POLITECNICO DI TORINO

Master's Degree in Nuclear Engineering

Social Acceptability of Electric Cars: an Energy System Optimization-based Analysis in the European Case

Advisors:

Prof. Laura Savoldi

Prof. Valeria Di Cosmo

Dr. Dario Cottafava

Dr. Daniele Lerede

Candidate:

Teresa Brach del Prever

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Abstract

Social acceptance of innovative technologies is often overlooked in the framework of energy system optimization modeling (ESOM), especially concerning the decarbonization of the transport sector. Neglecting social acceptance in Energy System Optimization Systems can translate into ineffective support to policy-making and sub-optimal strategies. The goal of this research is to explore the influence of social acceptability on the development of the electric vehicle market within the European Union. In particular this study aims to answer the following questions: 1) Is it possible to include Social Acceptability of new transport technologies in ESOMs? 2) Is it possible to use ESOMs as a tool to evaluate the importance and relative influence of Social Acceptability factors? 3) Can Social Acceptability have a pivotal role in the EU decarbonization path? An extensive process of literature review has been brought on to evaluate the existing knowledge about public perception of new transport technologies. As primary result, the key criteria influencing social acceptance have been identified. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was used to identify the main criteria and to classify them into three categories: a. social-psychological factors (i.e., level of education, gender, awareness of electric vehicles, income level, environmental concern) b. technological features (i.e., driving range, charging duration, charging rate, perceived risks), c. economic and market aspects (i.e., economic benefits, purchase cost, battery cost, incentive-based policies). Among this list of criteria, three have been elected as suitable for inclusion in TEMOA-Europe: risk perception and environmental concern have been traduced in hurdle rate and purchase cost in investment costs. Since the literature review outlined how the majority of existing knowledge on new transport technologies' social acceptability focuses on electricity as fuel and on cars as means of transport, the focus was put only on electric cars for the remaining analysis. Five distinct scenarios were implemented: the first one considers the respect of the full decarbonization target by 2050 envisaged in the European Green Deal; the second one, instead, considers no specific environmental constraints, the third one no emission constraints and electric vehicle purchase (CFVs) cost equal to conventional fuel vehicles costs from now on, the fourth one the discount rate for electric cars decreased to 2% and the one of CFVs increased to 30% to capture the evolving nature of people's risk perceptions over time (emphasizing in this way the crucial linkage between techno-market criteria and socio-psychological factors), and the fifth one the modifications of the previous two scenarios together. The results clearly showed that risk perception and environmental concern have a significantly higher influence on EVs adoption than purchase costs. Moreover, considering the present push towards banning measures as extreme tools to reduce European Union net greenhouse gas emissions, it has been possible to understand that through the implementation of only Social Acceptability measures, totally equivalent results to the ones obtainable from banning measures can be reached. This further highlighted the wide influence that Social Acceptability can have in the path towards the entire transport sector decarboonization.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Climate Change

Climate Change is one of the most pressing and complex challenges facing our humanity as a whole today. It regards long-term shifts in temperature and weather patterns, in particular due to human activities such as the burning of fossil fuels like coal, oil, and gas. The main sectors causing greenhouse gas emissions are energy, industry, transport, buildings, agriculture, and land use [14]. Climate Change results now in intense droughts, water scarcity, catastrophic fires, rising sea levels, flooding melting polar ice, and severe storms. Figure 1.1 shows the change in global surface temperature compared to the long-term average from 1951 to 1980. The year 2020 statistically tied with 2016 for the hottest year on record since recordkeeping began in 1880 [1].

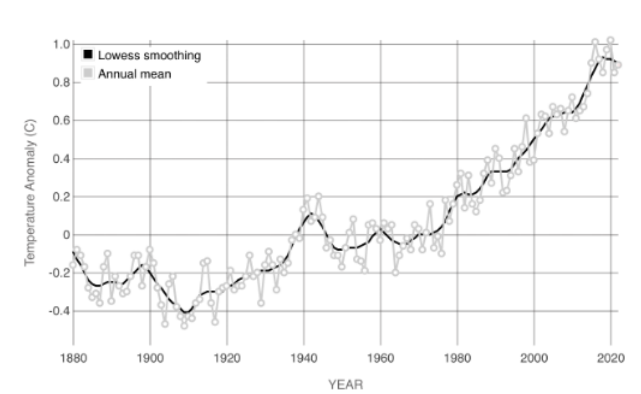

Figure 1.1: Change in global surface temperature during years. [1]

As the Intergovernmental Panel on Climate Change states, "the magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions, and projected adverse impacts and related losses and damages escalate with every increment of global warming" [15].

Carbon dioxide (CO2) is a greenhouse gas coming from the burning of fossil fuels (coal, oil, natural gas), from wildfires, and natural processes like volcanic eruptions. It is an important heat-trapping gas which is linked therefore to the global warming and climate change. Figure 1.2 shows atmospheric CO2 levels measured by NOAA at Mauna Loa Observatory, Hawaii, since 1958 [1]: it is straightforward to see how it constantly increased in time.

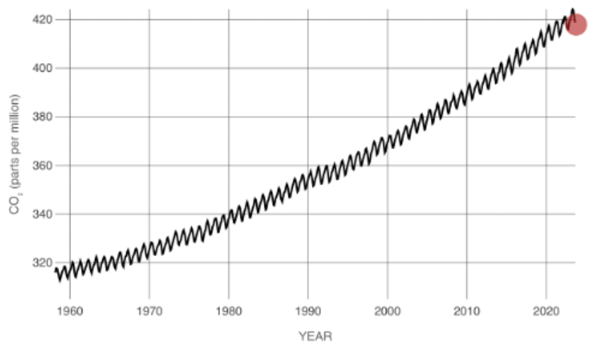

Figure 1.2: The historical changes in global carbon dioxide over time.[1]

In recent years, climate change has been object of significant focus from governments all over the world. In particular, the general aim is to reduce the exploitation of fossil fuels and to increase the share of consumption of renewable energy sectors.

1.2 Energy System Optimization Modeling

Changes and transformations are obligatory to maintain the global balance between demand and supply. In order to progress towards sustainability, towards a reduction in carbon footprint and a reduction in the production of carbon dioxide, Energy System Optimization Models (ESOMs) are gaining relevance worldwide. Optimization models are based on a set of boundary conditions represented by *inequality constraints*, that bring the problem to have a higher number of available solutions: the aim is to get to the solution that optimizes a certain aspect (for a single-objective approach) that could be a financial one or an environmental one, or even others like a social aspect.
Energy Economy Optimization (EEO) models are becoming more and more a reference for policymakers in order to make energy policies supported by solid scientific studies. They have emerged as key tools for the analysis of energy and climate policies at the regional, national, and international scale. Over the past two decades, the increasing availability of energy and environmental data has led to the development of increasingly complex EEO models.
Energy models are data-intensive multi-objective tools that need energy resource

supply, energy consumption sector-by-sector, energy transformation technologies, greenhouse gas emission, and energy pricing to model the energy sector in a sufficiently extensive and detailed way [16]. There is an enormous number of energy models well-established and focused on different sectors within the energy system and which present different attributes. The taxonomy of energy system models is particularly wide and diversified. Among the models available worldwide, we can cite bottom-up models, top-down models, simulation, optimization, equilibrium, and so on [17].

Top-down models, also known as macroeconomic models or aggregate models, provide a wide perspective. They prefer the general vision to the detailed one. Data are aggregated and parameters are generalized in order to model the behavior of the system as a whole. They focus on general trends, overall energy use, and high-level representation of the energy system preferring simplicity to the details. They start with a high-level view and then break down the system into various components. They examine cities at a macro scale and they are not concerned with individual end-uses. These models are useful for understanding the overall dynamics and general trends of a system but may overlook finer details and heterogeneity within the system. Top-down models are typically adopted by economists and public administrations. These models focus on connecting the energy system to other macro-economic sectors.

Bottom-up models, on the other hand, take a more detailed and granular approach to modeling. These models start from the single element and then aggregate all the similar ones to obtain a more general result in the macroeconomic study. They require a huge amount of data with a higher quality of precision. They will take more time to be evaluated but will give more precise and descriptive results. These detailed models from a techno-economic point of view allow the user to compare the impact of different technologies on the energy system and to evaluate the best future alternatives to lower Greenhouse Gas (GHG) emissions for the achievement of the energy targets. However, the bottom-up approach does not take into account the connections between the energy system and the macroeconomic sectors, thus neglecting the impacts on these sectors. In bottom-up models, a first classification can be made depending on the time horizon chosen. This feature subdivides these models into:

- **Static or short-term models:** the time horizon is short, usually a year.
- **Long-term models:** the time horizon is longer and this implies including additional variables such as life-cycle, residual capacity, plant decommissioning, and commissioning within the transition. Within the long-term models, another distinction can be made on the basis of the approach to the optimization problem:
  - **Perfect-foresight approach:** these types of models are based on the assumption that decision-makers have complete knowledge on the whole

transition, full information on costs, consumption variation, decay of performance of certain technologies, future decommissioning of power plants, future improvement of the efficiencies of certain technologies, and many more parameters. This approach is realized through the formulation of a unique optimization problem by analyzing all the time periods simultaneously.

  – **Myopic approach:** in this types of model, the time horizon is divided into a sequence of optimization problems where the output of the prior serves as input for the following. For this reason, these models can also be called *recursive*. The decision makers have not a complete knowledge of the whole time horizon. This approach is more realistic since in reality the decisions are taken without a complete information about the future changes.

The choice between these modeling approaches depends on the specific research question, the available data, and the level of detail required to address the problem at hand.

The basic idea of the Energy System Optimization models (ESOMs) is that a mathematical problem solver gives as output the optimal configuration of the reference energy system in terms of the evolution of new technologies, total cost of the system, etc. The inputs to the solver are:

- techno-economic characterization of the Reference Energy System (RES),
- energy demand,
- cost parameters,
- constraints

These data can come from various sources, including statistical databases, energy market reports, expert knowledge, and scenario analyses. The present and future techno-economic characterization of the RES is the main issue of the modeler and is based on 3 key elements:

- *technologies:* physical devices that transform commodities into other commodities
- *commodities:* energy carriers, energy services, materials, emission and demand commodities either consumed or produced by technologies.
- *commodity flows:* the way a commodity is used by a technology.

The higher the disaggregation level is, the higher is the level of detail and precision of the results, but also the higher the computational stress is. After techno-economic parameters have been assigned, the Reference Energy System (RES) is changed to satisfy the requirement for a particular scenario.

Time horizon is another main point of the ESOMs environment: a proper horizon and a proper time grid are needed. The time is more refined in the beginning and less refined in the future and milestone years are defined in order to represent a longer period. The outcomes are then computed for the single milestone year and they are considered constant in the whole period. Time slices are also adopted to represent seasonal and time-of-the-day behavior.
The main kinds of decision variables obtained as results from the optimization algorithm are: new capacity additions, total installed capacity and activity levels of each technology.

1.3 Transport sector decarbonization and Alternative Fuels

In 2021 the European Commission released a number of policy proposals in its “Fit for 55” package. The aim was to achieve the European Union’s (EU) goal of decreasing greenhouse gas (GHG) emissions by 55% in 2030 compared to 1990 levels. The transportation sector, including road, air and waterborne transport, is the fastest growing sector of energy consumption in the world, accounting for slightly more than 20% of primary energy consumption[18]. The European Union aims to reduce the GHG emissions from transport by 60% (compared to 1990) before 2050, however, decarbonizing this sector presents several problems [2]. GHG emissions from transport can be reduced by decreasing the total energy demand, the emission intensity, or both. If we consider reducing the emission intensity, the main answer seems to be the electrification of passenger transport and the decarbonization of the grid electricity supply, but what is widely accepted is the fact that aviation, heavy-duty road vehicles, and shipping are very unlikely to be decarbonized solely through electrification [19]. The introduction of low-fossil-carbon fuels is a key feature to reduce fossil carbon intensity. According to the EU Directives 2018/2001 (Renewable Energy Directive – RED II), alternative fuels, include several energy vectors:

- "traditional" biofuel produced by biomass
- "advanced biofuels" produced from biological sources (acellulosic and ligno-cellulosic materials, such as agricultural and forestry residues, wastes, energy crops, or aquatic biomass). This results in a higher yield in terms of net GJ energy produced per hectare land used. Preferably, energy crops are grown on marginal land that does not compete directly with (or displace) land used for food crops.
- "Recycled carbon fuels”, liquid or gaseous fuels produced from liquid or solid waste or industrial exhaust gas of non-renewable origin ;
- “Renewable liquid and gaseous transport fuels of non-biological origin” (RFNBO), which are called also electrofuels or e-fuels or synthetic fuels or power-to-gas/liquid/fuels (for example liquid or gaseous fuels derived from renewable sources).

