ID.3 are at the top in sales in the electric car market[63], proving that Fiat and Volkswagen are probably moving in the right direction to promote such vehicles. Nevertheless, two answers could represent an obstacle to electric mobility, in particular, Italians seem to consider electric cars that have a similar price to their diesel and petrol counterparts and, in general, they prefer to stay with conventional vehicles even though the price of fuel is around 1.75 euro/liter. For what concerns the price difference factor, it can be observed that, in general, the price of electric cars is very different, using the compact cars segment as reference, there are very few cars which stay in between the 10%-20% interval of price difference, since the electric segment is still at the initial stage in its lifecycle. As a matter of fact, the average price difference lies in between the 40%-50% interval, and this could be observed with two examples taken from the previous list:

[61] Volkswagen, "Nuova e-up!", 2021, https://www.volkswagen.it/it/modelli/e-up.html

[62] Peugeot, "Peugeot e-208: la city car elettrica a 5 porte", 2021, https://www.peugeot.it/gamma-modelli/peugeot-e-208.html

[63] "La Fiat 500 è l'elettrica più venduta in Italia ad aprile 2022", HDMotori.it, 2022

- The Peugeot e-208 costs around 34 thousand euro and its diesel version costs around 18 thousand euro; in this case the electric version costs almost 50% more that its diesel counterpart;

- The same happens considering the Volkswagen e-up! and its diesel counterpart: the first costs around 25 thousand, while the second one costs 15 thousand euro, so to buy the e-up! we need to spend 40% more than its diesel version.

These two examples represented the general view regarding the price difference between the powertrains, as the electric technology requires more money that the diesel and petrol counterparts, so, we are still far from a price difference between 10% and 20%, even though there were made some important steps in promoting and selling electric vehicles. Eco-bonuses were introduced to decrease such price difference, and the new formula should decrease such price difference, in order to push towards a decrease in the number of conventional vehicles and, finally, should improve the infrastructure of charging stations. Such eco-bonuses are valid during the three-year period covering 2022-2024 and there three different state aids classified for emissions levels and vehicle scrapping[64]:

- 3 thousand euro for the purchase of a low emission vehicle (0-20 gCO2/km) plus 2 thousand euro, if the consumer decides to scrap his old vehicle if it is a Euro 5 or below polluting car;

- 2 thousand euro for the purchase of a mid emission vehicle (21-60 gCO2/km) plus 2 thousand euro, if the consumer decides to scrap his old vehicle and if it is a Euro 5 or below polluting car;

- 2 thousand euro for the purchase of a high emission vehicle (61-135 gCO2/km) without any vehicle scrapping surplus.

For what concerns the price of diesel and petrol fuels, the high price for fuels seems not to be a problem for Italians, as the average price level should reach 1.75

[64]"Ecobonus 2022 Auto, come funziona, IlSole24Ore, 2022

euro/liter, before consumers start considering the purchase of an electric car. This could represent an obstacle that could slow down the sales of electric cars, and, so, a possible transition in mobility trends. If we compare the prices of the fuels, it is possible to observe that, in general, the price to fully charge the battery of an electric car is much less than that required to fill in the fuel tank. If we look at some data, it can be observed that normal charging stations (until 22 kWh charge power) have a price of 0.45 euro/kWh, while fast charging stations (over 22 kWh charge power) have a price of 0.50 euro/kWh. So, assuming we have a 45 kWh battery capacity, it requires 20 euro and 2 hours to fully charge the battery, while it takes 22.5 euro and 45 minutes to fully charge the battery at a fast charge station that has a 60 kWh charge power. All these figures are computed according to Enel-X base tariffs[65]. Yet, Enel-X has changed the prices for charging electric cars, and such plan has been implemented in March 2022, and here below we can observe the different types of tariffs[66]:

- 0.58 euro/kWh using alternating current at normal charging stations;
- 0.68 euro/kWh up to 100 kW using direct current at fast charging stations;
- 0.75 euro/kWh up to 150 kW using direct current;
- 0.79 euro/kWh over 150 kW at high power charger stations.

Thus, such change in price tariffs should have negative effects on first adopters of electric cars, but such investment in money should serve the purpose to improve the infrastructure of the charging stations net, as part of the strategy of Enel-X. Anyway, Enel-X is not the unique provider of such service, and given the multiplicity of different charging tariffs, some major car constructors such as BMW, Mercedes, Volkswagen, Audi and Porsche formed a joint venture, Ionity[67], offering new cheaper

[65] "Quanto costa ricaricare un'auto elettrica?", Enel-X, 2022
[66] "I costi dell'energia aumentano: Enel X incrementa i prezzi per la ricarica", HDMotori.it, 2022
[67] Ionity, "About us", 2021, https://ionity.eu/en/ionity/who-we-are

plans, in order to favour their consumers. Here below in the following table, there are few examples of some flat tariffs' plans promoted by the constructors:

Constructor	Tariff Plan	Monthly Lease	Yearly Lease	Euro/kWh	Reference kWh	Total Expense Plus Lease	Euro/kWh After Lease
BMW	BMW Charging Active and Ionity Plus	16,90 €	0,00 €	0,31	300	109,90 €	0,37
Mercedes	Mercedes Me Charge	0,00 €	99,00 €	0,29	3600	1.143,00 €*	0,32
Volkswagen	Volkswagen WeCharge Plus	9,99 €	0,00 €	0,30	300	99,99 €	0,33
Audi	Audi e-tron Charging Service Transit	17,51 €	0,00 €	0,31	300	110,51 €	0,37
Porsche	Porsche Charging Service	0,00 €	0,00 €	0,33	300	99,00 €	0,33

Table 2.2.2: Tariff plans organized by the above constructors in cooperation with Ionity (*Mercedes total expense is calculated on a yearly base)

All these data were elaborated on a usage scenario of 300 kWh per month and using ultra-fast charging stations offered by Ionity, so these figures are adjusted on the tariff plans promoted by the constructors. As it can be observed, if consumers use such plans, they can save much more money than using Enel-X charging stations and they can get even more advantages, like Porsche's service, where consumers do not pay any lease fee for the first three-year period[68]. Moreover, it can be observed that the total expense for a consumption of 300 kWh is less expensive than what an average consumer spends to refuel his car at fuel stations: it is estimated that in the year 2022 consumers could reach 1750 Euro yearly[69], which is equal to almost 146 Euro per month. With these figures, it turns out that electric cars could be a good investment in the long term, as consumers can recover the full expense through state aids (Eco-bonuses), charging plans that offer competitive prices and time efficiency at the same time, yet there are still very few charging stations, and this represents the main barrier to electric mobility implementation. Moving to the ranking of factors, respondents answered the question "If you were considering buying an EV, how will you rank the following factors?", considering their habits and their needs, and the graph below shows the ranking importance of five factors that could improve electric

[68]Porsche, "Porsche Charging Service", 2021, https://www.porsche.com/italy/aboutporsche/e-performance/charging-bev/

[69]IlMessaggero, "Benzina, con caro-prezzi fino a 1.750 euro spesa annua per un pieno. Il 72% ha già iniziato a ridurre gli spostamenti in auto", 2022

vehicles' sales:

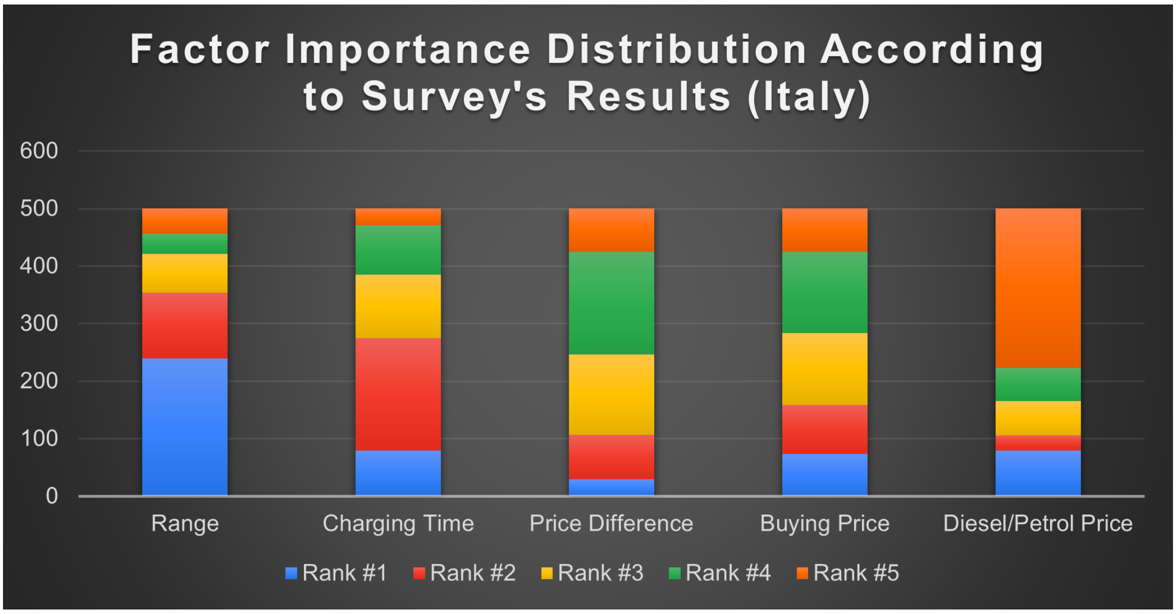


Figure 2.2.1: Ranking of factors elaborated from the question "If you were considering buying an EV, how will you rank the following factors?" (Reference: Italy)

The graph shows that most of the respondents put the range factor as the most important one out of the other factors. This is in line with the average answer that came out in the first question, pointed out in table 2.1.1, so, people cover mid-long distances during the day, in particular this should regard workers. In terms of range, the technology applied to batteries has moved big steps forward, as it started from very low range values in which, battery capacity was only at the beginning of its lifecycle, and now, it has reached important results where some cars can fit a battery that allows a range value of 770 kilometers [70].Yet, the price to buy cars with such characteristics remains very high, as electric cars are in their growth stage of their lifecycle, which is proved by an exponential increase in the market share and by high investments in R&D departments to improve the technology and build "second-life" and battery recycling strategies. For what concerns the second factor by importance, people most preferred choice was on charging time, which is in line with the answer pointed out in the second question, where most of the respondents chose

[70]Mercedes-Benz, "New EQS", 2022, https://www.mercedes-benz.it/passengercars/mercedes-benz-cars/models/eqs/saloon-v297/explore/numbers.module.html

the answers between one and two hours, and less than half an hour. In fact, normal charging stations having a power capacity of 22 kWh completely charge a battery in two hours, while fast charging and ultra fast charging stations having a power capacity that is way higher than 22 kWh can completely charge a battery in less than half an hour. So, it seems that consumers' expectations regarding charging time are met, yet the infrastructure in Europe and in Italy, in particular, represents the main problem: there are very few fast and ultra fast charging stations in the Italian territory, moreover, most of them are placed in industrial areas, very far from city centres or some other places of entertainment. The placement of a charging station can be exploited in a very strategic way: restaurants, theatres, parks, supermarkets, shopping centres, gyms and near historic centres are some examples where charging stations can be implemented in the right way[71]. The main reasoning behind this is to create a new experience for electric cars' drivers, as they need to plan their road trips considering range and time constraints. So, the strategic positioning of the charging stations could transform the road trip, as drivers could choose some entertaining breaks. For example, consumers can charge their cars exploiting points of charge at the supermarket, as they could spend some time in grocery shopping, while they wait to recharge their car. On the same line, placing charging stations near theatres, cinemas or restaurants could be a good move from both perspective: the owners can attract new potential customers that can spend some time eating a good meal, enjoying a play or watching a movie, while they wait for their car to be charged up. Firms such as Engie, Enel-X, E.ON, BeCharge (division of ENI Plenitude) and Ionity, which are the main providers of points of charge, should consider this aspect, so that the infrastructure and network of charging stations can reach important results, which can lead to an increase in the share of electric cars, while consumers can enjoy a new experience. For what concerns the third factor, the majority of respondents chose buying price, which is reasonable after having observed the previous factors, since range and charging time are two main sources that define the price of a car.