Other types of "green" possible vehicles that must be considered in the framework of transport sector decarbonization are electric vehicles, in which the energy vector is electricity, hybrid electric vehicles, Plug-in electric vehicles, and Fuel Cell Electric Vehicles (FCEVs), in which the energy vector is hydrogen.

1.3.1 Electrofuels

Electrofuels are produced from water and carbon dioxide (CO_2) with the use of electricity as the primary source of energy. The fundamental steps in electrofuel production are two (Figure 1.3):

- *electroysis*: water is broken down into hydrogen and oxygen using electrical energy
- *chemical fuel synthesis (Fischer Tropsch synthesis)*: hydrogen is reacted with the carbon from carbon dioxide to produce more complex hydrocarbons.

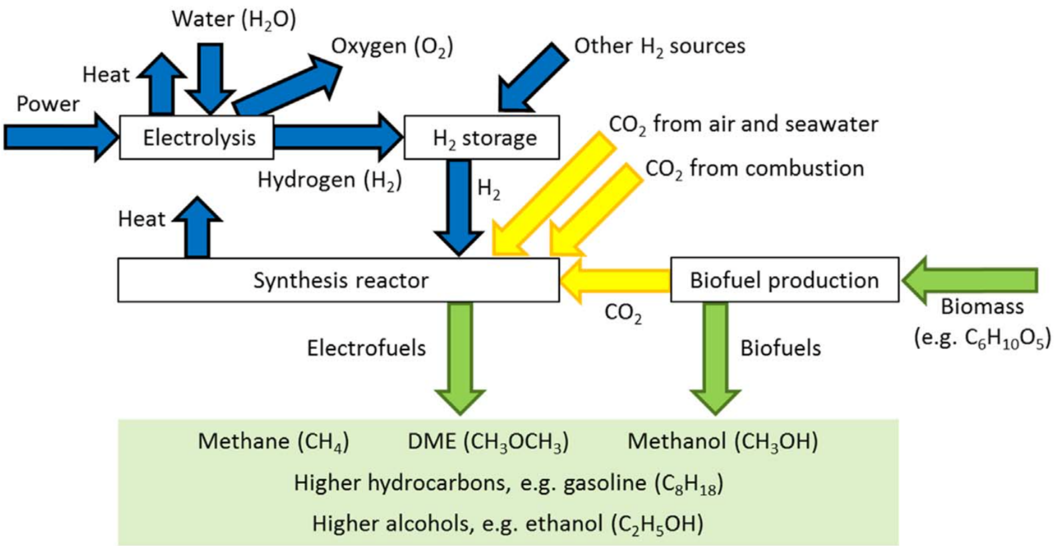

Figure 1.3: Process steps in the production of electrofuels [2]

Power-to-liquid technologies allow the synthesis of liquid electrofuels such as methanol, di-methyl ether and drop-in synthetic diesel, petrol and jet fuels. Many of the technological blocks necessary for liquid electrofuel production are already widely used in other industrial applications, but some of them have lower technology-readiness levels, and the entire process, from electricity to e-fuel, has never been demonstrated at commercial scale (however pilot scale facilities exist already). Almost any hydrocarbon can be produced with this process and they are potentially of interest for all transport modes (see Figure 1.4), aviation and maritime transport sectors included. This is why synthetic fuels are considered crucial means to decarbonize the transport sector. The issue related to the use of these fuels is the costs: there will be the need of large investments in order to produce renewable energy to make electrolysis reactions function and of new industrial production plants (or to convert the existing ones) [19].

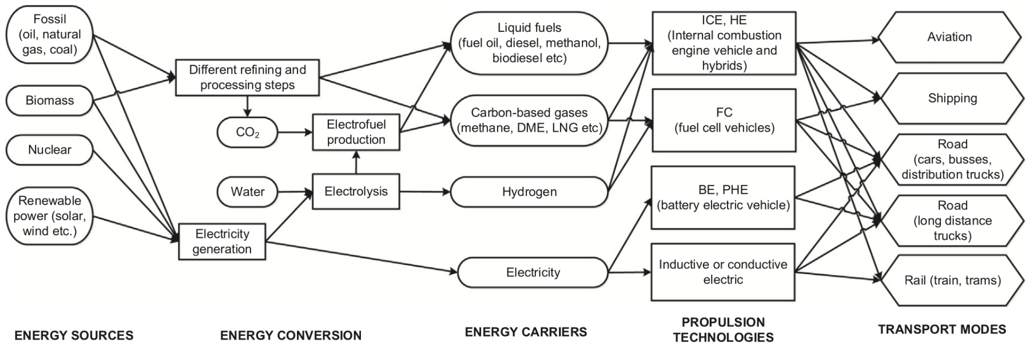

Figure 1.4: Simplified schematic of primary energy sources, energy conversion technologies, and energy carriers for different transport modes. DME = dimethyl ether, LNG = liquefied natural gas, ICE = internal combustion engines, HE = hybrid electric propulsion, FC = fuel cells, BE = battery electric propulsion, PHE = plug-in hybrid electric propulsion [2].

1.3.2 Advanced Biofuels

Biofuels have long been considered as a potential solution to decarbonization since they can be used roughly in every type of transportation mode. However, the use of land for bioenergy cropping remains controversial on sustainability grounds, and the volumes of advanced biofuel supply that are sustainably achievable are likely to be really lower than the liquid fuel demand in the transport sector [19]. The reduction of GHG emissions can be calculated by a Life Cycle Assessment (LCA), for any specific pathway, considering the cultivation, harvest, transport and conversion (Figure 1.5. They are able to close the carbon cycle. Advanced bioenergy offers a great reduction of GHG emissions compared to "traditional" bioenergy (and more when compared to fossil fuel or energy) [3].

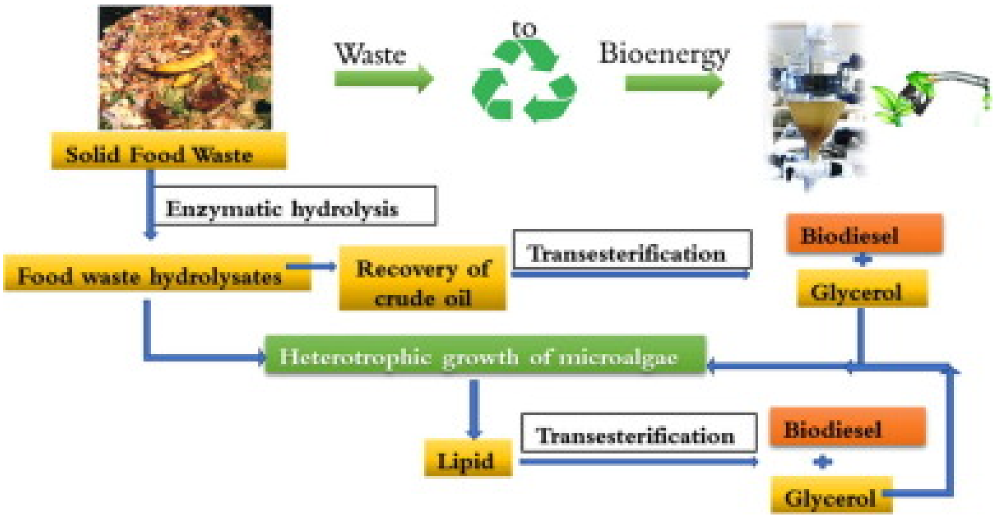

Figure 1.5: Life Cycle Assessment of advanced biodiesel [3]

1.3.3 Electric Vehicles (EV)

Electric car market is seeing an exponential increase in the electric vehicles sales during the last years, reaching 10 million in 2022. The share of electric cars in total sales has more than triples in three years, from around 4% in 2020 to 14% in 2022 [4] (see Figure 1.6).

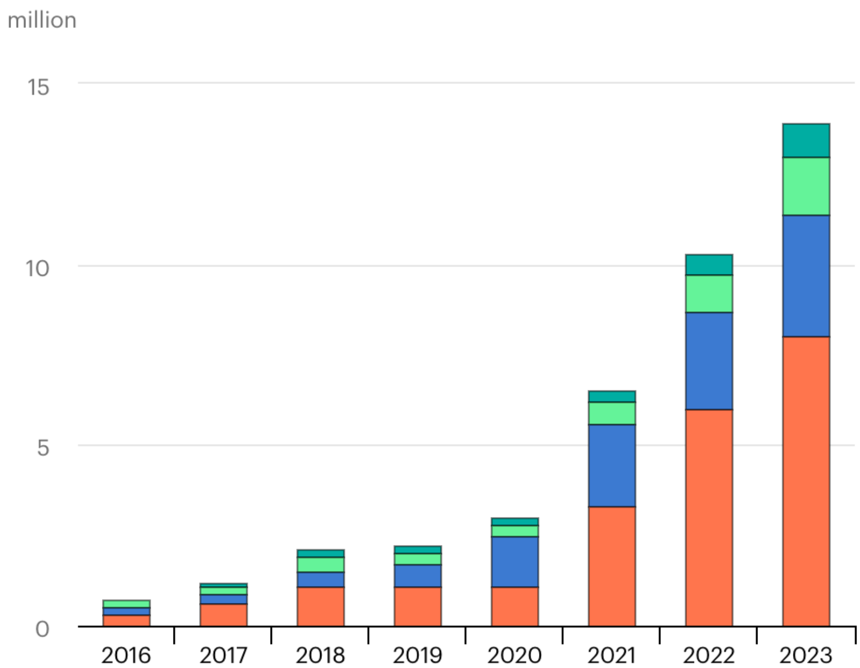

Figure 1.6: Increase in electric vehicles sales [4]

Even if electric vehicles are considered the key technology to decarbonize road transport and are considered zero-emission vehicles, their overall GHG emissions is not null. It results from the fact that emissions coming out from its operation are attributed to the electricity sector and not to the technology. Moreover, the general environmental benefits of EV (e.g. recycling of batteries, high material demand for the development of the grid infrastructure) are still widely argued.

Hybrid electric vehicles

Hybrid electric vehicles (HEVs) use an internal combustion engine and one or more electric motors that use energy stored in batteries. In this way, they combine the benefits of high fuel economy and low tailpipe emissions with the power and range of conventional vehicles.

Plug-in electric vehicles

Plug-in hybrid electric vehicles (PHEVs) have both an internal combustion engine (ICE) and an electric motor. They use batteries to power the electric motor and an additional fuel, like gasoline, to power the ICE. PHEV batteries can be recharged via charging equipment or by regenerative braking. Generally, the vehicle operates on electric power until the battery charge diminishes, at which point it automatically transitions to using the ICE. PHEVs produce lower levels of emissions, depending on the electricity source and how often the vehicle is operated in all-electric mode [20]. Figure 1.7 shows the comparison between emissions of different types of light-duty vehicles.