[71]"Three ways to grow your business with electric car charging stations", EVBOX, 2022

Anyway, the buying price is defined after state aids and eco-bonuses are applied to the purchase price, so, alongside the characteristics of the electric car which are power, design and safety, people consider the possibility to buy a low emission car, in order to be eligible for eco-bonuses and have a discount on the price of the car. The fourth question of the survey pointed out that the desired price to buy a car should be around 28 and 38 thousand euro, which offers an extended choice in the vehicle fleet, and some of them were mentioned previously in this paragraph. As fourth factor by importance, respondents chose price difference, which could be though as consequential to the buying price, as consumers investigate the reasons why an electric car, in general, costs more than their diesel and petrol fuelled counterparts. Among many factors that make an electric car more expensive than conventional vehicles, surely batteries represent an important cost driver, and, since it is an emergent technology, this implies that production costs are higher as well, moreover, the scale production has not been reached yet. In fact, respondents consider to spend between 10% and 20% more at maximum for an electric car, in comparison to its conventional counterparts, as pointed out in the third question of the survey. Still, electric vehicles are very far from that interval, since these cars cost, in general, between 35% and 50% more than diesel and petrol fuelled cars. Anyway, there are many positive points for consumers, for example maintenance costs are much lower compared to conventional vehicles. Since the battery and the engine form a unique block, electric cars require less maintenance[72] and do not require extra controls other than the usual inspections, which occur after having reached the distance deadline (in general, after 10 or 20 thousand kilometres) or the time deadline, which could occur yearly. This represents a big advantage for electric cars, while conventional vehicles require more maintenance since many mechanical components require periodic controls, such as oil changes, cooling systems, gearbox and transmission controls, as each of these represent a single mechanical component. Finally, diesel/petrol price was chosen by

[72]"Maintenance and Safety of Hybrid and Plug-In Electric Vehicles", US Department of Energy, 2020

respondents as the least important factor, as drivers take fuel as a primary good, since it is necessary to cover long distances and fuel stations are available in many points along street roads. Moreover, the price difference among petrol suppliers is very low, and it mostly depends on the amount of taxes that the fuel station has to pay. Anyway, respondents seem to sustain higher costs, in fact the price for diesel and petrol is around 1.74-1.78 euro per litre[73], instead of changing powertrain, as pointed out in the fifth question of the survey. As a matter of fact, these last two factors could represent an obstacle for electric vehicles implementation, if the price difference between the two powertrains remains very high and the price of fuels remains low compared to the price of charging stations. Nevertheless, most of the respondents placed these factors as the least important in the ranking, so consumers seem to consider them less than the other three. Moreover, the major car producers and corporations are focusing their efforts on improving the battery production process, in order to make it less expensive for consumers, and on how to improve the quality of the technology ensuring reliability and performance. On the refuelling side, petrol and diesel fuels tend to be more expensive than electric fuel, since many energy companies are dealing partnerships with important car brands (as shown in table 2.1.2), which offer monthly leases at very cheap prices. If we compare the same cars but with different powertrains, for example the Volkswagen ID.3 and the 8th generation Golf, assuming to cover the same distance (around 1800-2000 kilometres per month) at a reasonable speed, so that the consumptions figures are respected, we can observe some interesting aspects:

- starting from the Golf, Volkswagen guarantees that this car's consumption figure (such version is obtained considering petrol as fuel) is 18.2 km/L and it has a 50 litres fuel tank, so it would require 110 litres to cover the reference distance, which is equal to two complete refuels. Then, to refuel the car it will cost 1.74 euro/litre, which will be equal to a 191.4 euro per month;

[73]IlGiorno, "Prezzo carburante, quanto costano oggi benzina e diesel", 2022

- considering the ID.3, the 45 kWh battery allows the car to reach 330 kilometres, according to WLTP figures, to cover 2000 kilometres the car needs to be refuelled between 6 and 7 times, as the requires 300 kWh in total. If we look at table 2.1.2, the consumer has the possibility to sign a lease contract with Ionity to charge his car at the price of 100 euro per month, which is much less compared to the expenses required for the Golf.

To conclude, electric cars cost surely more than their conventional counterparts, and the price difference is still very high, but these cars can turn out to be cheaper in the long term, as much of the expenses related to maintenance and refuelling can be cut out. Moreover, consumers should consider that the electric technology is growing, so it is reasonable to expect that the price of these vehicles is higher, but once the scale production of such vehicles will be reached, prices will decrease exponentially, even though it will take few years. Putting together the model settings and the calibration of parameters from the survey's results, in the next paragraph the simulated results of the model will be presented.

2.3 The Veneto Case Study: Results and Evaluations

To test the reliability of the model, we cannot take the national case, as more extensions to the model are required, so, it is first implemented at the regional level, starting with the region Veneto as a case study. After a deep analysis of each branch, which has been performed in the previous paragraphs, while concerning the factors characterinzing the third branch, a pool selection among factors has been performed. As a matter of fact, the chosen factors should represent the scenario of a potential car purchase, in which the consumer has to made a choice between electric and conventional vehicles, so that the car satisfies his needs while being envirnomental friendly, mitigating and decreasing the GHG emissions problem. The results that will be presented in this subsection are obtained after many trials and errors calibration through a one-to -one sensitivity, in which each parameter was varied taking small percentage increments, aiming at understanding how the variables could impact the scale production of electric vehicles, and so pushing towards a transition to "more green" vehicles in the mobility sector. The following table shows the parameter setting that brought to the three best simulation runs in terms of percentage share of electric vehicles:

Variables\Simulation N°	Simulation 1	Simulation 2	Simulation 3	Units of Measure
Initial EV	287	287	287	
Initial CV	1014220	1014220	1014220	
Starting Year	2015	2015	2015	t=0 is 2015, t=300 is 2040. For t=12, we have a year
Final Year	2040	2040	2040	
GDP Growth Rate	-0,052	-0,052	0,01	%
Net Population Growth Rate	-0,062	-0,062	0,03	%
Demand Growth Factor	0,01	0,01	0,01	
Range	160	320	320	KM
Selling Price of CV	25000	25000	25000	Euro
Selling Price of EV	45000	45000	45000	Euro
Subsidy for EV Purchase	3500	5000	5000	Euro
Price Decline Rate	0,2	0,49	1,86	%
Charging Time	360	360	180	Minutes
Fuel Change Rate	14,7	25	20	%
Purchase Share of EV	50,2	60,1	72,0	%

Table 2.3.1: Table with initial values and the final purchase share of electric vehicles. The time steps represent months time instants, for t=0 we start from 2015, for t=300 we arrive at 2040. Each multiple of 12 represent a year time instant.

Starting from the first simulation, it can be observed that the initial number of circulating electric and conventional vehicles was fixed at the real value registered in Veneto in 2015 (t=0), and such values were kept equal in the other simulations. For what concerns the economic and social development of the region, the GDP and the net population growth rates were computed from a 10-year average in the ISTAT datasets, such values were not changed between the first and second simulation, while the demand growth factor was fixed at 0.01 in all three simulations, as small increments of it were bringing very inconsistent results regarding the vehicle demand side. Instead, it was more important to study how the different initial values describing the survey and factor analysis branch, as different assumptions in the factors' starting values will guide towards important conclusions characterizing the purchase share of electric vehicles. As a matter of fact, the different values can be observed in the table, in particular it can be observed that keeping the highest amount for the subsidy, so assuming that consumers will all buy very low emission cars, for fixed initial prices of both conventional and electric vehicles, we could reach a very optimistic percentage share of electric vehicles by 2040. Moreover, to reach such optimistic value, it can be observed how doubling the range initial value, halving the initial charging time and assuming that the learning curve describing the production process for batteries and electric vehicles has reached higher levels of units produced per time, electric cars will cost less in the future, so favouring the increase in the purchase share and a powertrain transition in the mobility sector. To visualize the results of the simulation, in the next pages the graphs related to the third simulation run, the best of the three ones, will be presented. Starting from the first branch, we will observe how the scale production of both types of vehicle will look like in a long run simulation, assuming as initial values the figures reported in the table 2.3.1., and here below we can observe the evolution:

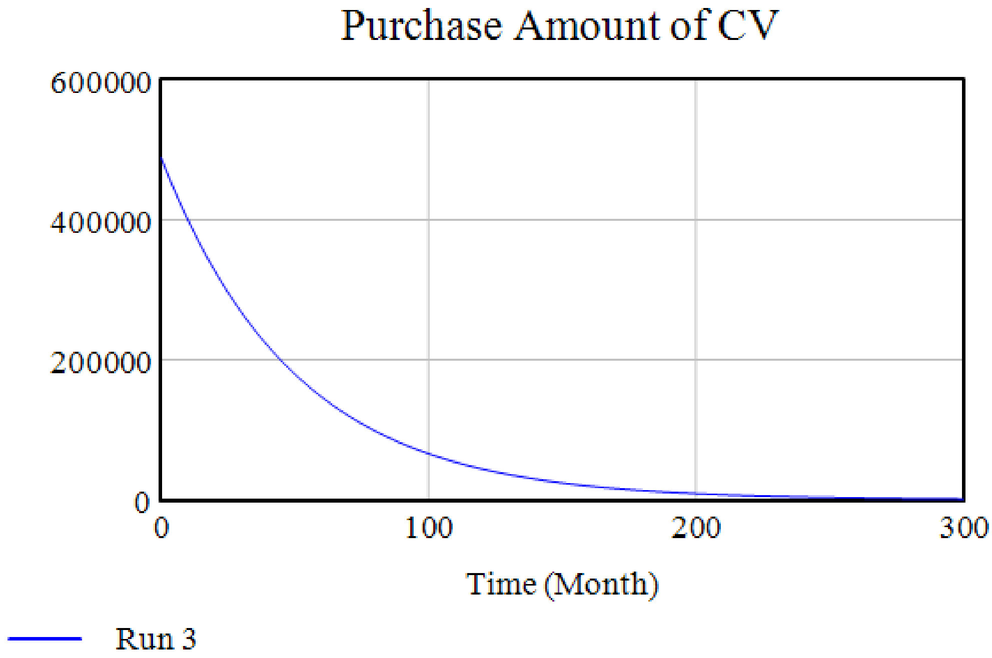


Figure 2.3.1: Evolution of the purchase trend for conventional vehicles. For t=0 it is referred as year 2015 and the starting value represents the number of conventional cars bought in 2015 in Veneto; for t=300 it is referred as year 2040.

Starting from the analysis of the conventional vehicles purchase trend, we can observe that such cars will experience an exponential decay, which should reach zero levels by the year 2040. In particular, it can be observed that around the year 2034 (t=228), the amount of conventional cars purchased is very low, reaching almost the zero level, and such finding could be a possible real scenario, which reflects the objective of the European Parliament to stop the production of petrol and diesel cars[74]. Such finding could be an important result that could bring an important turning point, favouring the development of electric vehicles and all its infrastructure, while becoming the next mean of transportation in the mobility sector, so signing an evolution in the street passenger cars. So, the purchase amount of conventional vehicles affects the scale production of such vehicles, so it is expected to decay exponentially following the path described previously, yet, it will take many years to reach zero-level of scale production for conventional vehicles, as car producer need time to rethink

[74]"MEPs vote to end sale of petrol and diesel car by 2035 in EU", The Guardian, 2022

the production process and train the workforce that needs to acquire new skills. The following graph will show the path of the scale production for conventional vehicles:

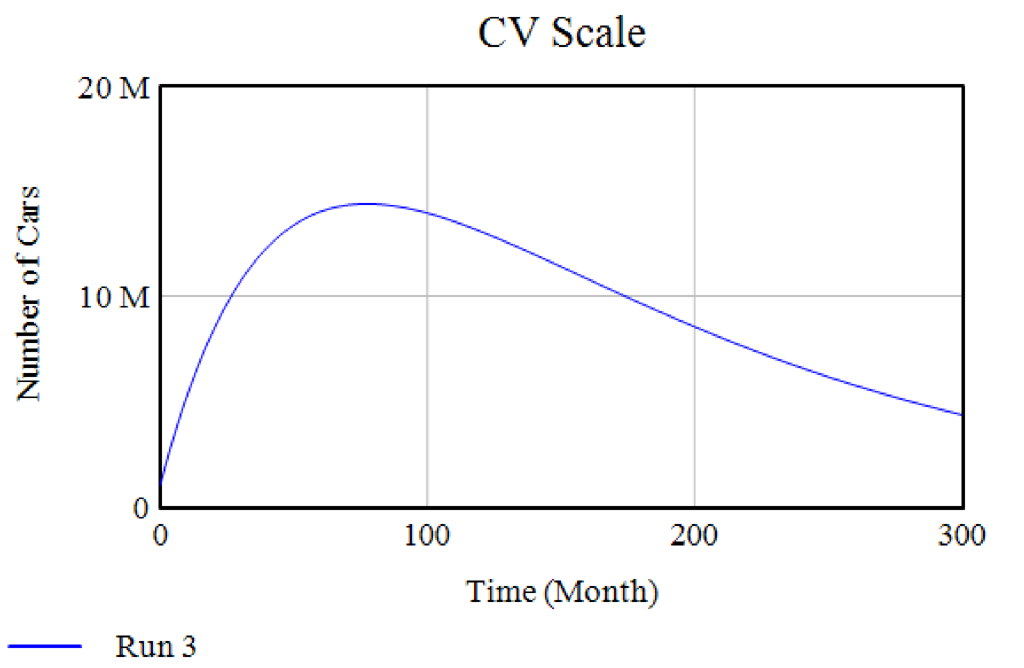


Figure 2.3.2: Evolution of the scale production trend for conventional vehicles. For t=0 it is referred as year 2015 and the starting value represents the number of conventional cars produced in 2015 in Veneto; for t=300 it is referred as year 2040.