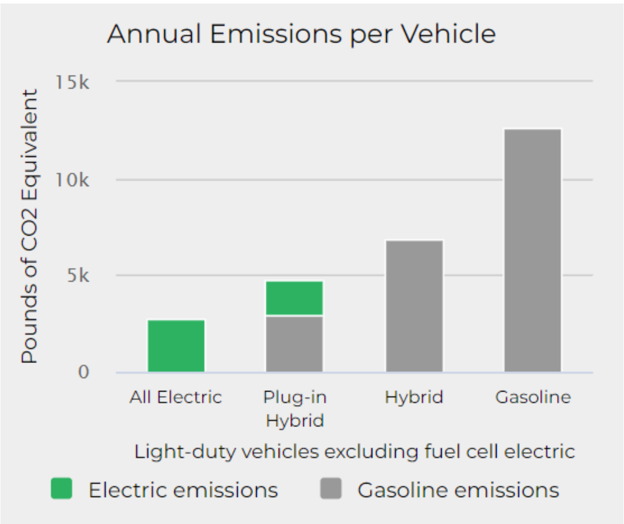

Figure 1.7: Emissions per vehicle based on assumptions with 2022 data from EIA [5]

1.3.4 Fuel Cell Electric Vehicles (FCEVs)

Fuel cell electric vehicles (FCEVs) are powered by hydrogen. The most common type of fuel cell for vehicle applications is the polymer electrolyte membrane (PEM) fuel cell, in which an electrolyte membrane is sandwiched between a positive electrode (cathode) and a negative electrode (anode). Hydrogen is introduced to the anode, and oxygen (from air) is introduced to the cathode. The hydrogen molecules break apart into protons and electrons due to an electrochemical reaction in the fuel cell catalyst. Protons then travel through the membrane to the cathode. The electrons are forced to travel through an external circuit to perform work (providing power to the electric car) and then recombine with the protons on the cathode side where the protons, electrons, and oxygen molecules combine to form water [21]. Although it represents a necessary input for synthetic fuel production, hydrogen does not represent a possible solution in the short term for the aviation sector (while it is for the maritime one).

1.4 The importance of Social Acceptance

The decarbonization of the transport sector is a priority for meeting national climate change targets and electric vehicles, alternative fuels, and fuel-cell electric vehicles offer the potential for significant reductions in greenhouse gas emissions [22]. Public perception cannot be disregarded since socio-economic factors, in addition to techno-economic, socio-technical, and political factors, may prevent nations from achieving national energy transitions and climate change targets [6]. Despite this imperative, sustainability scholars have largely overlooked the social acceptance of renewable energy technologies (RETs) and, in particular, transport sector sustainable technologies. There is a scarcity of information regarding consumer perceptions and expectations regarding this transition and this deficit of knowledge can translate in ineffective policymaking and suboptimal strategies.
Before proceeding with the topics faced in this thesis, it is crucial to make clear the difference between three substantives: acceptability, acceptance, and adoption. With the word "acceptability" we mean the behavior either in favor or against a technology. On the other hand, “acceptance” is a behavior that favors and promotes the use of a technology, rather than inhibiting or criticizing it. The “adoption” of a technology is a process made of several steps of selecting, purchasing, and committing to use it until achieving persistent use [23]. Just to make an example, there are various factors that reduce the social acceptance of such transport modes: reduced range of distance that can be driven without refueling, long refueling time, high purchase costs, scarcely developed charging stations (or in general necessary infrastructures), and limited choice of vehicles [22]. The problem, still partly unsolved, is to understand the weight of each of these factors: is it possible to make a scale of influence? And if yes, on the base of what?

Historically, there have been three waves of research on social acceptance theories [6] as assumed by Batel in [24]. The first wave (*Normative approaches*) can be traced back to the mid-1990 and focuses primarily on *Not in my backyard* (NIMBY) syndromes. The NIMBY phenomenon suggests the idea that people oppose to RETs being built in their backyard primarily because of self-interest (not considering the greater good), ignorance (failure to grasp the necessity of these constructions) and irrationality (reacting emotionally) [24]. The NIMBY syndrome sought to explain local opposition to RETs at a time when opposition to these types of facilities were spreading. The second wave is also called *Criticism approaches* because the main focus was on criticizing NIMBY theory in favor of new alternative explanations [24]. During this wave, scholars turned their attention to examining socio-psychological and contextual aspects linked to perceived benefits, costs, and risks. In 2007, Wüstenhagen et al. [25] proposed a tripartite framework to comprehend the social acceptance of RETs, comprising socio-political, community, and market dimensions. Therefore, behind the social acceptance of RETs some different actors and factors can be schematically summarized, as shown in Figure 1.8 : the sociopolitical acceptance comprehend the ability of regulators, policymakers, and other stakeholders to make effective policies, the community acceptance encompasses the trust and invest in of local stakeholders, the market acceptance stands for the support that investors want to give to RETs.

Acceptance dimension and definition	Scale	Actors	Factors
Sociopolitical acceptance The ability for regulators, policymakers, and other key stakeholders to craft effective policies or frameworks that effectively foster and enhance community, market, and public acceptance of RETs [110,167]	**Macro** Supply-side acceptance of RETs at the policy or national level [48]	• Regulators	• Technology type, scale, and context
		• Legislative authorities • Policy actors • Key stakeholders • General public [76,167]	• Legal and regulatory frameworks • Institutional capacity • Political commitment [111,167]
Community acceptance The extent to which new renewable energy projects or appliances are invested in or trusted by local stakeholders, and the scope of justice (procedural and distributional), trust and legitimacy [110,167]	***Meso*** Acceptance of new renewable energy infrastructure, facilities, and technologies at the local level [48]	• Local stakeholders	• Infrastructure and resource availability
		• Local authorities	• Historical and cultural heritage
		• Residents • End-users [76,110,167]	• Place attachment • Participatory project siting • Transparent communication and planning procedures • Local stakeholder engagement • Recognition of externalities [110–111,142,167]
Market acceptance The extent to which investors want to support the manufacturing and use of RETs, and the level of market uptake [110,167]	***Meso*** Acceptance of a renewable energy technology or application at the household and organization level [48], which operates at a *meso*-level between national politics and local communities [167]	• Incumbents	• Competitive installation and production costs
		• Small and medium-sized enterprises (SMEs) • Producers	• Cost-competitiveness of the technology for consumers • Financing mechanisms for producers and consumers
		• Consumers • Distributors Investors • Other intermediaries [76,167,168]	• Business models and tariffs • Mechanisms for information and feedback [167,168]

Figure 1.8: Actors and factors behind social acceptance of renewable RETs [6].

Wave 3 (Critical approaches) can be traced back to 2015 when Batel and Devine-Wright [26] tried to establish "a better understanding of people's responses" to RETs linking together theories of behavior, practice, and social representation and therefore merging Social Practice Theory (SPT) with Social Representations Theory (SRT). The third wave principally focused on four key areas which are shown and further described in Figure 1.9.

Scope of pillar	Perspective and framing	Key studies
Exploring the spatial dynamics of social acceptance through relational frameworks	Social acceptance is viewed as a multi- and cross-scalar phenomenon, operating within the energy production-consumption nexus	[76,153,202,300]
Examining the impacts of pursuing 'just' energy pathways	Social acceptance contends against a pandemic of energy poverty rooted in the prevailing socio-political landscape	[171,173,179,198,301,302]
Exploring the influence of temporal and socio-historical factors on the energy transition and community acceptance	Social acceptance is linked to time, place, and space, such as the legacy of industrial heritage and absence/presence of regional energy cultures	[131,222,223,225,226,303,304]
Overcoming the reductionist nature of previous research waves (i.e. normative and criticism approaches)	Social acceptance is characterized by a matrix of potential attitudes and responses, reflecting the complexity and often paradoxical nature of human emotion	[54,76,243,305]

Figure 1.9: Four pillars of critical approaches to the study of social acceptance [6].

A summary of the key characteristics, objectives, and inquiries of all three waves is shown in Figure 1.10.

	Wave 1 (~1995–2007)	Wave 2 (~2007–2014)	Wave 3 (~2015–present)
Approach	Normative approaches	Criticism approaches	Critical approaches
Main assumptions regarding local opposition to RET	Examining NIMBY syndromes and responses	Criticizing NIMBYism and proposing alternative theories and explanations	Focusing on how spatial dynamics, energy justice, power relations, and historical factors shape people's responses to the development and diffusion of RET
Main lines of enquiry	Characterizing opposers and supporters	Examining which socio-psychological and community factors affect opposition to RET, especially in terms of procedural and distributional justice	Adopting a critical approach at *ideological* (e.g. revealing and contesting RET as business and usual), *theoretical* (e.g. applying agonist approaches to community engagement), and *methodological* levels (e.g. using discourse analysis)
Anticipated societal implications	To overcome local opposition to RET	To understand public resistance and ease the transition to RET	To question if opposition to RET should be reduced/overcome
Examples of key studies	[119]	[110–112,145,167]	[54,61,64,76,180,181,243]

Figure 1.10: Key aims and characteristics of the three waves of research on the social acceptance of RETs [6].

What is important to note is that one of the key factors in the mass acceptance of new transport solutions is the willingness and acceptance of private consumers. There have been some advancements towards more critical research approaches, yet the "social acceptance matrix" for the consumer side of sustainable transport solutions remains not so much explored in literature. In general, the social acceptance of RETs still has to evolve into a coherent, multi-dimensional body of research [6].

1.5 Thesis contribution and methodology

Considering that Social Acceptability is not included in ESOMs yet, this paper aims to answer the following three research questions:

- Is it possible to include Social Acceptability of new transport technologies in ESOMs?
- Is it possible to use ESOMs as a tool to evaluate the importance and influence of Social Acceptability factors?
- Can Social Acceptability have a pivotal role in the European decarbonization path?

To answer the first question it is crucial to understand in depth the state of the art of the knowledge around Social Acceptability in the transport sector in order to define the factors influencing it. To fill this gap, the first step in Chapter 2 is a comprehensive and empirical overview of the knowledge domain concerning the social acceptance of sustainable fuels through a multi-step process encompassing content and bibliometric analysis. The remaining part of the thesis is structured as follows: in Chapter 3 the topic of how to include Social Acceptability in ESOMs is addressed with an extensive overview on the TEMOA-Europe instance, and in Chapter 4 a deep analysis of the role of Social Acceptability in the decarbonization path is performed through the run of different scenarios to simulate the EU transport sector. To define social acceptability criteria for electric vehicle adoption and to evaluate their influence on the future European electric vehicle market, a four-step methodology has been developed and adopted as illustrated in Figure 1.11.

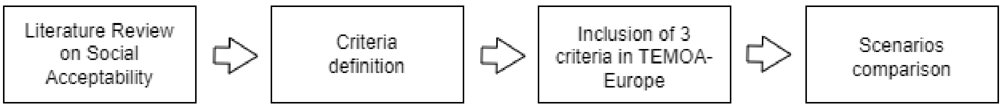

Figure 1.11: Flowchart of the general steps performed in the research.

The primary step was a thorough process of literature review on social acceptability criteria in the transport sector within the ESOM framework. From this first step, a precise list of criteria was defined (step 2), from which three specific criteria were selected according to their possibility to be traduced in economic tools includable in ESOMs, and in particular in TEMOA-Europe, an open source Energy System Optimization Model (step 3). Step 4 consisted of a deep analysis of the influence and role of Social Acceptability in the European Union's journey toward decarbonization. This was made through the definition of five different scenarios and their comparison.
Figure 1.12 illustrates the methodology of the research in a more specific way.

As can be seen, the three selected criteria are i. Purchase cost of EVs, ii. Risk perception and iii. Environmental concern. They have been chosen based on their compatibility with a translation in economic factors, although all other factors are equally pivotal for completely addressing the Social Acceptance issue; they simply require alternative methods such as surveys and experiments.
The three selected factors were included in TEMOA-Europe through 2 economic factors, *Investment Cost* (as for the purchase cost) and *Discount Rate* (as for risk perception and environmental concern). The 5 different scenarios are 1. Business as Usual (BAU) that works as a reference, 2. ECCS where only purchase cost criteria was included in the model, 3. HRS where both risk perception and environmental concern were added to the model, 4. ECCS+ which presented the outcome if all the three selected criteria influencing social acceptance were included in the model, and 5. DS, a top-down push policy scenario characterized by constraints in the greenhouse gas emissions reflecting the EU Decarbonization Strategy like Fitfor55 [27].