We can observe that the path shows a first increase, which should reflect the last phase for conventional vehicles: car producers will still produce diesel and petrol cars up to 2022 (t=84), which is represented by the peak. Once the peak is reached, the scale production of these cars should experience an exponential decay, so, they will start focusing more on the electric powertrain, and the turning point could be observed by 2025, which is the objective year for many car producers, in particular for the Volkswagen Group, but it is not the only one, as they want to improve their product line by increasing the models of electric vehicles[75]. Finally, the analysis of the trend for scrapping amounts of conventional vehicles will conclude the flow of such cars, and the graph below describes the path that we could expect across time:

[75]"Strategy TOGETHER 2025+", Volkswagen Group, 2019

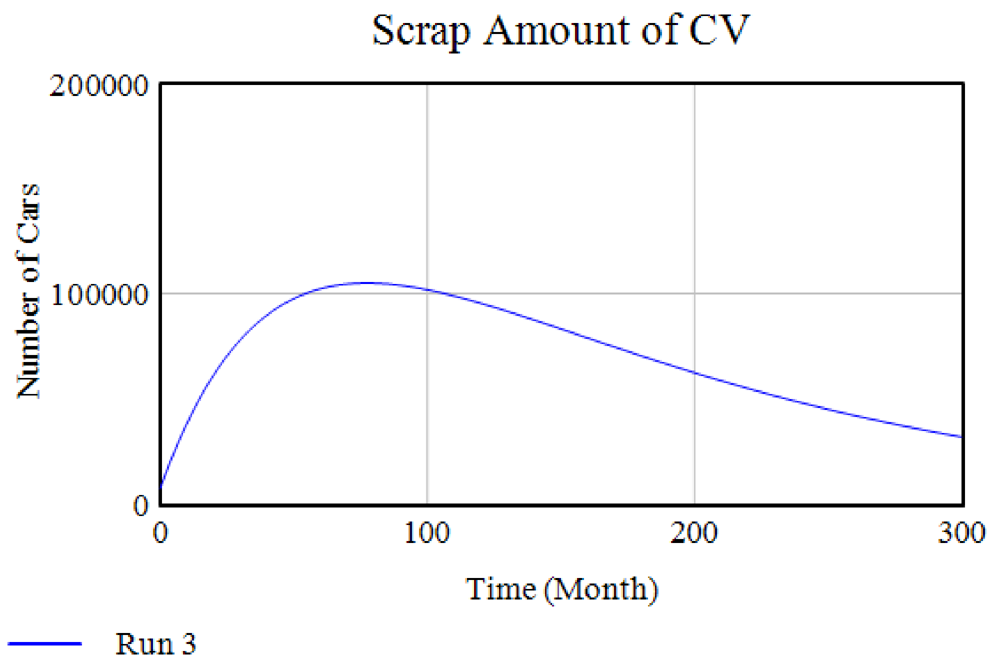


Figure 2.3.3: Evolution of the scrapping trend for conventional vehicles. For t=0 it is referred as year 2015 and the starting value represents the number of scrappings of conventional cars obtained through equation (2) in 2015 in Veneto; for t=300 it is referred as year 2040.

It can be observed that the curve describing the trend for the scrappings amount of conventional vehicles follows the same path of the scale production for conventional cars: an initial increase, where the peaks of the two curves are almost set to be around the same time instant, and, then a final decay which should sign the expected transition to electric vehicles. The initial peak that we can observe in the curve could describe the closing phase of the conventional vehicles' lifeycle, as consumers will scrap their old polluting cars, from which they are going to benefit from the eco-incentive, and car producers may be able to recycle some components to build electric cars, so limiting as much as possible the wasting of resources. Anyway, it can be observed that it will take time to reach the zero-level of scrap amounts, as petrol and diesel cars represent the majority in road mobility, but once this level is going to be reached, we should expect that the powertrain transition has been completed, signing an evolution in the automotive market. If we analyse the trend paths for electric vehicles, we should expect an opposite behaviour with respect to conventional cars. The following figures will represent the trends describing the purchase amount, the scale production and the scrappings amounts of electric vehicles:

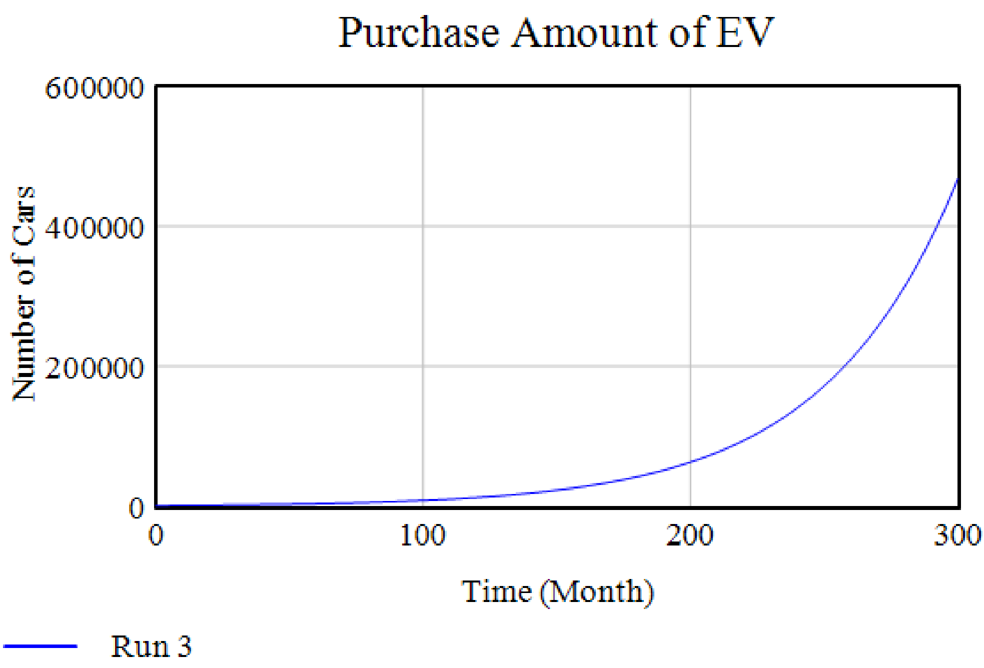


Figure 2.3.4: Evolution of the purchase trend for electric vehicles. For t=0 it is referred as year 2015 and the starting value represents the number of electric cars bought in 2015 in Veneto; for t=300 it is referred as year 2040.

In the graph we can observe that electric vehicles will start to show an increase in the purchase amount after the year 2023 (corresponding to t=96), so from 2015 to 2023 we could expect a slow increase in the number of circulating electric cars, which could become an even more promising and optimistic scenario considering the exponential increase after the year 2033 (corresponding to t=216). As a matter of fact, this finding should coincide with the view of European entities, aiming at stopping the production of conventional cars, in order to push in favour of the consolidation of the electric cars in the automotive and mobility sectors. As a consequence of this estimated path, we can expect to see an exponential increase considering the scale production of electric vehicles, which will be observed in the graph below:

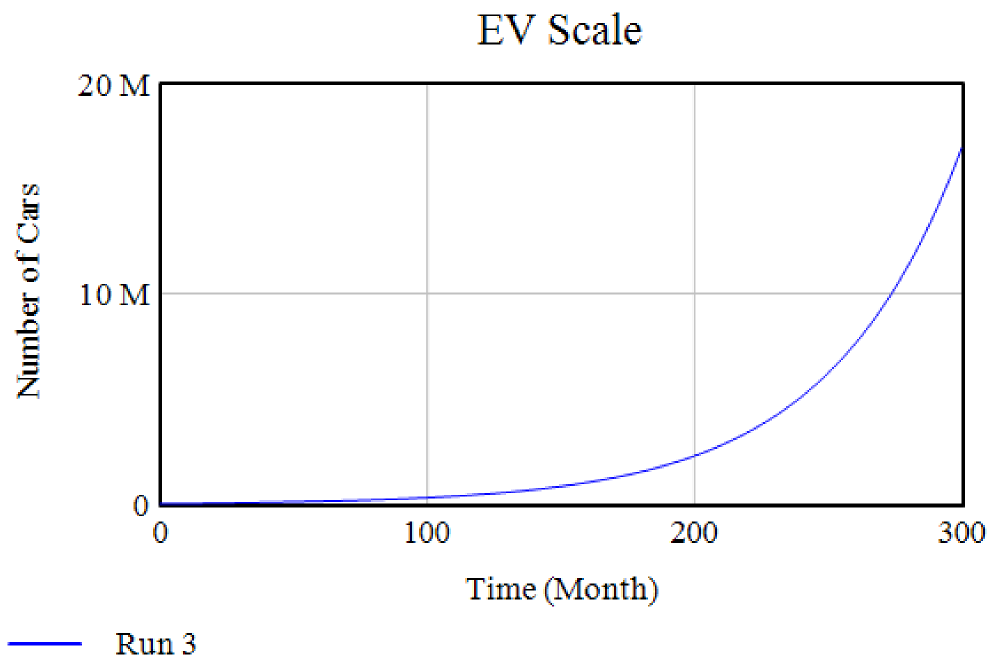


Figure 2.3.5: Evolution of the scale production trend for electric vehicles. For t=0 it is referred as year 2015 and the starting value represents the number of electric cars produced in 2015 in Veneto; for t=300 it is referred as year 2040.

In the graph we can observe the exponential trend that should reflect the cycle of the new electric vehicles. If we assume that the learning curve describing the production process of batteries and electric cars has reached an optimal level of units produced per time, we can expect this exponential growth in the production of such vehicles. Anyway, the orders of magnitude describing the curve should be revised, as reaching a very high level of units produced, around twenty million units produced should be out of boundaries, as we are using as a reference the region Veneto. Such reasoning regards the scale production of conventional vehicles as well, so a revision of the constraints and the boundaries of the system is required, in order to achieve a more realible figure. Finally, to close the flow of electric vehicles, we are going to analyse the curve that describes the scrapping amounts of electric vehicles, which is represented in the following figure:

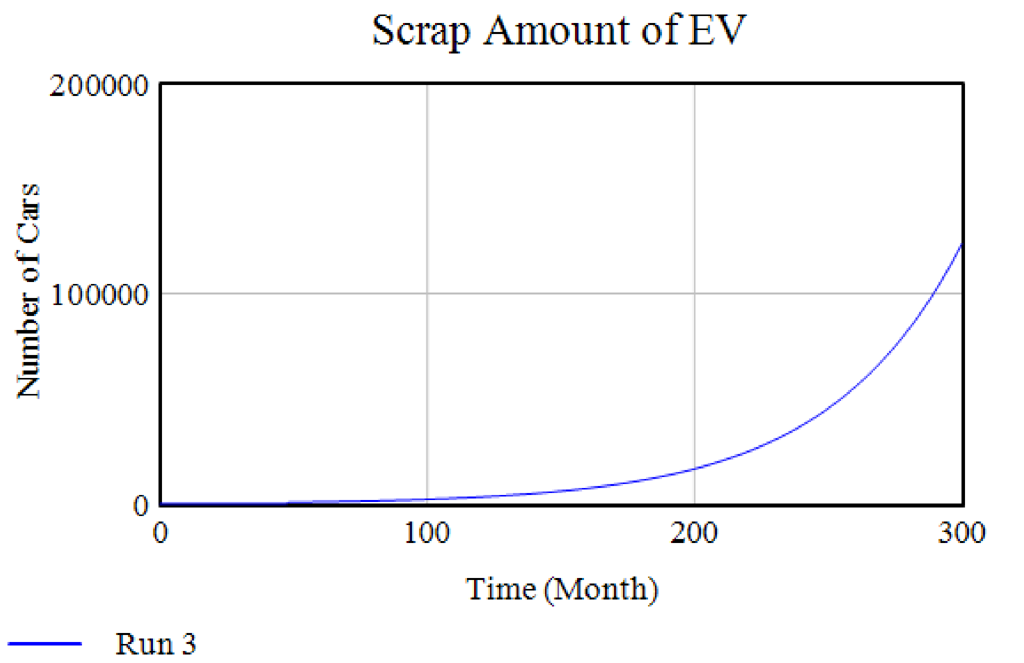


Figure 2.3.6: Evolution of the scrapping trend for electric vehicles. For t=0 it is referred as year 2015 and the starting value represents the number of scrappings of conventional cars obtained through equation (3) in 2015 in Veneto; for t=300 it is referred as year 2040.

As we can observe, the first electric cars to be scrapped should be around the year 2025 (corresponding to t=120), and this could be explained by early adopters consumers that have bought first generation electric vehicles, so we should assume that the technology was at the initial phase of development, so it is reasonable to expect some issues linked to batteries or the powertrain block. Still, we can observe that the scrapping amounts exhibit an exponential increase around the year 2035 (corresponding to t=240), so after a twenty-year period we should observe a very high increase in such variable. A possible explanation behind such phenomenon could be given by the fact that electric cars tend last longer than conventional vehicles, mostly because electric cars require less maintenance compared to diesel and petrol cars. As a matter of fact, the major car producers in Europe are aiming to develop batteries increasing their life, so limiting loss of power and capacity in the long term, and the objective is to create cars that can last around twenty years[76], before the recycle

[76] "All about electric car batteries", EDF Energy, 2021

process starts to take place. Thus, once the battery production process has reached higher levels of development, we can expect new generations of electric vehicles to replace older generations, so by 2040 (t=300) it is reasonable to expect an exponential increase in the scrapping amounts of electric cars. Then, if we move to the second branch of the model, we will now analyse the dynamics of GDP and population and the imapct that such dynamics could bring to the vehicles' demand, using as initial values the figures describing simulation number three reported in table 2.3.1. Starting from the growth rates, we first calibrated such parameters taking a ten-year average (from 2010 to 2020) from a dataset taken from ISTAT: Italy is assumed to keep very stable growth rates, almost equal to zero, both in terms of population and GDP. Using such values, results were not promising, as less money could be translated in less investment in all the infrastructure consisting electrification of mobility, so the demand for vehicles encountered some obstacles, bringing some issues in particular for electric cars. Nevertheless, if we assume a stable growth both in GDP and population, 0.01% and 0.03% respectively, we can observe some interesting results:

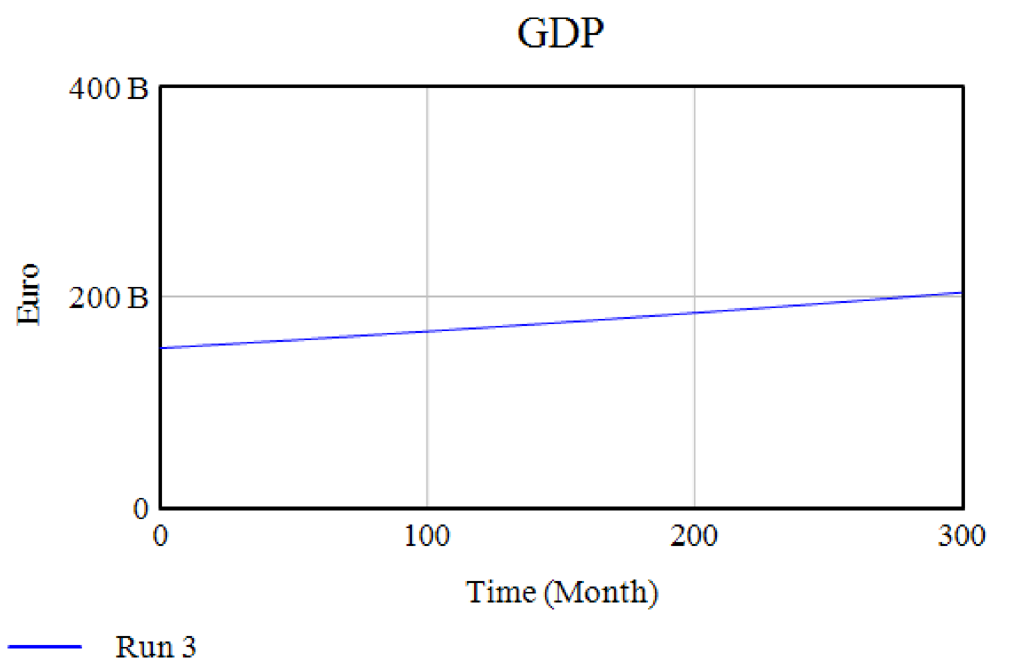


Figure 2.3.7: Evolution of the GDP dynamic. For t=0 it is referred as year 2015 and the starting value represents the GDP registered in 2015 in Veneto; for t=300 it is referred as year 2040.

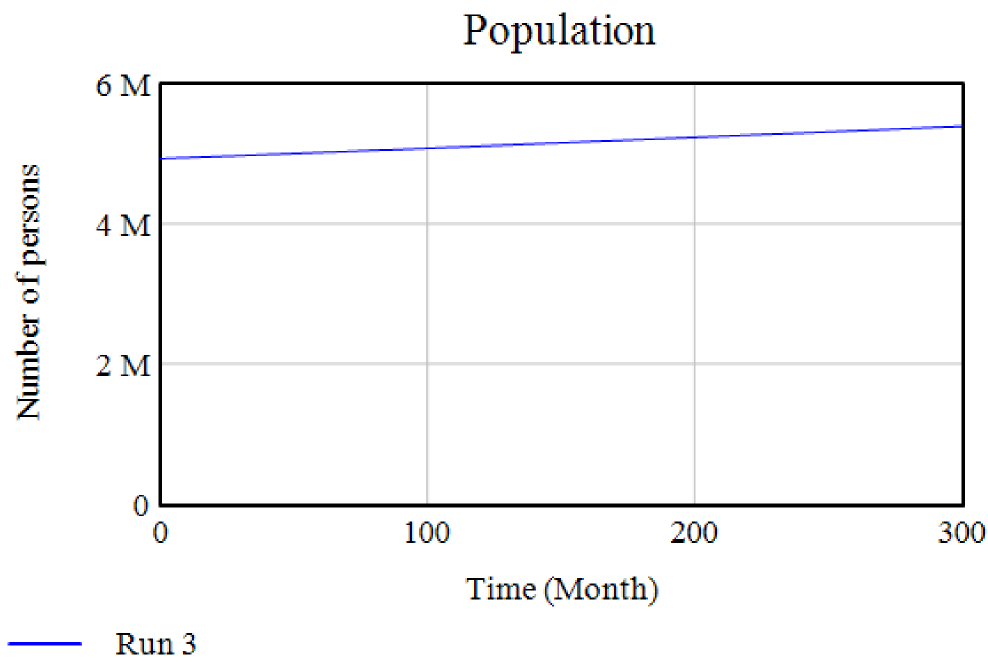


Figure 2.3.8: Evolution of the population dynamic. For t=0 it is referred as year 2015 and the starting value represents the total population registered in 2015 in Veneto; for t=300 it is referred as year 2040.

Assuming stable growth rates, we can observe a linear trend both in the GDP and population dynamics, which is an optimistic view. Moreover we can observe that Veneto region could reach 200 billion euro as total regional GDP by 2040 from the simulated results, so exhibiting a positive future pattern of stable growth. Moreover, the same reasoning can be applied to the total population pattern, the more a region is creating value and is making good investments, the more the population will find favourable conditions in terms of working opportunities and living standards, so confirming a good development for the region. Such good development is reflected in the average richness, which is given by the GDP per person variable, as it lies between 31 thousand and 38 thousand euro per person in a twentyfive-year period: this represents a good indicator of how much a region is developed, and it could give a future expectation on the performance of future investment projects. Assuming such trends in both economic and demographic dynamics, the model simulated the following results concerning the vehicle demand side:

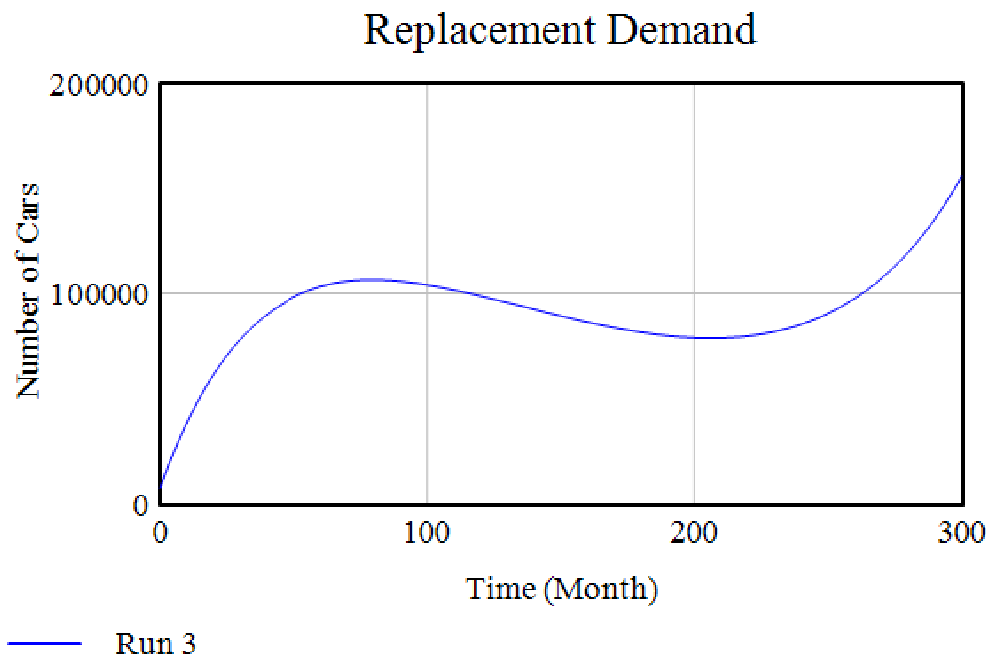


Figure 2.3.9: Replacement demand trend from 2015 to 2040. For t=0 it is referred as year 2015 and the starting value represents the number of electric vehicles that will substitute conventional vehicles registered in 2015 in Veneto; for t=300 it is referred as year 2040.

Starting from the analysis of the replacement demand we can observe that the curve shows a first increase, then a decrease and a final increase in the number of electric vehicles substituting the conventional vehicles. We can observe that the first increase can be explained by early adopters consumers buying first generation electric vehicles, as they will benefit more from the purchase of such vehicles, leading to a first step towards electric vehicles, which peaks around 2022 (corresponding to t=84). The second phase could be explained by a period of coexistence of electric and conventional vehicles together, as car producers will finish the production cycle for diesel and petrol cars, and by 2032 (corresponding to t=204), we can observe an inflection point, where the replacement demand increases exponentially, which should sign the end of conventional vehicles and a final transition towards electric cars.

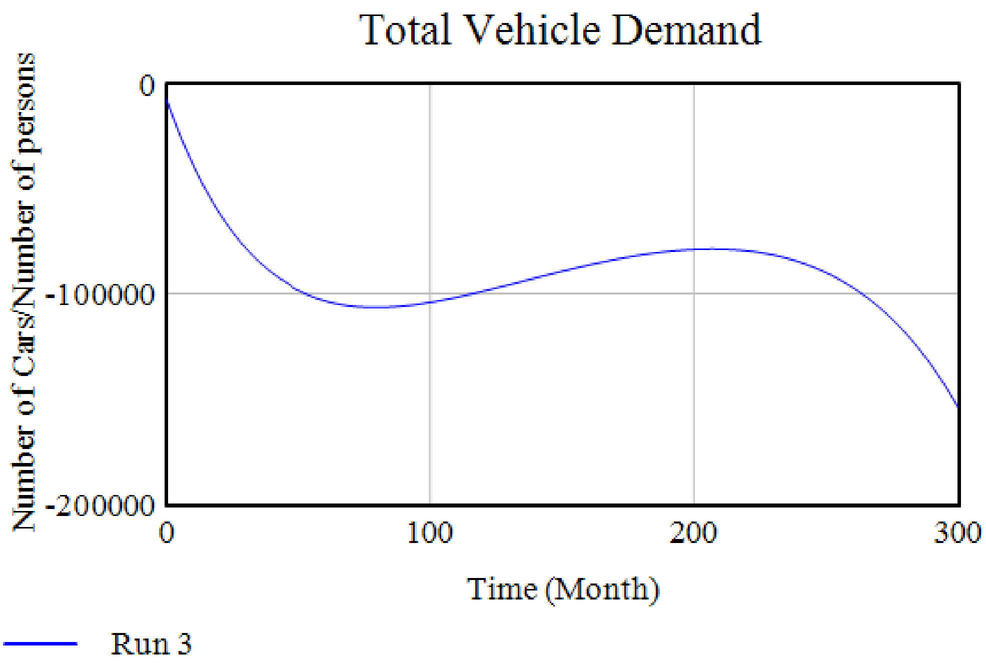


Figure 2.3.10: Total vehicle demand curve from 2015 to 2040. For t=0 it is referred as year 2015 and the starting value represents the total number of vehicles registered in 2015 in Veneto; for t=300 it is referred as year 2040.