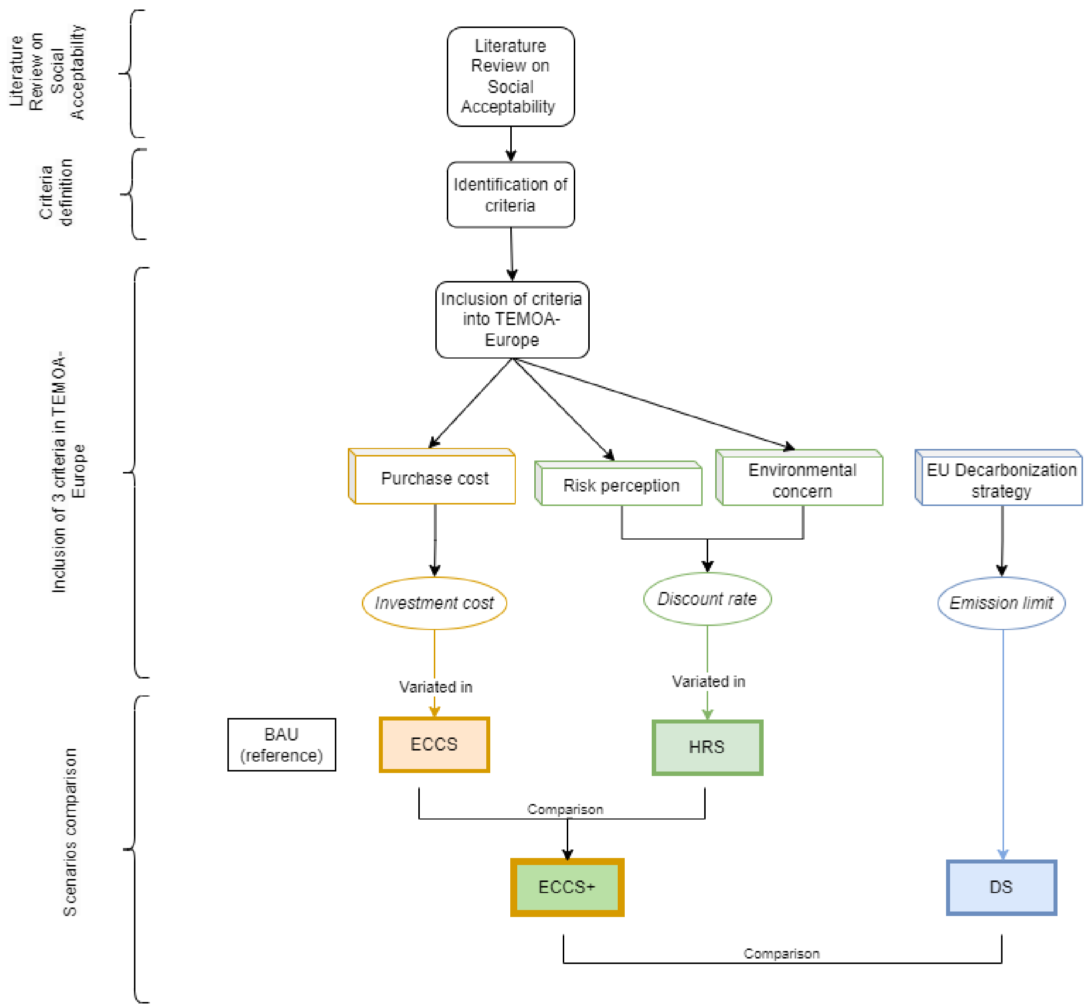

Figure 1.12: Schematic methodology of the research.

Chapter 2

Literature Review

2.1 Motivations, objectives and research questions

During a research process, no matter the field, it is crucial to relate the investigation to existing knowledge. However, the pace of knowledge generation in research is rapidly increasing, making it hard to keep up with state-of-the-art research and to be updated, as well as to assess the collective evidence in a particular research area. It is in this framework that literature review as a research method has become more relevant than ever. A literature review is a systematic way of collecting and synthesizing previous research [28]. An effective and well-conducted review creates a firm groundwork for advancing knowledge and fostering the development of theories. The aim of a literature review is to gather all the relevant research documents that fit pre-specified eligibility criteria to answer a specific research question. To ensure the quality of the review, it is essential to design an appropriate search query, choose a reliable database, and define clear inclusion and exclusion criteria for selecting relevant articles from the corpus of literature. In particular, to study the papers published on the topic of acceptance and adoption of emerging transport technologies, a systematic literature review has been conducted. This literature review aims to answer the following research questions:

- What is the current research on social acceptance of new sustainable technologies in the transport sector?
- How is social acceptance considered in the Energy System Optimization Modelling Framework?
- What are the main factors encouraging or hindering social acceptance of new sustainable technologies in the transport sector?

In this case, four main steps were carried out: (a) obtaining a body of literature and choosing documents for analysis, (b) clustering the collected documents by the keywords they share, (c) analyzing the content of each cluster of articles, (d) analyzing qualitatively every article and synthesizing the information in an Excel table. In particular, a search protocol based on the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement framework was followed. [7]. The remained part of this chapter is structured in the following manner. First, PRISMA method will be deeply explained. Secondly, the methodology part explains the query selection and the screening of the results. Third, the qualitative analysis is presented. Finally, the results of the cluster analysis are examined.

2.2 PRISMA method

The PRISMA Statement was developed by a group of 29 review authors, ethodologists, clinicians, medical editors, and consumers in 2005 [7]. It aims to help authors improve the reporting of systematic reviews and meta-analyses focusing on ways in which authors can guarantee transparent and comprehensive reporting. It consists of a four-phase flow diagram [7].

The PRISMA flow diagram (see Figure 2.1) is a scheme that outlines the flow of information throughout the process of a systematic review. It gives the possibility of illustrating the process of identification, screening, eligibility, and inclusion of studies in the review in a transparent and structured way. The flow diagram starts with the identification of the amount of documents found in one or more databases. It then shows the number of records screened, the number of records excluded, and the reasons for exclusion at each stage. Eventually, it highlights the final number of studies included in the systematic review or meta-analysis.

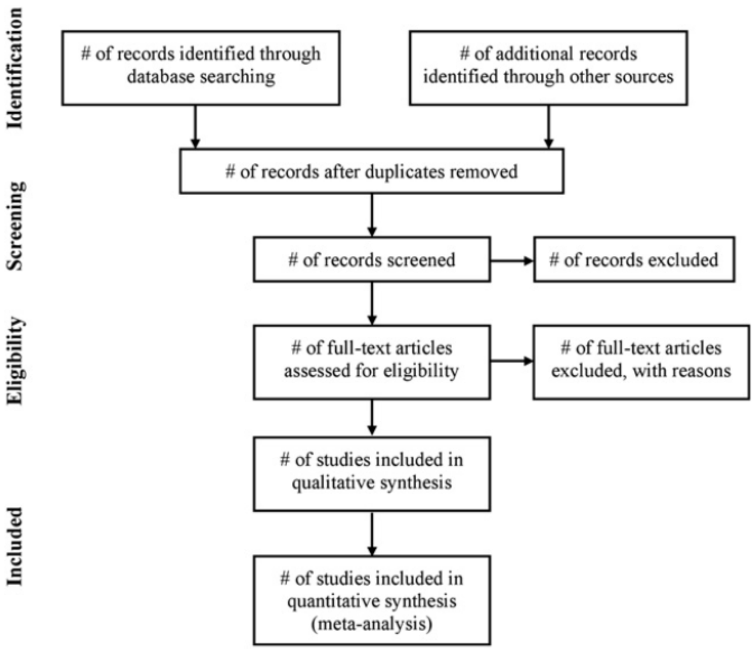

Figure 2.1: Flow of information through the different phases of a systematic review. [7]

2.3 Methodology

2.3.1 Query selection

The research question ("How is considered and measured Social Acceptability of new transport technologies in the framework of Energy System Modelling?") is made of three parts: (i) the first concept is *Social Acceptability*, (ii) the second one is *transport* and (iii) the last one *Energy System Modelling*. Given this threefold meaning of the research purpose, the query was first divided in three parts. However, as for *transport*, it is important to consider both the different transport modes (i.e. road, aviation, maritime, etc.) and the different new transport fuels (alternative fuels, electricity, hydrogen). Consequently, the final chosen query is made of four sections:

- *(social OR public) AND (acceptance OR acceptability OR adoption OR behavior OR behaviour OR approval OR confidence OR trust)*: this first part includes all the possible keywords referring to social acceptability;
- *energy AND (model* OR optimization OR simulation)*: this second part includes all the possible keywords referring to Energy System Modelling;
- *hydrogen OR biofuel* OR synfuel * OR e fuel* OR ioethanol OR biomethane OR biodiesel OR electric OR (alternative AND fuel))* : this third part

includes all the possible transportation fuels;

- *transport OR road OR aviation OR maritime OR car OR truck OR vehicle*: this forth part includes all the possible transportation modes.

The aforementioned elements were connected using the boolean operator "AND" to locate documents that specifically address these concepts simultaneously, aligning with the research objective. The query formulation up to this point was the following:

(social OR public) AND (acceptance OR acceptability OR adoption OR behavior OR behaviour OR approval OR confidence OR trust) AND (energy AND (model OR optimization OR simulation)) AND (hydrogen OR biofuel* OR synfuel* OR e-fuel* OR bioethanol OR biomethane OR biodiesel OR electric OR (alternative AND fuel)) AND (transport OR road OR aviation OR maritime OR car OR truck OR vehicle)*

Additionally, when conducting a database search, a crucial consideration is determining the specific sections within the document where the predetermined keywords should be sought. This particular choice finds its motivation in the fact that looking for a keyword only in the title is a much more stringent criterion than looking for it in the entire document. In this regard, Scopus is identified as the primary database for choosing pertinent articles due to its wider coverage compared to other databases. An initial search was carried out searching all the predefined keywords in the whole document, but the results were not accurate and presented many false positives. A new query was then implemented searching the keywords in the title, document keywords and abstract (TITLE-KEY-ABS), but in this case the problem was the opposite: many relevant documents were not selected, so a lot of knowledge was lost. The solution was found by searching the keywords of the first part of the query (the *social acceptability* part) only in the title, while all the other keywords were searched in the whole document. In this way, many false positives would have been included in the search (leading to a huge first exclusion process by title), but in the meanwhile no relevant documents would have been lost. Therefore, the query resulted to be:

TITLE((social OR public) AND (acceptance OR acceptability OR adoption OR behavior OR behaviour OR approval OR confidence OR trust)) AND (energy AND (model OR optimization OR simulation)) AND (hydrogen OR biofuel* OR synfuel* OR e-fuel* OR bioethanol OR biomethane OR biodiesel OR electric OR (alternative AND fuel)) AND (transport OR road OR aviation OR maritime OR car OR truck OR vehicle)*

At this point, it has been decided to limit the outcomes to articles and review in order to streamline the search and improve the relevance of the information retrieved. Consequently, the query has been refined to focus specifically on these types of content and became as follows:

TITLE((social OR public) AND (acceptance OR acceptability OR adoption OR behavior OR behaviour OR approval OR confidence OR trust)) AND (energy AND (model OR optimization OR simulation)) AND (hydrogen OR biofuel* OR synfuel* OR e-fuel* OR bioethanol OR biomethane OR biodiesel OR electric OR (alternative AND fuel)) AND (transport OR road OR aviation OR maritime OR car OR truck OR vehicle) AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"re"))*

2.3.2 Results screening

The final query returned a total of 369 results. First, it has been decided to exclude papers published by the Multidisciplinary Digital Publishing Institute (MDPI). This decision follows recent criticism of the accuracy of MDPI's peer review process. The core of the criticism is that they may not undergo the same level of scrutiny and attention to quality control as more traditional journals. Certain MDPI journals have been accused of low standards for accepting new publications. Therefore, there is widespread concern about the reliability of some documents published under MDPI. Since this debate is still ongoing, to make this review as objective and reliable as possible, it was decided to exclude *a priori* all documents published in MDPI journals and the number of articles becomes 321. The second step was a screening of the remaining 321 results by title. This process resulted in 249 items being excluded out of 321 and only 72 results remained.
The remained subset of articles (72 documents) underwent a thematic cluster analysis through Bibliometrics, an open-source tool for quantitative research in scientometrics and bibliometrics that includes all the main bibliometric methods of analysis. Afterward, the remained documents were screened one last time by reading the full text and this step resulted in the exclusion of an additional 30 articles due to irrilevance.