Analysing the total vehicle demand curve, we can observe a decreasing trend, meaning that conventional vehicles will be abandoned and not considered by consumers in the long run, so the total demand should be described only by the electric vehicle demand. Moreover, we can suppose that a lower number of electric vehicles should satisfy the total vehicle demand, as electric cars are characterized by a longer lifecycle, and at the same time we can assume that transports regulating organizations want to keep a stable number of circulating vehicles, in order to avoid traffic congestions ensuring a viable mobility on the roads. Finally, we will go thorugh the analysis of the last branch of the model, where we calibrated the parameters aiming at identify the most impacting factors, that will accelerate the rate describing the share of electric vehicles. As we can observe in table 2.3.1 we decided to double the initial value for the range compared to the 2015 average figure, assuming a more optimistic scenario in the battery technology and the values for the selling prices were kept fixed in all the simulations, in order to replicate the behaviour of prices fluctuation in the real market. For what concerns the subsidy, we assumed an optimistic case, where consumers buy only zero or low emission cars and scrap their old conventional cars, so that they can get the maximum reduction in the selling price for the purchase of electric vehicles, moreover we decided to increase the price decline rate, assuming that car producers are investing in improving the workforce's skills that are needed, in order to increase the learning rate concerning the electric technology, while they keep investing in the search for new resources that are cost and quality efficient. As a result, this should bring to more units produced and an exponential decrease in the prices across time. Finally, we decided to halve the initial charging time, in order to investigate the effect of this factor in the purchase share of electric cars, and we decided to decrease the fuel change rate from 25% (as initially set in the second simulation run) to 20%. The graph below will represent the share of electric vehicles as a result of the combined effect of all the branches that we described all along this subsection

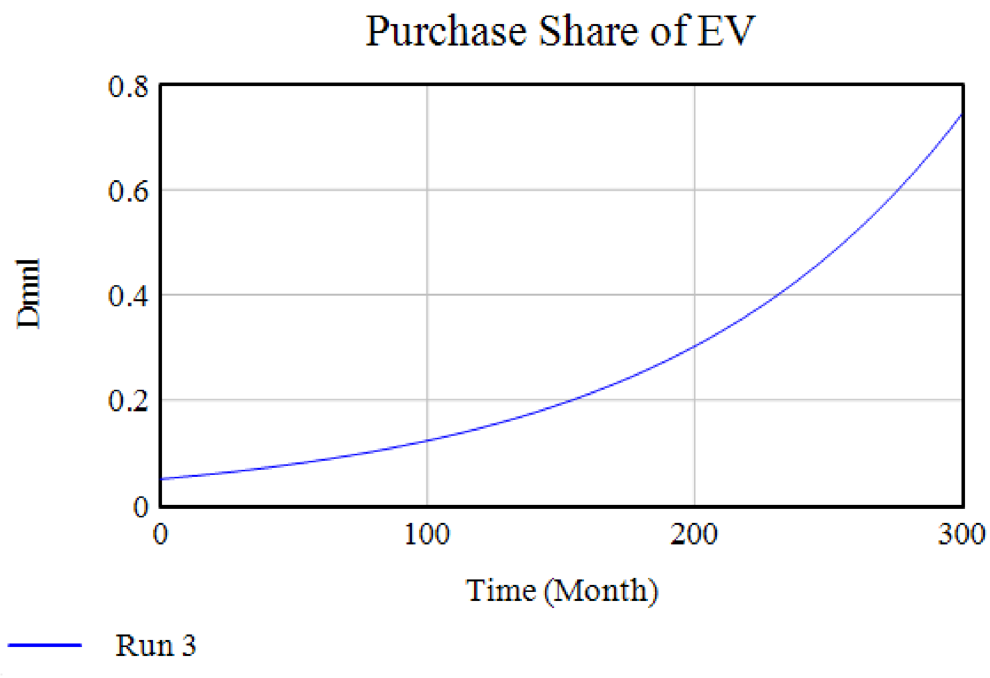


Figure 2.3.11: Evolution curve describing the percentage share of electric vehicles from 2015 to 2040. For t=0 it is referred as year 2015 and the starting value represents the percentage of electric vehicles registered in 2015 in Veneto; for t=300 it is referred as year 2040.

As we can observe, the combined effect of the "vehicle scales branch", the "vehicle demand & socio-economic development" branch and the survey & factor analysis" branch should make possible to reach a 72% of electric vehicles by 2040 in Veneto. To conclude this subsection, we will go through a comparison of the three simulation runs:

- Simulation No.1: we decided to represent a scenario that should replicate the behaviour of the market and the sectors in 2015. The initial number of electric and conventional vehicles was kept fixed in all the simulations, as these figures represent real data registered in 2015. The growth rates were kept equal in the first and in the second simulation, as we wanted to replicate the behaviour of the population and GDP dynamics, as they were in 2015. Concerning the factors' initial values concerning range, charging time and selling prices, fuel change rate and the subsidy for electric vehicles, we decided to elaborate an average taking in consideration the sitaution in 2015, while for the subsidy we assumed consumers will buy mid emission vehicles, so that they can perceive 3500 euro as price reduction for the purchase of an electric car. The combined effect generated by all these initial values brought to an achievement of 50.2% by 2040 in the share of electric vehicles;

- Simulation No.2: in this simulation run, we decided to put more attention on the analysis of the effect that the factors characterizing an electric vehicle will have on the their share, thus we changed the range initial value by doubling it, increased the price decline rate up to 0.49%, increased the subsidy assuming that consumers will buy zero or low emission vehicles and increased the fuel change rate up to 25%. As pointed out in the figure 2.2.1, describing the ranking order by importance for all the five factors chosen, increasing the change rate of fuel, which means an increase in fuel prices, and decreasing the purchase price of electric vehicles through the price decline rate and the subsidy, create a low increase in the share of electric cars reaching 60.1% by 2040. So, it turns out that focusing on the least important factors (buying price and fuel price) does not increase so much the purchase share of electric vehicles, while most of the effect is caused by the range initial value;

- Simulation No.3: in this final simulation, we tried to calibrate parameters aiming at improving the share of electric vehicles taking in considerations previous simulations. In fact, we assumed stable growth rates for both social and economic sides, then we kept the initial range value equal to that used in the second simulation, further differentiated values were assumed in the charging time, which was halved to 180 minutes, and in the price decline rate, which was increased up to 1.86%, while the other parameters were fixed to the second simulation levels. It is possible to observe that focusing on the most important factors (range, charging time and price difference) the share of electric vehicles increased by a good increment, compared to the other simulations, reaching 72.0% by 2040, which is a very good result. Moreover, such increase in the share of electric vehicles does not seem to be offset by a lower fuel price, confirming that fuel price does not create great effects in the share of electric cars.

This final recap of simulated results concludes the chapter about the model and the description of the Italian automotive market situation. In the final section we will go through an analysis of side problems that affect the automotive and energy sectors, concluding with the evaluation of alternatives to electric vehicles (for future mobility sector concerns) and some considerations about the role of environmetal humanities in relation to the automotive sector.

3 Final Considerations: Energy Sourcing Problem and Environmental Humanities

3.1 Energy supply: the search for renewable energies

After having described the results that came out in the model simulation and having presented some further improvements that could be implemented in the model, so that it could resemble the real behaviour of the automotive market, it should have been mentioned the problem of finding sources of energy, the so called energy supply problem. In fact, the energy sector should be coupled with the automotive industry as most of the elements characterizing these two industries are strictly correlated. Electric vehicles need electricity to power their batteries, yet, most of the electricity comes form fossil fuels and carbon sources, representing one of the main drivers of CO2 emissions. There is no point to think electric vehicles are not clean, they represent a “green” alternative to conventional vehicles, but what happens before the introduction of an electric car in the market, should be revised: the production of such cars and the production of electricity is still dependent on carbon and fossil fuels, especially in Europe. As a result, to make the electric car a “full green” alternative to conventional vehicles, the term should regard the entire flow starting from the production arriving to car utilization; in this sense, Europe could reach the desired targets highlighted in the Paris’ Agreement. Before looking at some data, the global energy sector is affected by two problems mainly: the energy poverty and too high CO2 emissions in rich countries. For energy poverty, the university of Oxford defines such problem as the lack to access to modern energy and technology for all countries characterised by a low GDP per capita[77]. The relation between these two variables directly describes that in such countries, the CO2 emissions are very low, and the other way round is true as well. As a consequence, this problem is related to African countries mainly, while for Europe this is not the case, since it has full access to all

[77] “The world’s energy problem”, Our World in Data, 2020

the sources of energies. The second problem defines that, in general, rich countries that have access to energy produce CO2 emissions and greenhouse gases (GHG) that are too high and might be unsustainable in the long term. For example, taking the richest 1% in Europe, they produced 43 tonnes od CO2 emissions, which is a value that is 9 times as much as the global average. It can be noted that such problem is not only restricted to the richest, instead, it refers to the whole Europe, where the population can appreciate good living conditions, good access to education and demographics are stable. In fact, this second problem makes evidence of the relation linking good living conditions, so higher GDP per capita figures and CO2 emissions: the more the living conditions tend to be good, the more CO2 emissions are usually produced. This second energy problem pointed out that the majority of the world population have greenhouse gas emissions that are far too high to be sustainable over the long run, even though some EU countries were able to keep higher living conditions while decreasing the CO2 emissions, as shown in the graph below:

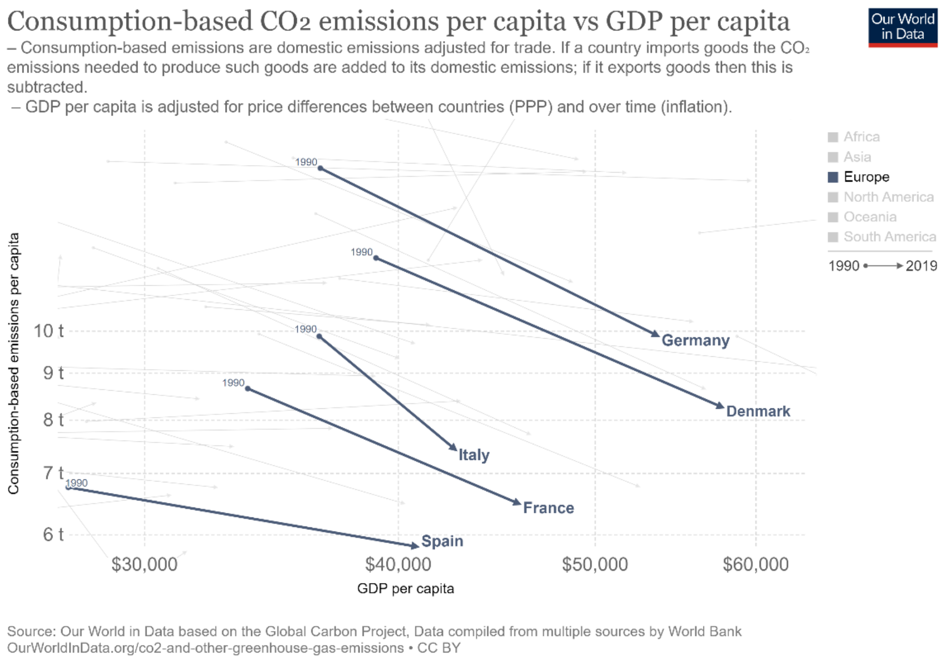


Figure 3.2.1: CO2 based consumption vs GDP per capita for some EU countries Source: Our World in Data based on the Global Carbon Project, Our World in Data, 2022, https://ourworldindata.org/worlds-energy-problem