The entire process of Literature Review is shown in Figure 2.2 in the form of PRISMA flow diagram.

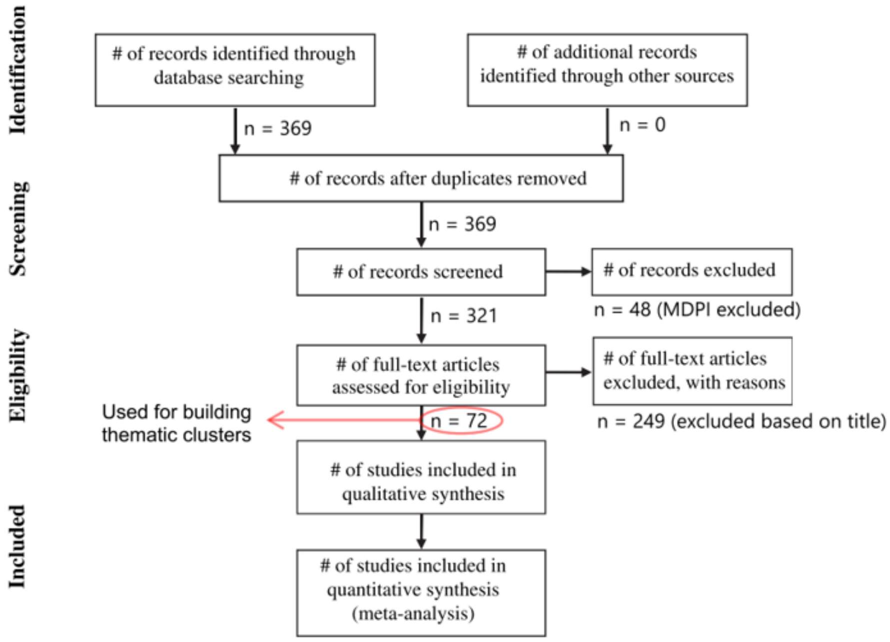

Figure 2.2: Flow diagram of the Literature Review process (graph made by the authors)

2.4 Cluster Analysis through Bibliometrix

To refine the content analysis of the retrieved documents, a clustering analysis was utilized via the *Bibliometrix* R package. Bibliometrix is an open-source tool for executing a comprehensive science mapping analysis of scientific literature. The package's extensive availability of statistical and graphical tools and its flexibility in integrating other statistical and graphical packages make Bibliometrix a fundamental device for science mapping analysis. Bibliometrix package also includes Biblioshiny, a web-base app that combines the functionality of Bibliometrix package with the ease of use web apps using the Shiny package environment [29]. Before proceeding, a deeper explanation of the bibliometric methodology and of the bibliometric analysis tools is provided in the following sections.

2.4.1 The bibliometric methodology

The bibliometric methodology involves using quantitative techniques on bibliometric data, such as publication and citation units. Even if discussions on bibliometrics began in the 1950s, bibliometric analysis spread quite recently. This growth is particularly evident in fields like "business, management, and accounting," "economics, econometrics, and finance," and "social sciences" [8]. It is interesting to compare bibliometric analysis with other commonly used review alternatives, such as meta-analysis and systematic literature review. In brief, as can be seen in Figure 2.3, while a bibliometric analysis aims to summarize large quantities of bibliometric data, meta-analysis aims to summarize empirical evidence and explore relationships between variables that previous studies haven't examined and a systematic review persues a qualitative summary and synthesis of the findings of existing literature on a research topic or field.

Review type	Goal	When to use	When not to use	Scope	Dataset	Analysis
Bibliometric analysis	• Summarizes large quantities of bibliometric data to present the state of the intellectual structure and emerging trends of a research topic or field.	• When the scope of review is broad. • When the dataset is too large for manual review.	• When the scope of review is specific. • When the dataset is small and manageable enough that its content can be manually reviewed.	• Broad	• Large	• Quantitative (evaluation and interpretation) • Qualitative (interpretation only)
Meta-analysis	• Summarizes the empirical evidence of relationship between variables while uncovering relationships not studied in existing studies.	• When the focus of review is to summarize results rather than to engage with content, which may be broad or specific. • When studies in the field are homogenous. • When the number of homogeneous studies available is sufficiently high. • When the number of homogeneous studies remaining after removing low quality studies is sufficiently high.	• When studies in the field are heterogeneous. • When the number of homogenous studies is relatively low. • When the number of high-quality homogeneous studies is relatively low.	• Broad • Specific	• Large • Small but adequate	• Quantitative (evaluation and interpretation)
Systematic literature review	• Summarizes and synthesizes the findings of existing literature on a research topic or field.	• When the scope of review is specific. • When the dataset is small and manageable enough that its content can be manually reviewed.	• When the scope of review is broad. • When the dataset is too large for manual review.	• Specific	• Small	• Qualitative (evaluation and interpretation)

Figure 2.3: Comparison of major review methods [8].

In the following paragraphs, some outcomes from Bibliometrix will be evaluated. In particular, as already said in Section 2.3.2, only the 73 documents that remained after the exclusion by title were uploaded in Bibliometrix. A complete bibliometric analysis should encompass numerous different types of analysis, from citation analysis to author analysis, bibliographic coupling, and more. In this document, it has been chosen to show only some bibliometric analysis, selected on their level of relevance for the study purpose: annual scientific production, world cloud, and thematic map.

Annual Scientific Production

Figure 2.4 shows the annual scientific articles production from 2010 to 2023. There has been a significant increase in the production of content regarding this topic, indicating its increasing relevance.

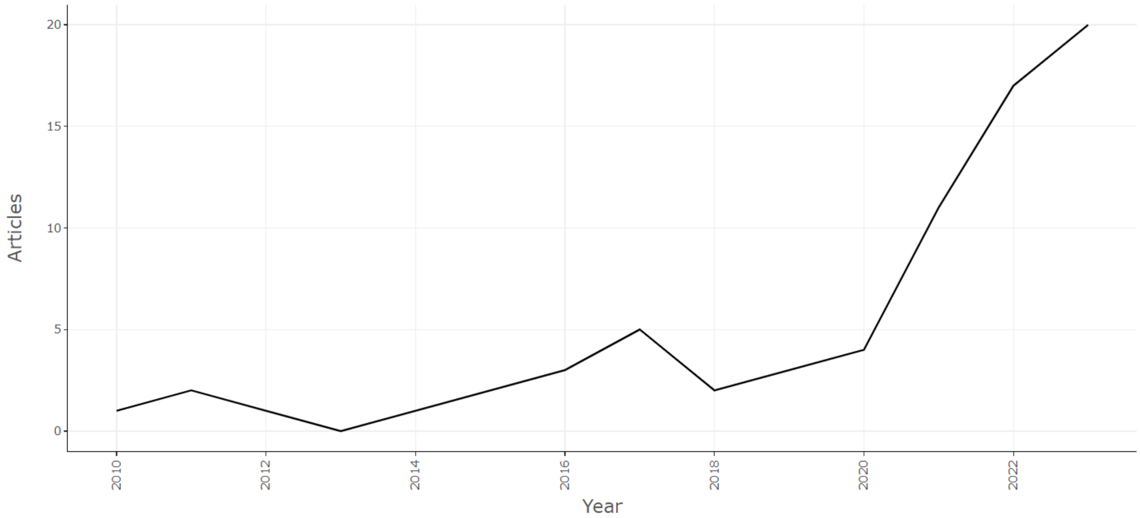

Figure 2.4: The production of articles during time, from 2010 to the half of 2023, (graph made by the authors through Bibliometrix).

WordCloud

A word cloud is a collection, or cluster, of words depicted in different sizes. They operate in a simple wanner: the more a particular word appears in the body of a text, the larger and bolder it appears in the word cloud. In this case, the biggest word is "public acceptance", consistently with the objective and principal topic of the study. Public acceptance is followed by "electric vehicles", "climate change", "sustainable development", "technology adoption", "surveys", "economic and social effects", "energy policy" and others.

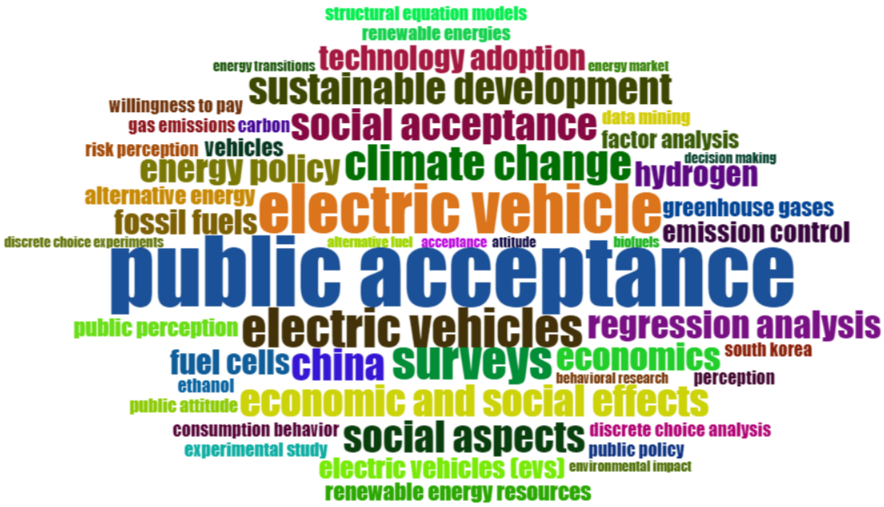

Figure 2.5: Word cloud (graph made by the author through Bibliometrix).

2.4.2 Thematic network

The goal is to categorize documents based on their thematic resemblances. This involved the use of a keyword co-occurrence algorithm and a topic was selected for each identified cluster. Figure 2.6 presents the five different clusters of keywords: (i) Public acceptance, (ii) electric vehicles and methodology, (iii) energy policy and energy market, (iv) economic and social effects, and (v) alternative fuels.

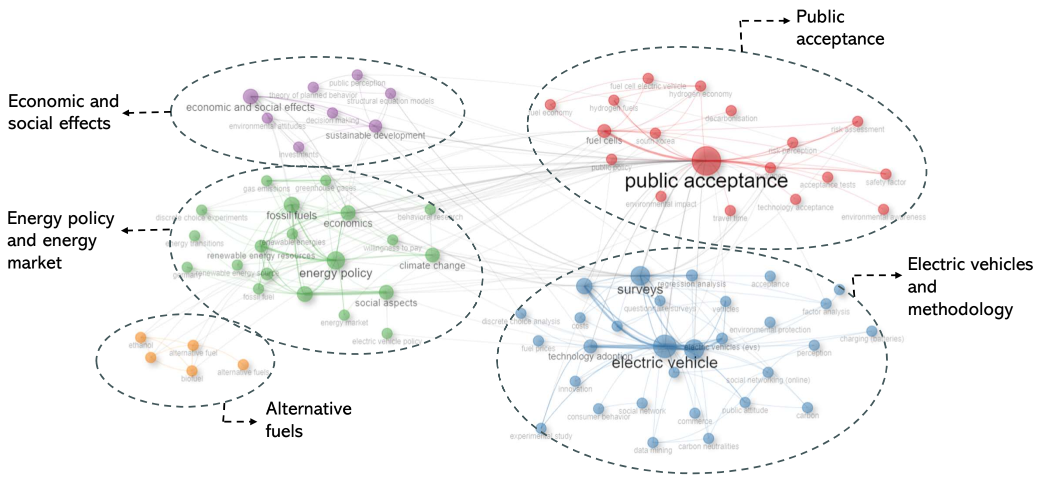

Figure 2.6: Visualization of clusters (made by the author).