Over the period 1990-2019, Italy reduced the tonnes of consumption-based CO2 emissions per capita from 10 to 7.43 tonnes, while the GDP per capita has increased from 36 thousand to 42 thousand, confirming the right direction that Italy is pursuing. On the same path, Germany, Denmark, France and Spain are adopting crucial changes in order to decrease consumption-based CO2 emissions, while maintaining good quality of life. Anyway, energy poverty and unsustainability of GHG over the long run represent two sides of a much bigger problem: the lack of large-scale energy alternatives to fossil fuels that are cheap, safe, and sustainable. Having a large-scale production of renewable energies will solve energy poverty and the emission concerns, yet most of the renewables are not as efficient as the carbon and fossil fuels, in terms of performance and costs. Even though the energy sector requires high investments, as costs and sourcing are the main barriers, European countries have been trying to exploit new sources of renewable energies, while improving nuclear power plants, in order to decrease the utilization of carbon and fossil fuels. The following graph will show the electricity production grouped by different source of energy in Europe and in Italy throughout the period 1990-2021:

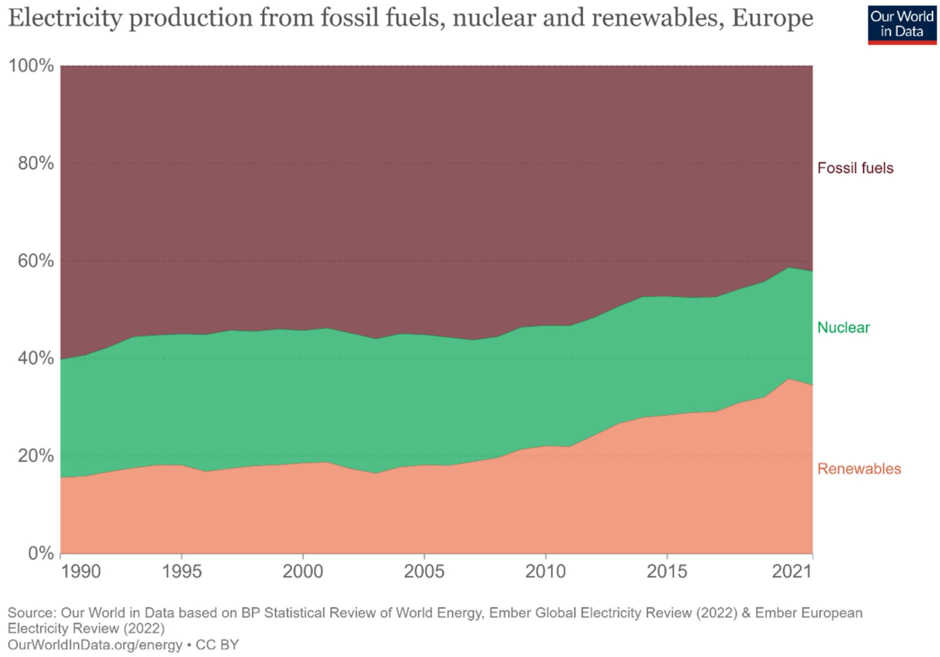


Figure 3.2.2: Electricity production from fossil fuels, nuclear and renewables in Europe 1990-2021
Source: Our World in Data based on BP Statistical Review of World Energy, Our World in Data, 2022, https://ourworldindata.org/worlds-energy-problem

It can be noted that all over Europe the portions regarding the three main sources of energy have been stable up to 2007-2008, after that point, electricity obtained from renewables registered an important increase up to 2020, where nuclear and renewables combined were able to cover almost 60% of total production, yet 40% of total electricity was produced by fossil fuels. For what concerns Italy, it can be noted that the nuclear energy is not even implemented after 1987, remembering that in 1986 occurred the failure of reactor number 4 in Chernobyl, and Italy decided to stop using nuclear as source of energy, confirmed by the two Referendums voted in 1987 and in 2011. So, the Italian government has decided to pursue the renewable energy path, and it can be noted that from 2008 up to now, Italy was able to reach important results in the electricity production reaching 40% of the total production, still most of the electricity is produced through fossil fuels. As previously said, this could represent a big problem in the long term, moreover it should affect all the sectors that are strictly correlated with the energy sector, one of them is certainly

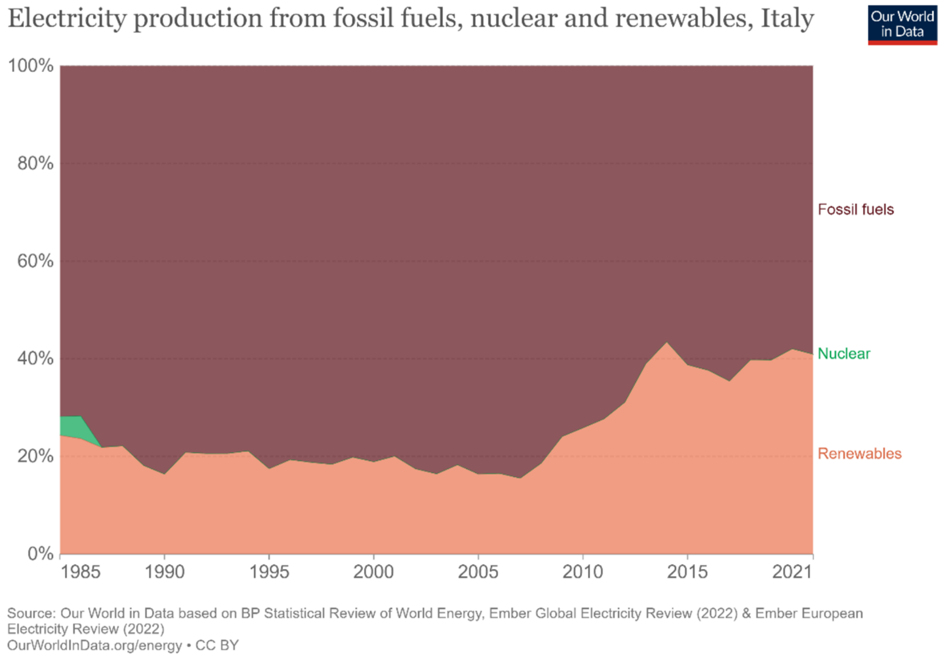


Figure 3.2.3: Electricity production from fossil fuels, nuclear and renewables in Italy 1990-2021
Source: Our World in Data based on BP Statistical Review of World Energy, Our World in Data, 2022, https://ourworldindata.org/worlds-energy-problem

the automotive industry. In fact, electric vehicles could challenge the demand for electricity: Bloomberg estimates pointed out that with growing share of electric vehicles, it is reasonable to expect a significant increase in the demand for electricity, which could stress the electric infrastructure. Anyway, this forecasted increase in the share of electric vehicles is linked with a positive effect in CO2 emissions: the EU Commission projection expects that the additional emissions produced by the energy sector are outweighed by the increase in the electric mobility share, reaching a net reduction of 100 Mt of CO2 by 2030 and of 255 Mt by 2050[78]. The problem remains in all the EU countries characterized by a high share of fossil fuel power plants, where, the satisfaction of the electric cars demand could lead to higher CO2 emissions, so putting at risk the environmental benefits of such vehicles. Thus, on one side, the increasing share of electric vehicles leads to the problem of additional electric demand, while on the other it regards mobility per se, as this could be translated

[78]”Electric vehicles and the energy sector - impacts on Europes's future emissions”, EEA, 2019

in more circulating vehicles bringing up the problem of congestions or traffic jams, so leading to an improvement in the road infrastructure and point of charge infrastructure. The above-mentioned concerns are connected to one much bigger problem which is energy supply, in particular a low-emission source of energy, which should satisfy the increment of demand for electricity and the improvement in the road and charging infrastructures, which could bring up indirect effects such as an increase in CO2 emissions. To answer such problem European countries invested differently according to their best fitting renewable energy: France and Germany focused their investments in improving the nuclear as source of energy, Scandinavian countries focused on the exploitation of the wind as source of energy, Spain decided to pursue the hydroelectric and wind exploitation as sources of energy, finally, Italy has been trying to exploit solar energy through photovoltaic systems, which make it the top investor in Europe regarding such type of energy. In 2022, some remarkable results have been reached in nuclear energy, one of them is certainly the Joint European Torus (JET) tokamak reacto[79] in the UK, used as a workbench test for another fusion experiment performed by ITER in France[80]. JET's reactor was able to peak 59 megajoules of energy over a 5 second time window, doubling the energy produced in the first test. Researchers and scientists believe that, if the same conditions were applied to the ITER reactor, the energy produced could be 10 times more than the energy put in[81]. According to these figures, nuclear energy should have a double benefit: first, through the process the energy output is higher than the energy input, second, such energy produced has zero impact on the environment, as CO2 and other pollutant are not produced in the fusion process; thus, through such energy we can answer both the energy supply problem and the environmental concerns. However, nuclear energy, as the Italian case, is not publicly accepted, so as an alternative Italy decided to invest in solar energy captured through photovoltaic systems. Basically solar panels work as accumulators of solar energy absorbed during morning and noon hours, which is

[79]"Nuclear-fusion reactor smashes energy record", Nature, 2022
[80]ibid
[81]ibid

then transformed in electricity, through a converter, which could be used for private use. In general, the electricity produced through this process is not as high as we expect it to be, usually, photovoltaic systems are used as auxiliary source combined with other renewable sources, if we want to implement such source of energy on a large-scale production. Still, for private use, solar panels turned out to be a good alternative to gas and fossil fuels systems, in particular when it comes to domestic charge for electric vehicles: the tradeoff is cost-time, where at home the costs are lower than those perceived at points of charge, but the time required is much longer than using a charging station. Even though it represents a quite big investment for a household, photovoltaic systems are a long-term investment as most of the benefit, in particular less fee costs, less waste of energy and less maintenance costs, are perceived in long-term horizon. In fact, solar energy could become a driving force of Italy's energy transition as pointed out in an article published by Nature: the buildings adopting photovoltaic systems were able to produce 120 GWp (gigawatt peak), as a first result; then, such photovoltaic modules are estimated to generate 200 TWh which is twice as much the national target projected for 2030[82]. From these figures, we can imagine that at an industrial level, implementing such source of energy would be a better alternative to fossil fuels: the production processes will decrease pollutants emissions and such energy net could be implemented in the charging points infrastructure. Anyway, to unlock such potential, reseach in the energy sector, regarding infrastructure-integrated photovoltaics, should deepen three aspects: integrated design, new material and technologies and manufacturing[83]. Integrated design should combine the architecture and the structural integrability ensuring long-term efficiency, cost reduction and ease of implementation. Moreover, research should continue the search for new material and technologies that can improve the development of such photovoltaics panels, ensuring continuous higher efficiency in the production of energy thorugh such system. Finally, manufacturing is focused on finding the best

[82]"How solar energy could power Italy without using more land", Nature, 2021
[83]ibid

solution to produce modules specifically thought for the buildings and firms, ensuring an improvement in the energy production network. These three aspects are key components to make photovoltaic modules as the best solution to answer energy supply and environmental problems, while providing a big improvement in the industrial production processes. Alongside the supply energy problem, the automotive sector, and electric vehicles in particular, has to face the mineral supply challenge. Electric cars are powered through batteries, and to produce them, many minerals such as manganese, lithium, cobalt, nickel and graphite are required. In general, most of the batteries implement ions of lithium in the electric cars as the main component to produce electricity, and this could be explained for two reasons:

- lithium can produce much more energy in less space, among the existing types of batteries[84];
- lithium represents the dominant technology in battery production, as its costs have become very low in recent years[85].

To get the idea of the functioning of a battery, lithium is implemented as the main element in the anode, one of the three components of a battery, while other minerals such as cobalt, nickel and manganese are the key minerals implemented in the cathode, finally, the electrolyte separates the anode and the cathode, which takes part in the process which produces electricity. As a matter of fact, lithium-ion batteries represent the standard technology applied to battery electric vehicles, but, the increasing demand of such cars and the extraction methods of lithium (and other minerals, cobalt in particular) will increase the attention on recycling and environmental concerns. Concerning the increasing demand of vehicles, it is straightforward to think that this will directly imply an increase of mineral extractions, causing a massive use of the above-mentioned minerals. Thus, one challenge is to understand how to cut down the intensive use of such resources, which can be guided through an

[84]"Electric cars and batteries: how will the world produce enough?", Nature, 2021
[85]ibid

improvement of battery production processes and through "second-life" or recycling processes[86]. In particular, such concerns were discussed in chapter one, in particular referring to Volkswagen and COBAT. So, if on one side we have to face the supply problem and the management of scarce resources, on the other side, we should not forget the environmental concerns that arise from the extraction of such resources. Lithium mining has a big effect on quality of air, water waste and energy waste, where CO2 emissions and a big amount of energy are the product and requirement, respectively, for this process[87]. Anyway, instead of lithium, experts are more worried about cobalt, as two-thirds of global supply are mined in the Democratic Republic of Congo, implying very high social costs, where heavy working conditions and child labour represent the main negative aspects[88]. As a consequence, European countries are trying to face this problem considering possible alternatives, through investments in recycling processes and development regarding new materials that could substitute lithium or other scarce resources. In this sense, researchers have developed sodium-ion batteries as an alternative to lithium-ion batteries and it offers many advantages[89] over the conventional battery option:

- sodium is much more abundant than lithium;
- sodium is more sustainable than lithium;
- sodium-ion batteries tend to be safer;
- sodium is more feasible than lithium, as the costs that car makers will bear tend to be lower.

Anyway, sodium-ion batteries are not only characterized by pros, on the cons side we can find less energy density, as sodium ions tend to be heavier than lithium ions, we will need a higher battery pack to produce the same amount of electricity

[86]ibid
[87]ibid
[88]"Lithium-ion batteries need to be greener and more ethical", Nature, 2021
[89]"Sodium Batteries May Power Your New Electric Car", Wired, 2021

that will be produced through a lithium-ion battery. So, the tradeoff is focused on considering sustainability and energy efficiency: sodium-ion batteries tend to be more sustainable and safer than lithium-ion batteries, but they are less efficient in terms of energy density[90]. To conclude this paragraph, we have observed how energy supply and mineral supply problems represent the main challenges from a sustainability and energy efficiency perspectives, for both the automotive and energy sector. Thus, such challenges cannot be taken on its own, they should be considered together, in order to achieve net zero emission target by 2050[91] and, at the same time, to develop the best car technology that satisfies performance, safety and sustainability objectives. Considering car technology, electric mobility is the focus of another debate, as car makers are pursuing hydrogen powered cars as another clean alternative, and this wil be presented in the following paragraph.

[90]"Charting a sustainable course for batteries", Nature, 2022
[91]"Net Zero by 2050", IEA, 2021

3.2 Hydrogen powered cars: the new future mobility?

Electric vehicles have been the focus of mobility debates, particularly in recent years, as climate change and environmental concerns guided the automotive sector thorugh a revision of transport means, reworking the conventional vehicles in an envirnomentally friendly way. That is why electric cars have been proposed and many car brands have invested quite a lot to make these a reality for individuals, while converting such sector from being one cause of environmental problems to being a more environmental friendly sector, revising production processes and focusing on recycling processes. Anyway, electric cars were not the only possible proposition to make mobility and automotive "cleaner" sectors, as, on the same direction, hydrogen powered cars were considered, in particular, at the initial stage, as these cars provided more advantages with respect to electric vehicles. Less time to refuel and longer range, for example, were two features that made hydrogen fuel cells cars a more preferable choice than electric vehicles. When batteries could offer a very limited range value and the charging infrastructure was not as developed as today, fuel cell vehicles gained an important share in the market for long-distance travel and cars in general[92]. As a matter of fact, hydrogen fuel cell technology is a bit more complex than the technology applied to battery electric cars, as more components are required. Practically speaking, the functioning require a battery pack, a direct current converter, the electric traction motor, fuel tank and a cooling system. Firstly, the battery pack provides electricity to power the car before the traction battery (powering the traction motor) is engaged, then the converter converts higher voltage direct current into lower voltage direct current power needed to charge the battery pack, which, then, powers the electric traction motor. This motor exploits the electricity power elaborated by the fuel cells and the battery pack, in order to drive vehicle's wheels. Fuel cells need hydrogen and oxygen to produce electricity, so a fuel tank is required to store hydrogen. Finally, the combination of the battery and the motor components require cooling systems, in order to maintain a proper tem-

[92] "Hydrogen unlikely to play major role in road transport, even for heavy trucks", Nature, 2022

perature range avoiding combustion reactions that can provoke explosions causes[93]. As it can be noted, such engine technology is much more complex than that applied to battery electric vehicles, since the latter can be assumed to be made of a unique block, while hydrogen fuel cells can be imagined as single components. Anyway, fuel cells engines can offer many positive aspects compared to battery electric vehicles, without forgetting the cons that such engine might bring, and it will be shown in the following table:

FACTOR	PRO	CONS
EMISSIONS & SAFETY CONCERNS	1) No GHG or CO2 emissions (water vapor and warm air are the main gas emissions)	1) Hydrogen is highly flammable fuel source arising safety concerns
CHARGING TIME & COSTS TO REFUEL	2) Lower charging time compared to electric vehicles	2) The overall cost for a unit of hydrogen fuel cell power is higher than other energy sources including solar panels
RESOURCE ABUNDANCE & METALS SCARCITY	3) Ready abundance of hydrogen	3) Raw materials and precious metals (as platinum and iridium) represent high cost barriers and such materials are very scarce
FOSSIL FUELS INDEPENDENCE & EXTRACTION PROCESS	4) Potential dependence reduction on fossil fuels	4) Hydrogen extraction requires a significant amount of energy (typically through fossil fuels)

Table 3.3.1: Pros and cons for hydrogen fuel cell vehicles

Examining the above-mentioned factors, hydrogen fuel cells experienced a higher market share with respect to battery electric vehicles, when the latter were at their initial stage and batteries could offer very limited range, while the higher energy density of compressed hydrogen could ensure higher range figures, charging time required was much lower and emissions were much lower, reaching almost zero gCO2/km. All these positive aspects made hydrogen fuel cells vehicles the most advantageous choice over battery electric vehicles. Nevertheless, electric vehicles now, have been developed and its market has grown exponentially and it has expected to grow even more in the future, because car producers and European initiatives invested in the devel-

[93]"How Do Fuel Cell Electric Vehicles Work Using Hydrogen?", US Department of Energy, 2021

opment of such vehicles. Moreover, according to research journals, experts tend to be skeptical with respect to hydrogen fuel cell cars, as the sales' figure reported only 7500 cars sold globally in 2019[94], while electric cars topped 2.1 million units sold globally[95]. As a matter of fact, the market for hydrogen cars is stagnating, and the main reasons could be the found through the analysis of these facts:

- BMW was pioneering hydrogen fuel cell technology in Europe, fitting such engine in their brand new i3 and i8, as first attempts. In the first test drives, these cars showed very positive results, but as hydrogen is very flammable, in safety tests, such cars were not so reliable as fire and explosion causes arose safety concerns. In fact, BMW has stopped the hydrogen implementation on these cars, moreover, it has planned to end the production of the i3 by July 2022[96] to leave the space for second generation cars, which will be presented under the iX line;
- up to now the market for hydrogen fuel cells cars offers a very limited choice, as the Toyota Mirai and Hyundai Nexo are the only models that are available to pruchase. Such limited choice is a consequence of the few investments made by the main car producers, as they focused more on electric mobility[97];
- the refuelling infrastructure is not as developed as the one devoted for battery electric vehicles, especially in Europe [98].

Given such context, Patrick Plötz, co-ordinator of the energy economy business unit at the Fraunhofer Institute for Systems and Innovation Research (ISI) in Germany, affirms that electric vehicles will be the next clean transport mean, in contrast to hydrogen fuel cell cars. As all over Europe car makers, European government initiatives and major electricity suppliers are investing many resources in order to

[94]"Why Hydrogen Will Never Be The Future Of Electric Cars", Forbes, 2019
[95]"Global EV Outlook 2020", IEA, 2020
[96]"BMW i3 to cease production in July after nine years", Autocar, 2022
[97]"'Hydrogen unlikely to play major role in road transport, even for heavy trucks'", Nature, 2022
[98]ibid

reach the economies of scale for batteries, facilitating the production with reduction in the costs for materials, while keeping good performance and providing continuous development for electric vehicles and for charging points, it is highly unlikely that hydrogen fuel cell cars will gain market share in the clean mobility sector. To reach such development, many car makers tested their technologies through race competitions and championships such as Formula 1, Formula-E and a brand new competition that will start in 2023 and it will be exclusively for hydrogen cars, the Hyraze. In the next section, we will see in detail how brands as, Mercedes, Porsche, Nissan and DS (division of Citroën) tested batteries for electric vehicles and improved them through the years.

3.3 Motorsport as testing workbench for new technologies

Motorsport has brought some important changes in the automotive sector, both in terms of safety and performance characterizing the today's mobility. Race competitions such as Formula 1 championship, the 24 hours of Le Mans and the Indy 500 were, and still are, the most famous competitions worlwide. During the first years of such competitions, cars were very dangerous and drivers risked their life in many moments during the races, in particular in long-distance races (or endurance races) where drivers, the mechanics and the car itself were tested in terms of their performance, reliability and resistence. Even though in these races car crashes, fatal accidents and fires were almost certain in most of the race tracks, FIA (Federation Internationale de l'Automobile) has the objective to analyse all the accidents in cooperation with the racing teams, in order to provide new safety systems improving the reliability of the cars. Some of the safety systems adopted in nowadays Formula 1 cars is the side impact protection[99], which was introduced in 2014, in order to protect the driver from very intense hits and to avoid terrible accidents. Another recent innovation was the Halo[100] safety device, introduced in 2018, becoming now a key component in modern motorsport ensuring safety for drivers. These two important safety innovations are the result of the accurate analysis of the car accidents that occured during the championship, as reference to Robert Kubica's crash in 2007 in Canada[101] and Jules Bianchi fatal accident in 2014 in Japan, as well as mentioning Charles Leclerc and Fernando Alonso crash in Belgium in 2018.[102]. Safety systems are not the only improvements that FIA is focusing on, performance and emissions are the other two aspects that the association wants to continuously improve, through the promotion of less polluting technologies. In particular, Formula 1 is best known for the advancements that teams have brought on hybrid engines, keeping the objective of carbon neutrality by 2030[103]. Many solutions have been proposed to reach such long-term

[99] Formula 1 technical regulations, FIA, 2022

[100] "Halo protection system to be introduced for 2018", Formula 1, 2018

[101] "F1 Side Impact Protection", FIA, 2014

[102] "Halo system is drivers' guardian angel", FIA, 2018

[103] "Formula 1 announces plan to be Net Zero Carbon by 2030", Formula 1, 2019

target, the use of sustainable fuels is certainly one of them, as improvements on fuels are under observation, with the aim to use 100% sustainable fuels[104]. Thanks to Formula 1 improvements in technology, engines have become more reliable and the constant search for sustainable fuels might have positive implications in road transport through a more clean mobility. Moreover, many of the safety systems have been part of passengers cars, as the deep analysis of car crashes guided car makers in the revision of safety devices for road cars: the side impact protection system improved the car resistence protecting the driver and all the passengers into the car. Finally, even though the use of dash cams on the cars and into the cockpit of a Formula 1 car might not seem to be a safety system at first, its application to road cars had important implications providing an assistance to the driver in the parking manouvre, as well as driving in very narrow spaces, reducing the accidents and making the car safer. For what concerns e-mobility and electric cars, Formula-E racing competition had many positive effects in developing the battery electric technology and understand how car prototypes adapt to streets forces, as all the races of the season are settled in city tracks, around city centres streets to be more specific. The analysis of such cars could bring many important improvements to electric cars, as this competition can replicate the behaviour of passenger cars in city centre streets. As a matter of fact, some of the teams participating in such competition are Mercedes, Porsche, Nissan and DS (division of Citroën) which are some of the main car brands pioneering in the production of electric vehicles. In the first editions of Formula-E championships (2014-2015 took place the first edition), cars were at the initial stage of their cycle, as teams and car producers have just started to invest in electric batteries, and it took many years to see particular improvements. During the first races in 2014-2015, drivers could not finish the race with the car they started with, they have to swap to their second car in the middle of the race, as batteries were not as developed as today's batteries to cover an average distance between 80 and 100 kilometers at an average speed of 100 km/h. Anyway, the format of the races has started to gain more and more audience through