Moreover, analyzing keywords within each identified cluster offers valuable insights into the related sub-topics present in each cluster. This thematic subdivision will help the analysis of the content of the selected articles to gain a comprehensive understanding of the research areas.

Public acceptance. The public acceptance cluster constitutes the largest portion of the analyzed literature. This outcome aligns with the aim of the research and the chosen query which stabilizes to select only those articles that presented "public acceptance", and its synonyms, in the title (see 2.3.1). In particular within this cluster is possible to find some other keywords like "risk assessment", "safety factor", "risk perception", and "travel time". All these keywords refer to some factors chosen in multiple papers to measure public acceptance and technology acceptance. Understanding how the different factors affect the consumers' perception of EMs can provide the government and stakeholders with valuable knowledge for designing effective policies and incentives [30]. Yang et al. [31] reveal that social trust positively influences public acceptance, directly or indirectly through perceived benefit and -risks and self-efficacy. The support of new energy vehicles and purchase intention are affected by public awareness, perceived risks, moral obligations, environmental concerns and other social psychological factors, too [32]. The criteria considered in the documents to study social acceptance are numerous and differ from study to study. However one of the criteria present in every study is the "risk perception". Murtiningrum et al. [30], for example, state that risk does not affect attitude toward electric vehicle adoption of Indonesian people. On the contrary, in [32] it is stated that subjective norms, perceived cost, perceived risk and quality have a more significant impact on public acceptance of new energy vehicles than perceived usefulness, supportive policies and charging services. As for "travel time", a study by Schmuch et al. states that electric vehicles need to meet a range of at least 500 km to make the market penetration of electric vehicles increase and to make them widely accepted by consumers [32].

Electric vehicles and methodology. The Electric vehicle cluster constitutes a large portion of the map. Switching to electric vehicles (EVs) brings a profound change in the social life of the people, potentially enhancing their social status and way of life [33]. The gradual introduction of electric technology will provide an average 21% reduction in greenhouse gases emissions and 26% savings in fuel consumption [34]. This transition can be considered a valuable stepping stone to a low-carbon future.
It is valuable to notice that electric vehicles are separated in the map from alternative fuels. This is because, so far, the majority of papers that study new transport technologies' social acceptability focus on electric vehicles and only a minority on alternative fuels. The reason behind this is that, all around the world, various policies and incentives on electric vehicles are being implemented. For example, the Government of India is implementing various policies and incentives that push a faster adoption and manufacturing of (hybrid) and electric vehicles [35]. Therefore, since a great number of studies that assess social acceptance take electric vehicles as field of study, it is for this reason that in the same cluster there can be found also keywords like "surveys", "questionnaire surveys" and "regression analysis". Numerous studies uses surveys as mean of data mining from people (i.e. [36], [37], [30], [38], [39], [34], [40]).

Alternative fuels. Beside electricity, alternative fuels have the potential to reduce emissions in road transport, shipping, and aviation. It is becoming more and more important to study these new technologies that can be produced from biomass (biofuels) or CO2, water, and renewable electricity(e-fuels or CO2-based fuels) and to study their acceptance in the society. Even if the studies are really less numerous than those on electric vehicles, a few very interesting must be mentioned. Savvanidou et al. in [40] state that there is a significant lack of information about biofuels. In particular, most survey participants prioritize saving energy over using an alternative source of energy, with a clear preference for other renewable energy sources than biofuels [40]. Only a minority shows a preference for biofuels compared to other renewable energy sources [40]. Moreover, the high production costs could be an obstacle to their economic viability and competitiveness to conventional diesel and gasoline [41].

Energy policy and energy market. The forth cluster is made of some principal keywords: "energy policy", "fossil fuels", "climate change", "economics", "energy market" and "willingness-to-pay". Fossil fuels have been of capital importance for the technological advancement of the latest centuries. However, they have also contributed to both serious environmental problems, such as climate change and pollution, and related health and well-being problems for humans and other forms of life [32]. Climate change represents an economic issue as well because the transition from fossil fuels to other technologies entails substantial economic transformations within a nation. Countries are adopting numerous policies in order to go toward a carbon-neutral future. For instance, the Indonesia's Auto Industry 4.0 roadmap put forward by the Ministry of Industry outlines a definite strategy to phase out fuel-based vehicles while building required infrastructure and encouraging the adoption of electric vehicles as a crucial goal to attain by 2025 [30]. Also the European Clean Bus Deployment Initiative (through the combined effort of cities, regions, transport authorities and manufacturers), seeks the promotion of low-and-zero-emission mobility in the European cities and regions [34]. Brückmann at al. in [42] state that pull measures (more charging infrastructure, purchase subsidies, energy labels) attract more public support than push measures (banning fossil fuels cars). This is due to the fact that pull measures are often perceived to have lower costs compared to push measures, contributing to higher public support [42]. Trust in authority drives public perceptions across a variety of benefit and risk domains and enhances their self-confidence in dealing with social [31]. As for the willingness-to-pay, there are consumers that are willingness-to-pay (WTP) more for the deployment of EV [43]. Jang et al. in [44], for example, showed that most of the consumers are willingness to pay higher prices if the charging time is fast. The charging infrastructure was found to be the most desirable attribute, as well as home charging facility and reduced time of charging or fast chargers' availability.

Economic and social effects. In the final cluster can be found different keywords, from economic and social effects to Theory of Planned Behavior and Structural equation model. The theory of Planned Behavior (TPB) is a psychological theory that links beliefs to behavior and has been widely used in numerous studies. In [30] it has been used to investigate for example the factors influencing purchase intentions such as perceived behavioral control, attitude, and subjective norm. On the other hand, Structural Equation Modeling (SEM) (used for example in [45] and [39]) is a multivariate statistical analysis technique that is used to analyze structural relationships. This technique comes from the combination of factor analysis and multiple regression analysis. It is commonly used for finding the output of various social and behavioral analyses but it is also used in epidemiology, business, and other fields. It assesses the latent variable from the observed variables [35].

2.5 Social Acceptance factors of new transport technologies

Define which are the factors influencing the social acceptance of new transport technologies (electric vehicles, alternative fuels, hydrogen vehicles) is a fundamental step to achieve the research goal. To do this, 14 documents out of the previous 72 have been selected. The selected documents are listed in Tables 2.1, 2.2, 2.3, 2.4, 2.5 and 2.6. In particular, these documents have been chosen because of their research methodology. In each of the papers listed, the authors have attempted to identify the criteria on which social acceptability of transport technologies depends and to determine the more influential ones. As can be seen from the tables, the majority of papers (10 out of 14) refer to electric vehicles, aligning with what is written in 2.4.2, three papers refer to biofuels and only one to hydrogen vehicles. The chosen criteria slightly differ from document to document. However, they can be more or less summarized in three categories:

- **Social-psychological factors:** age, gender, income level, level of education, awareness of electric vehicles, environmental concern, day traveled kilometers, perceived risk.
- **Technology features:** driving range, charging duration, charging rate, charger type, life of battery, charging infrastructure.
- **Economic and market aspects:** economic benefits, purchase cost, battery cost, incentive-based policies, energy prices.

Prices, perceived costs, perceived economic benefits, and perceived incentive policies result to be the most important motives of respondents to adopt new transport technologies. This trend is common to all types of new transport technologies, electric vehicles, hydrogen vehicles, biofuels, and e-fuels, even if for biofuels the economic side seems to be less influential than the perceptions of risks and environmental effects. This is probably because biofuels, compared to EVs, require less economic commitment and, while in the short term they will cost for the consumer more than fossil fuels, in the long term this gap will be reduced. The majority of studies analyzed principally provide qualitative findings and do not dispense specific price reductions necessary to overcome the acceptance barrier. There are only three exceptions:

- in [34] there is the exact number of willingness-to-pay of each respondent per single bus (€ 0.33);
- in [35] the authors affirm that some consumers are willing to wait until the purchase cost for EVs is at par with that of conventional fossil fuel-powered vehicles (CFFVs) and that the total cost of ownership of EVs should be reduced to 50% (even after a higher purchase price);

- in [40] the authors affirm that the 44.8% of the respondents are willing to pay the supplementary amount of 0.06 €/L of the fuel market price.

Consumer attribute variables deeply influence the acceptance, too. In particular, it has been studied how education, gender, awareness of electric vehicles, as well as environmental awareness, perceived risks and others affect social acceptance. Almost all studies show how they all tend to deeply affect acceptance: for example, educational level has a positive effect on sales while age has a negative correlation to acceptance. The only exception is [46] where authors state that factors such as environmental awareness, gender, and fuel availability have no obvious effect on consumer's adoption of EVs.

	Type of transport	Geographical Area of research	Year	Chosen criteria	Findings
[36]	EV	India	2022	• product innovativeness, • perceived usefulness • information influence, • value-expressive influence • Electric vehicle acceptance	1) Significant relationship between informational influence, value-expressive influence, and product innovativeness and electric vehicle acceptance. 2) Positive moderation effect of age, income and gender was identified on the paths between perceived usefulness and electric vehicle acceptance.
[43]	EV	-	2023	• driving range, • charging location, •charging duration, • charger type, • charging rate,- • willingness-to-pay, - • environmental factor.	1) Factors related to utility and price are the most important motives of respondents to adopt Evs. 2) Behavior and social influence have an important role in individuals' decisions when purchasing Evs.
[32]	EV	China	2021	• Perceived usefulness, • perceived risk, • perceived cost, • subjective norm • support policy on public acceptance of NEVs in underdeveloped areas.	3) The acceptance of females, young and less educated public are relatively higher, decreases with aging and increases with education attainment. 4) Perceived risk and perceived cost are significantly negative correlated with public acceptance of NEVs, while subjective norm and the quality of NEVs positively correlated with public acceptance. 5) Support policy is significantly positively correlated with perceived cost while perceived cost is positively corelated with perceived risk

Table 2.1: Tables with selected documents and three columns: type of transport, chosen criteria and findings. EV = Electric Vehicles, EV* = Electric Motorcycles, EV** = Electric Buses, HV = Hydrogen Vehicles, BFV = Biofuel Vehicles.

	Type of transport	Geographical Area of research	Year	Chosen criteria	Findings
[47]	EV	France	2022	• Consumer attribute variables (education, awareness of electric vehicles) • Geographic variables (average winter temperature, population density) • Variables related to the cost of energy (gasoline and electricity costs) • Ability to access charging infrastructure away from home • Market characteristics (the number of available PHEV models) • Incentives (financial and non-financial incentives) • Economic variables (income, taxes exemption, the ratio of subsidies over the vehicle's price) • Technical variables (fast and ultra-fast charging density) • Education level • Energy prices • Proportions of ages between 19-39 and 40–59 12. Slow-and-normal chargers density • Solar production • Daily travelled kilometres • Unemployment rate • At-home parking availability	1) Economic variables (income, taxes exemption, the ratio of subsidies over the vehicle's price), technical variables (fast and ultra-fast charging density), education level, and the number of available BEV models have a positive effect on BEV sales. 2) The number of PHEV models, income, slow-and-normal chargers density, solar production, and daily travelled kilometres are positively correlated with PHEV sales include.
[30]	EV*	Indonesia	2022	• Perception of EMs • Perceived environmental benefits (PEB) • Perceived economic benefits • Perceived cost (PC) • Perceived risks (PR) • Perceived incentive policies (PIP) • Knowledge • Environmental concern (EC) • Perceived behavioral control (PBC) • Subjective norm (PN) • Attitude	1) PEB, perceived economic benefits, PIP positively affect the attitude toward the adoption. 2) PC and PR insignificantly affect attitude towards the EM adoption in our study. 4) The incentive-based policies is more viable than the command-and-control policies. Such incentive-based policies will directly influence perceived economic benefit and PIP.