[104]"Climate emergency accelerates F1's efforts to clean up its image", The Guardian, 2021

the years, and electric cars started to gain popularity as a cleaner mean of transport. Teams' parent companies provide further investments to develop the battery technology in cooperation with ABB and the FIA which are the main organizing entities of the Formula-E championship. In fact, the developments of such prototypes made possible the design of the second generation Formula-E car: new higher-performance battery, higher stability, lighter and more efficient in terms of power-to-weight ratio. One of the most important improvements in the battery range, as drivers are able to complete the race with the car they started, the average speed has increased and such new generation can reach peaks of 280 km/h[105], which are very impressive figures, affirming an important evolution of this competition and of the electric cars. The point of strength characterizing Formula-E is represented by the partnerships deals between the teams and the electricity suppliers, where Enel-X is one of them. Such partnerships made possible to reach important changes even in the mobility for passenger cars, as improvements in the battery technology have been guided by the continuous investments in R&D departments bringing the modern batteries that are implemented in today's electric vehicles, and, at the same time improving the charging infrastructure. The evolution of electric batteries has not stopped yet, as in Monaco, the third generation of Formula-E cars has been presented for the next season taking place in 2023[106]. The batteries that will fit in these car should provide even higher performances compared to last generation, promising a turning point in motorsports, as well as in mobility, since electric vehicles will adopt this new battery technology. Thus, electric cars might experience an even higher share in the next year, thanks to the popolarity that Formula-E has gained, especially in recent years, affecting positively the relevance that electric powertrain has now reached making the transition from conventional vehicles to electric vehicles a real possibility. Finally, even though hydrogen fuel cells vehicles are not as popular as electric vehicles, a racing competition exclusive for such vehicles will be launched in 2023: the Hyraze

[105]"Formula E vs Formula 1: what are the differences?", Enel-X, 2022
[106]"Formula-E and FIA reveal all-electric GEN3 race car in Monaco", FIA, 2022

League[107]. This is a pioneering project, where European motorsport organizations such as Dekra and ADAC (Allgemeiner Deutscher Automobil-Club) aim to promote such racing competition through the concepts of sustainability and safety. As it is known, hydrogen powered cars are subject to many dangers, where fires and explosions represent the main causes, so the first focus is to find the best safety devices that protect the fuel tanks, in order to avoid serious consequences, which is the basic requirement in the FIA regulations. The second focus is on sustainability, as Hyraze is been promoted through a zero-emissions campaign, representing the main point of strength of such competition. It can be pointed out that motorsport has, certainly, an important impact in the automotive and mobility sectors, both in terms of testing technologies and in the powertrain promotion. Car producers use these competitions as workbench for their engines and for their car chassis, which could fit in the passenger cars, moreover, resulting as the winning team could help the promotion and the sales for the parent company; Mercedes represents an example, as the dominance in the hybrid era in the Formula 1 competition ensured the company more sales and more money to invest in other projects, such as the development of the EQ department, which is devoted to the research and improvement of the batteries that will be installed inside the electric vehicles. This subsection concludes the analysis and the review of contents concerning environmental humanities; the next final section will sum up this research, while providing further improvements to the model and a deeper analysis considering other sectors, that could be related to the automotive industry, in order to continue the research in this field, which could bring some interesting findings regarding the future of mobility.

[107]"The Racing Series for the motorsport of the future", Dekra, 2021

3.4 A push to investigate more on this subject

In this final subsection we will go through a brief recap of the research, remarking the objectives and the approach adopted. Starting from an analysis of the different mitigation strategies aimed at reducing the impact generated by greenhouse gas emissions, the European bodies in cooperation with big automotive corporations, want to guide the automotive market towards a cleaner and less impacting direction, as of now, the automotive sector is the fourth biggest producer of pollutants. The EU Commission and the EU Parliament have stipulated Regulations and agreements' plans with long-term objectives aiming at reducing emissions and carbon neutrality by 2050. To reach such goals, these bodies are taking important decisions that are leading the automotive market towards a transition from conventional to electric vehicles, considered to be the right choice for the achievement of the above mentioned goals. In particular, it has taken place a debate in last years, regarding electric and conventional cars, with the purpose to evaluate all possible pros and cons of electric mobility, considering perfromance and production aspects up to safety and environmental concerns. In the last year, we can observe how the electric cars have started to be very popular in the global automotive market, with the projection that such segment is expected to grow even more in the near future. Anyway, such growth cannot be explained per se, as the automotive sector is stricltly connected with many other sectors, we should consider energy and heavy industry some of the main drivers affecting the behaviour of the automotive sector. Clearly, the social and economic development of a country has direct effect on the production of vehicles in general, as the more a country is characterized by good indicators defining average richness and good living standards, the more that country is expected to grow as good investments have been made through the years. Moreover, in this sense we should also ask ourseleves, which factors could improve the promotion and expansion of electric cars from a consumer perspective, so that a car that should represent a sustainable and a cleaner alternative to conventional cars will be able to satisfy consumers' needs and desires. To do so, multiple approaches could have been implemented, but for our analysis system dynamics represented the most suitable approach for our study, as we wanted to analyse causal loops and interconnections among variables, identifying specific sectors, so that we could investigate different scenarios assuming different initial values. The evaluation of several scenarios could guide us towards the best possible case, assuming behaviours that try to resemble near-reality situations. Anyway, this research should represent an initial point, not the the ending regarding this research field, as there are many improvements that could make the model even nearer to reality. For example, at a lower and more detailed ground of the scale production of electric cars, we could analyse the factors and the resources that play a key role, so deepening the study about the production process. Another important aspect that should be considered for future advancements is related to the energy sector, in particular analysing the factors that can influence the electricity costs, which could represent barriers that could limit the expansion of electric cars. Another interesting analysis could be related to regional differences in Italy, as in this research around half of the survey's answers were coming from Veneto region. A regional analysis could be interesting to observe regional differences in consumers' perceptions, as the factors selected may have different importance across Italy, which could be explained by morphological aspects and different consumers' needs, so leading to an implementation of differentiated policies with the objective to increase the share of electric mobility. These further proposed analyses are only few examples of how much spread is the automotive sector and how many research opportunities it could offer, so we should continue investing in this research field, as improvements can be achieved with an optimistic possibility to discover important results.

A Variables List

Table 1: List of variables per branch

BRANCH	SYMBOL	DEFINITION	VARIABLE TYPE
Vehicle Development Branch	$SCALE_{i,t}$	vehicle scale for different powertrains (i=CV,EV)	Endogenous
	$D_{i,t}$	scrap amounts for different powertrain (i=CV,EV)	Endogenous
	$B_{i,t}$	purchase amounts for different powertrain (i=CV,EV)	Endogenous
	ALV	average lifetime of vehicles	Exogenous
	TD_t	total demand at time t	Endogenous
	$EV_{\%share}$	percentage share of electric vehicles	Endogenous
Vehicle Demand Branch	POP_t	population at time t	Endogenous
	PV_t	population increment at time t	Endogenous
	$r_{POP,t}$	net population growth rate	Exogenous
	$GDP_{TOT,t}$	total gross domestic product	Endogenous
	$X_{GDP,t}$	gross domestic product increment	Endogenous
	$r_{GDP,t}$	growth rate of gross domestic product	Exogenous
	VP_t	vehicle number per 1000 people	Endogenous
	VPT	target vehicle number per 1000 people	Exogenous
	α	demand factor	Exogenous
	$VD_{TOT,t}$	total vehicle demand	Endogenous
	NVD_t	new vehicle demand	Endogenous
Evolution Branch	β_m	weight factor parameter, m=1,...,5	Exogenous
	P_{BUY}	purchase price	Exogenous
	P_{SELL}	selling price	Exogenous
	P_{SUB}	subsidy for electric vehicle purchase	Exogenous
	$n_{j,k}$	number of respondents putting factor k in the rank j	Exogenous
	$rank_j$	$rank_j$=p, where p is the value of the rank. (If rank(1)=5, rank(2)=4 and so on)	Exogenous
	$EV_{R,t}$	range factor	Exogenous
	$EV_{CT,t}$	charging time factor	Exogenous
	$P_{EV,t}$	purchase price factor	Exogenous
	$P_{Fuel,t}$	fuel factor	Exogenous
	$P_{PD,t}$	price difference factor	Exogenous

References

[1] Global Fuel Efficiency Initiative, 2020. Vehicle Efficiency and Electrification: a Global Status Report;

[2] International Environmental Agency, 2019. World Energy Outlook 2019;

[3] M. Muratori et al., 2020. Implications of climate change mitigation strategies on international bioenergy trade;

[4] V. Daioglou et al., 2020. The climate change mitigation potential of bioenergy with carbon capture and storage;

[5] E. Noppers et al, 2015. The adoption of sustainable innovations: The role of instrumental, environmental, and symbolic attributes for earlier and later adopters;

[6] S. Haustein, A. F. Jensen, 2018. Factors of electric vehicle adoption: A comparison of conventional and electric car users based on an extended theory of planned behavior;

[7] F. Liao, 2017. Consumer preferences for electric vehicles: a literature review;

[8] Z. P. Cano, 2018. Batteries and fuel cells for emerging electric vehicle markets;

[9] K. Tokimatsu et al., 2018. Energy modeling approach to the global energy-mineral nexus: Exploring metal requirements and the well-below 2°C target with 100 percent renewable energy;

[10] Intergovernmental Panel on Climate Change, 2021. WG III contribution to the Sixth Assessment Report, Chapters 6-10-16;

[11] D. Pevec, 2019. Electric Vehicle Range Anxiety: An Obstacle for the Personal Transportation (R)evolution?;

[12] D. Hall, N. Lutsey, 2017. Emerging Best Practices for Electric Vehicle Charging;

[13] M. A. Melliger et al., 2018. Anxiety vs reality - Sufficiency of battery electric vehicle range in Switzerland and Finland;

[14] E. Narassimhan, C. Johnson, 2018. The role of demand-side incentives and charging infrastructure on plug-in electric vehicle adoption: analysis of US States;

[15] United Nations Framework Convention on Climate Change, 1997. Kyoto Protocol - Status of Ratification;

[16] United Nations Framework Convention on Climate Change, 2015. Paris Agreement - Status of Ratification;

[17] Italian Parliament, 2016. D. lgs. 204/2016;

[18] Ministero della Transizione Ecologica, 2020. Piano Nazionale Integrato per l'Energia e il Clima (PNIEC);

[19] European Commission, 2019. Regulation (EU) No. 2019/631;

[20] International Council on Clean Transportation, 2021. European Vehicle Market Statistics, Pocketbook 2021-22;

[21] European Automobile Manufacturers' Association, 2021. E-mobility: only 1 in 9 charging points in EU is fast;

[22] BloombergNEF, 2022. Electric Vehicle Outlook 2022;

[23] Forbes, 2022. Ambitious Electric Car Sales Targets May Fall Short And Reprieve ICE Power;

[24] Climate Analytics, 2018. Integrated Assessment Models: what are they and how do they arrive at their conclusions?;

[25] J. Rogelj et al., 2018 . Scenarios towards limiting global mean temperature increase below 1.5°C;

[26] R. Lee, S. Yazbeck, S. Brown, 2020. Validation and application of agent-based electric vehicle charging model;

[27] EA Technology, 2017. My Electric Avenue;

[28] S. Aeschliman, Y. Zhou, C. Macal, Z. Zhou 2020. Agent-based modeling of electric vehicles with time-of-use electricity rates;

[29] Y. Xiang, 2017. Scale Evolution of Electric Vehicles: A System Dynamics Approach;

[30] J. D. Sterman, 2000. Business Dynamics: Systems Thinking and Modelling for a Complex World;

[31] J. D. Sterman, 2002. System Dynamics Modelling: tools for learning in a complex world;

[32] Y. Barlas, 2009. System Dynamics: Systemic Feedback Modelling for Policy Analysis;

[33] Eurostat, 2020. What is the source of the electricity we consume?;

[34] US Department of Energy, 2020. Maintenance and Safety of Hybrid and Plug-In Electric Vehicles;

[35] Our World in Data, 2020. The World's Energy Problem;

[36] European Environmental Agency, 2019. Electric vehicles and the energy sector - impacts on Europes's future emissions;

[37] Nature, 2021. How solar energy could power Italy without using more land;

[38] Nature, 2021. Electric cars and batteries: how will the world produce enough?;

[39] Wired, 2021. Sodium Batteries May Power Your New Electric Car;

[40] International Environmental Agency, 2021. Net Zero by 2050;

[41] Formula 1, 2019. Formula 1 announces plan to be Net Zero Carbon by 2030;

[42] The Guardian, 2021. Climate emergency accelerates F1's efforts to clean up its image;

[43] Dekra, 2021. The Racing Series for the motorsport of the future;

[44] K. Chapman, 2022. Racing Green: How Motorsport Science Can Save the World;

[45] Federation Internationale de l'Automobile, 2021. Committed to a better future;

[46] Stockholm Resilience Centre, 2018. Transformation is feasible: How to achieve the Sustainable Development Goals within Planetary Boundaries.