Table 2.2: Tables with selected documents and three columns: type of transport, chosen criteria and findings. EV = Electric Vehicles, EV* = Electric Motorcycles, EV** = Electric Buses, HV = Hydrogen Vehicles, BFV = Biofuel Vehicles.

	Type of transport	Geographical Area of research	Year	Chosen criteria	Findings
[48]	BFV	Europe	2022	• Technology features • Economic and market aspects: - Price - Food and production costs - Economic benefits/economic support - Market availability - Local development and energy independence • Social-psychologica factors	1) Compared to EVs, biofuels requires less economic commitment and it would be more beneficial. 2) In the short term biofuels will cost for the consumer more than fossil fuels, but in the long term this gap will be reduced. 3) Biofuels production costs are considered by expert stakeholders as a barrier to acceptance. 4) The high biofuels costs could lead to an increase in transportation-related costs increasing food raw materials costs. 5) End-users would consider only the economic side rather than the environmental and social benefits in the adoption of biofuels. 6) Economic benefits are needed and economic support favors acceptability and adoption. 7)Among the negative aspects related to the use of biofuels versus fossil fuels, there is their market scarcity, which includes not only production aspects but also sales aspects.
[41]	BFV and e-fuels	Germany	2022	• Perceptions of risks & environmental effects • perceptions of benefits, cost and efficiency	1) Perceptions of risks and environmental effects are more influential than perceptions of benefits, costs, and efficiency. 2) The public generally had a positive attitude towards the use of CO_2-based fuels as an alternative propulsion technology.
[42]	EV	Switzerland	2020	• Preference for pull measures over push measures • Voluntariness and perceived benefits • Perceived costs • Support among EV holders • Stability of support despite cost implications	1) Pull measures (more charging infrastructure, purchase subsidies, energy labels) attract more public support than push measures (banning fossil fuels cars). 2) Pull measures are often perceived to have lower costs compared to push measures, contributing to higher public support

Table 2.3: Tables with selected documents and three columns: type of transport, chosen criteria and findings. EV = Electric Vehicles, EV* = Electric Motorcycles, EV** = Electric Buses, HV = Hydrogen Vehicles, BFV = Biofuel Vehicles.

	Type of transport	Geographical Area of research	Year	Chosen criteria	Findings
[34]	EV**	Spain (Valencia)	2020	• Gender, • age, • allowance, • psychology, • years university, • pro environmental behaviour, • health risk.	1) 67% of the respondents are willing to pay extra for the adoption of this electric hybrid technology, being the mean willingness to pay € 0.33 per single bus. 2) Mean willingness to pay for each class ranges from €0.25 to €0.38.
[35]	EV	India (Delhi)	2021	Finantial factors: • Battery cost • Purchase cost • Lack of awareness about maintenance cost • Lack of awareness about fuel cost • Public charging infrastructure Vehicle performance factors: • Driving range • Refuelling time • Vehicle power • Reliability • Safety • Life of battery Infrastructure factors: • Charging infrastructure on highways • Refuelling time • Charging infrastructure at work • Charging infrastructure at home	1) Battery cost and purchase cost are the top two concerns of the respondents. 2) Some customers are willing to wait until the purchase cost for EVs is at par with that of CFFVs, and switching to EVs would be affordable. Providing subsidy on the modification of a CFFV to EV might be a promising idea. 3) The customers should be convinced that the total cost of ownership of EVs would be reduced to 50% even after a higher purchase price.
[39]	HV	Norway	2012	• Personal characteristics • Environmental attitude, • Acceptance, • Willingness to pay.	1) Hydrogen acceptance negatively relates to hydrogen knowledge, showing greater support for hydrogen development among individuals with less knowledge. 2) The site of refuelling stations probably influence the probability of hydrogen's acceptance.

Table 2.4: Tables with selected documents and three columns: type of transport, chosen criteria and findings. EV = Electric Vehicles, EV* = Electric Motorcycles, EV** = Electric Buses, HV = Hydrogen Vehicles, BFV = Biofuel Vehicles.

	Type of transport	Geographical Area of research	Year	Chosen criteria	Findings
[40]	BFV	Greece	2010	• Demographic characteristics • perceived disadvantage of decrease of biodiversity and deforestation, • owner of car, • climate change beliefs and perception, • perceived importance of dependency from fossil fuels, • education, • perception of environmental advantages from less Fossil fuel extraction, • maximum amount willing to pay per liter of biofuels, • willingness to pay 0.06€/liter, • perception of priority of biofuels, • perception of biofuels as a solution, • trust in research.	1) Only 27.3% believe that priority must be given to biofuels over other renewable energy sources. 2) 44.8% are willing to pay the supplementary amount of 0.06 €/L of the fuel market price
[45]	EV	China (Shanghai)	2017	• EV technical performance, • EV adotpion context, • EV value perception and communication, • Consumers' characteristics	1) More than 60% of the respondents express their willingness to purchase electric vehicles, but they are more willing to buy EVs as the second car. There are only few consumers willing to buy EVs to replace their traditional fuel vehicles. 2) The 4 factors —technical level, marketing, perceived risks and environmental awareness — have significant impact on the EV public acceptance. EV technical level and environmental are positively correlated with EV public acceptance, while marketing and perceived risks are negatively correlated with EV public acceptance.

Table 2.5: Tables with selected documents and three columns: type of transport, chosen criteria and findings. EV = Electric Vehicles, EV* = Electric Motorcycles, EV** = Electric Buses, HV = Hydrogen Vehicles, BFV = Biofuel Vehicles.

	Type of transport	Geographical Area of Research	Year	Chosen criteria	Findings
[46]	EV	China	2000	• Demographic characteristics • consumer knowledge • experience • environmental benefits, • low fuel cost, • high degree of safety, • high quality, • good performance, • low maintenance cost, • short charging interval • better economic results • social responsability • significant attributes of vehicles • consumers' awareness of EVs • consumers' purchasing behaviour	1) The higher the tax incentives are (provided that the consumers are aware of government policies and the government offers tax incentives for EVs), the more likely that a consumer is willing to purchase an EV. 2) The factors such as previous experience with EVs, environmental awareness, gender, and fuel availability have no obvious effect on consumer's adoption of EVs.

Table 2.6: Tables with selected documents and three columns: type of transport, chosen criteria and findings. EV = Electric Vehicles, EV* = Electric Motorcycles, EV** = Electric Buses, HV = Hydrogen Vehicles, BFV = Biofuel Vehicles.

From the tables, it is evident that out of 14 studies, 10 investigate SA with focus Electric Vehicles. Among these ten studies, eight have cars as core field of analysis. The remaining four studies assess biofuels and fuel cell.
As for the geographical area of research, six papers focus their investigation on Asia (China, India, Indonesia), while eight on European countries.
Furthermore, the majority of these studies (10) were published from 2020 onward: three studies in 2020, two in 2021, five in 2022, and one in 2023.

Chapter 3

Social Acceptability in ESOMs

In Chapter 2, the principal criteria determining social acceptance of new transport technologies have been identified through a thorough process of literature review. As said in 2.5, the criteria can be summarized in three categories: social-psychological factors, technology features and economic and market aspects. The first goal of this research was to investigate if some of these factors determining Social Acceptance were suitable to be included in an Energy System Optimization Model. All the factors are crucial for a holistic examination of public acceptance, but the majority of them require, for their comprehensive exploration, other tools, such as surveys and questionnaires, as widely shown in the papers studied in the literature review (see paragraph 2.4.2). In the present research, a deliberate focus has been made on the investigation of three fundamental factors: purchase cost, risk perception and environmental concern. This decision is motivated by their endogenous compatibility with the quantitative measurement capabilities offered by the ESOMs. Before analyzing in detail the chosen model, scenarios, relative policies, and results, an essential remarks must be made. It has been decided to focus the analysis only on electric cars, excluding, therefore, all the other alternative fuels (see Section 1.3) and all the other means of transport. The reason behind this is that the process of literature review outlined how the majority of knowledge on new transport technologies' social acceptability present until now focuses on electricity as fuel and on cars as means of transport (see 2.4.2).

3.1 TEMOA in the framework of open science

Tools for Energy Model Optimization and Analysis (TEMOA) is an open-source bottom-up modeling framework for conducting energy system analyses [49]. The energy system is described as a network in which linked processes convert a raw energy commodity (e.g., coal, oil, biomass, uranium) into an end-use demand (e.g., lighting, transport, water heating, conditioned air), often through a one or more intermediate commodities (e.g., electricity, gasoline, ethanol). Temoa is formulated as a linear programming problem and is implemented in Python using Pyomo, a Python-based open-source software package (Figure 3.1). A Linear Programming (LP) problem consists of the minimization or maximization of an objective function. Elements of LP formulation are:

- *Decision variables:* unknowns determined by the optimization
- *Objective function:* criteria to be minimized/maximized (for example the cost)
- *Constraints:* equations or inequalities involving the decision variables (emissions, use of land, use of water, satisfaction of demand, adoption of a technology)

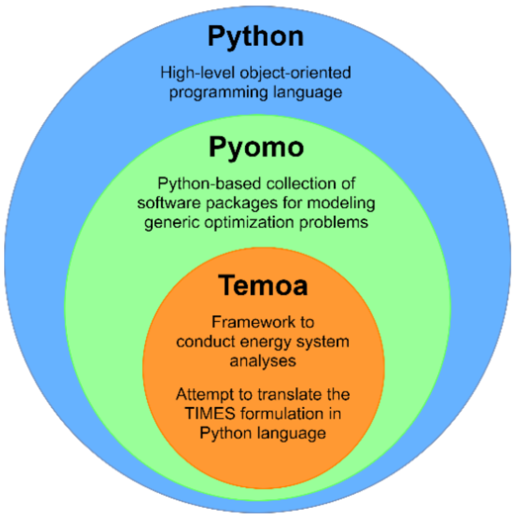

Figure 3.1: TEMOA framework [9]

It has been decided to choose TEMOA as the modeling framework where to carry out the scenarios analysis. TEMOA is intended to address two critical issues: the difficulty in conducting third-party verification of published model-based results and the struggle in conducting rigorous uncertainty analysis with large, complex models.
First, the fact that many models cannot be externally verified by third parties because the source code and input data are not publicly available [50]. There have been efforts to compare model results (e.g., Stanford Energy Modeling Forum, Innovative Modelling Comparison Project), however, the impossibility of accessing to source code prevents an external verification. Long timeframes, expansive system boundaries, and the contemplation of physical and social phenomena make the provided level of descriptive detail in model documentation and in peer-reviewed

journals insufficient to produce a specific set of published results [49].
Second, the treatment of uncertainty in EEO models is often absent or cursory [50]. The size and complexity of many energy-economy models make it difficult to validate their results. There is no practical solution to the validation problem, however, modelers must be conscious of the creeps in model complexity [49]. The choice of the level of model detail is subjective and is tailored to specific research objectives. On the other hand, what is necessary is that the results generated with such models must be robust to large future uncertainties, otherwise, they lose their practical value to policy planners and decision-makers.
The main objectives during the design of TEMOA were [49]:

- **Provide an open source energy system optimization model:** public access to the revision control system via the web is granted. Snapshots of model source code and data used to produce published model-based analysis are archived, enabling third-party verification of our work.
- **Utilize open source software tools wherever possible:** programming language, database, graphing and visualization tools, and solvers.
- **Design the model to make uncertainty analysis more tractable:** Temoa gives the possibility to conduct parametric sensitivity analysis, Monte Carlo simulation and multi-stage stochastic optimization.

TEMOA model formulation is strongly influenced by TIMES formulation. The TIMES (The Integrated MARKAL-EFOM System) model generator was developed as part of the IEA-ETSAP (Energy Technology Systems Analysis Program), an international community which uses long term energy scenarios to make energy and environmental analyses [51]. In the TIMES model, two different approaches to modeling energy are combined: a technical engineering approach and an economic approach. Figure 3.2 shows schematically the structure of Temoa framework.

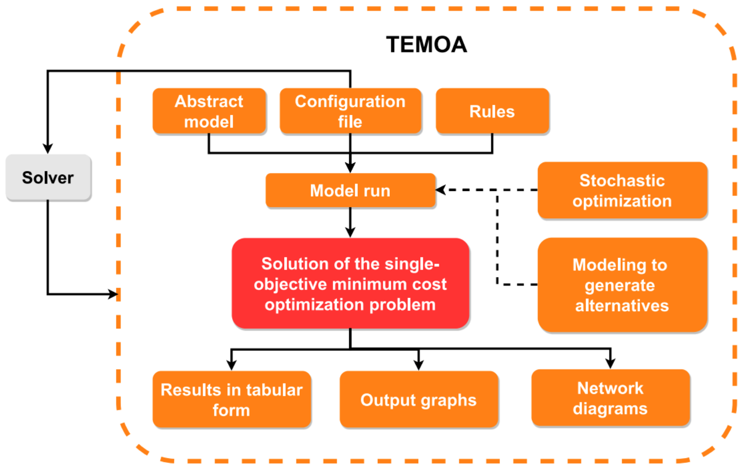

Figure 3.2: TEMOA structure [9]

3.1.1 TEMOA-Europe

TEMOA-Europe, a model instance for the optimization of the European energy system developed within an extended version of the TEMOA, was chosen as modeling framework for the successive analysis. TEMOA-Europe is a case study based on the OECD Europe Reference Energy System. Such model is developed on a time scale up to 2050 and calibrated against acknowledged energy statistics up to 2020.

TEMOA-Europe Reference Energy System (RES) is composed of various energy sectors divided into the supply side and demand side. In Figure 3.3, a schematic representation of TEMOA-Europe RES is shown.

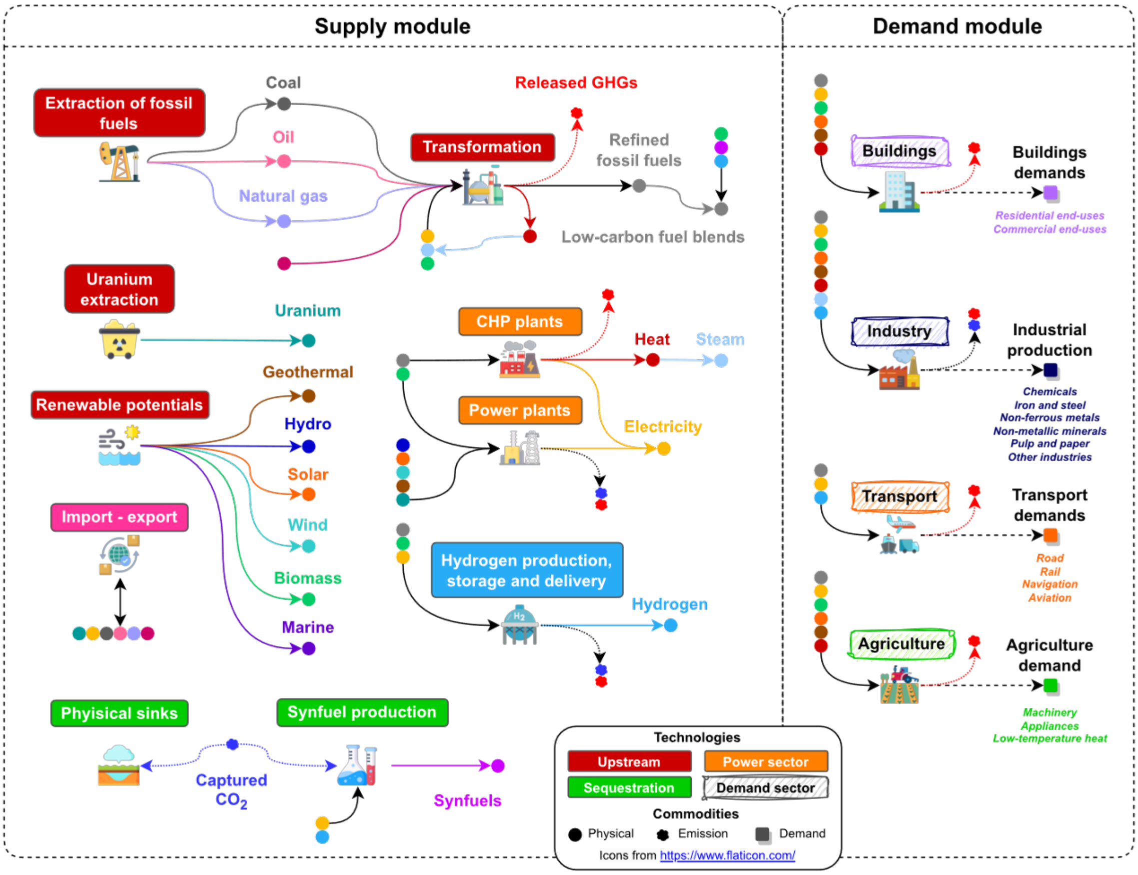

Figure 3.3: Representation of the TEMOA-Europe reference energy system [10]

As can be seen from Figure 3.3, the supply side includes the upstream sector (producing and transforming fossil fuels, biofuels and renewable potentials and modeling import/export), the power sector (devoted to the production of electricity and heat), the hydrogen module (including hydrogen production, distribution, and storage technologies) and the Carbon Capture Utilization and Storage (CCUS) module (modeling CO2 capture, utilization – through synfuels production – and storage). The demand side covers the building sector (which includes residential, commercial and agriculture end-uses), the transport sector (several road and non-road transport demands), and the industrial sector [10].
As for the temporal framework, it organized into consecutive 5-year increments. The milestone years are further divided into intervals: three seasons (intermediate, summer, winter) and three distinct periods of the day (day, night, and peak), resulting in a total of 9-time segments per year.

3.1.2 Techno-economic characterization of the Reference Energy System

There are three types of technologies in TEMOA-Europe:

- **Base year technologies:** they account for the demand and the energy use at the beginning of the time horizon and are identified by the $\_EXS$ at the end of their code name (e.g., TRA_ROA_CAR_ELC_EXS is the base year technology that identifies electric cars).

- **Fuel technologies:** they do not correspond to actual technologies, they only account for the fuel consumption in the different sectors. Fuel technologies present $\_FT$ between the name of the sector and the fuel they produce (e.g., TRA_FT_NGA is the fuel technology producing natural gas for transport).

- **New technologies:** they are added to the existing base year technologies from the second time step. They can include both currently available and innovative technologies not present of the market, yet. In this latter case, they require hypotheses for the first year of availability. New technologies are moreover characterized by a set of parameters shown in Figure 3.4.

Type of parameter	Definition	Description
Technical	Efficiency	Input-to-output transformation parameter
	Capacity factor	Utilization factor to define the available capacity fraction during a specific time slice
	Technical lifetime	Operational lifetime
	Capacity to activity	Conversion factor to be used in case capacity units differ from activity units
	Existing capacity	Capacity installed prior to the beginning of the time periods set for the optimization
Economic	Investment cost	Total cost of investment in new capacity
	Annual fixed operation and maintenance cost	-
	Variable operation and maintenance cost	-
	Technology-specific discount rate (optional)	Interest rate on investment for a specific technology
Environmental	Emission activity	Emission rate for the specific technology

Figure 3.4: Main parameters for the characterization of energy technologies in ESOMs. [11].

3.1.3 Demand projection

In TEMOA-Europe, demand levels are predetermined on the base of a set of socio-economic factors. These factors' trajectories are determined using the Energy Information Administration's (EIA) forecasts for Gross Domestic Product (GDP) and population. Future estimations of energy service demands follow the Equation 3.1, where $Demand_t$ and $Demand_{t-1}$ denote the service demand levels at time steps t and $t-1$, respectively. Similarly, δ_t and δ_{t-1} represent the values of the drivers at time steps t and $t-1$, while $e_{d,t}$ stands for the elasticity of the driver to the demand associated with the respective time step.

$$Demand_t = Demand_{t-1} \cdot [1 + (\frac{\delta_t}{\delta_{t-1}} - 1) \cdot e_{d,t}] \tag{3.1}$$

Figure 3.5 shows the projections (through Equation 3.1 for the road and non-road transport sectors. It is interesting to see the effects of the COVID pandemic for 2020 values in particular in the domestic aviation demand projection.

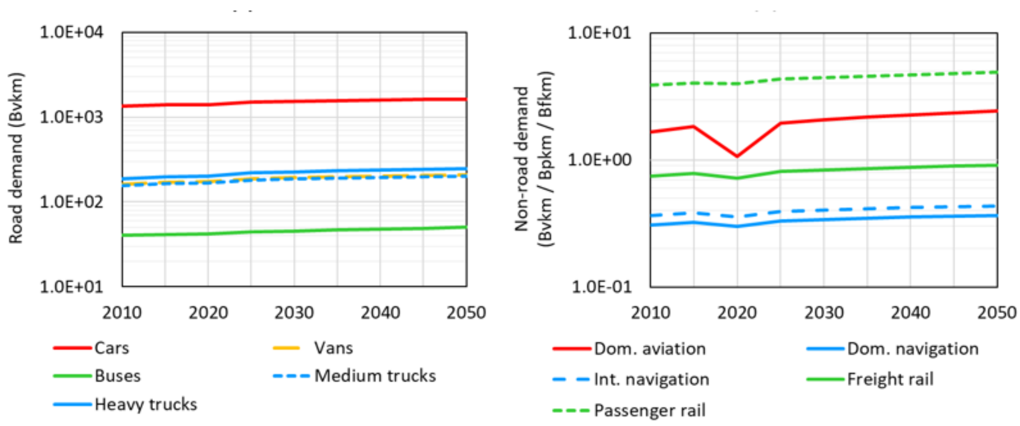

Figure 3.5: Demand projection for road and non-road sectors.

3.2 Transport Sector in TEMOA-Europe

3.2.1 Road transport

As written in [11], in road transport technologies there are 8 transport modes (shown in Figure 3.6): passenger car, light truck, van, two-wheeler, three-wheeler, medium truck, heavy truck, and bus.

Road transport mode	**Code**	**Features**
Passenger car	TRA_ROA_CAR	-
Light truck	TRA_ROA_LTR	Including SUVs and pick-ups
Van	TRA_ROA_LCV	Up to 3.5 t gross vehicle weight (GVW), for urban/regional freight transport
Two-wheeler	TRA_ROA_2WH	-
Three-wheeler	TRA_ROA_3WH	-
Medium truck	TRA_ROA_MTR	From 3.5 t up to 12 t GVW, for regional/national freight transport
Heavy truck	TRA_ROA_HTR	From 12 t up to 60 t GVW, for national/international freight transport
Bus	TRA_ROA_BUS	-

Figure 3.6: Road transport modes included in TEMOA-Europe [11].

In Figure 3.7, the road vehicle technologies currently considered in the database are listed.

Technology	**Description**	**Fuel(s)**
TRA_ROA_***_GSL_N	Gasoline (GSL) vehicle	Gasoline
TRA_ROA_***_DST_N	Diesel (DST) vehicle	Gas oil
TRA_ROA_***_NGA_N	Natural gas (NG) vehicle	Natural gas
TRA_ROA_***_LPG_N	Liquified petroleum gas (LPG) vehicle	LPG
TRA_ROA_***_ELC_N	Full-electric (ELC) vehicle	Electricity
TRA_ROA_***_GHE_N	Gasoline hybrid-electric (GHE) vehicle	Gasoline
TRA_ROA_***_DHE_N	Diesel hybrid-electric (DHE) vehicle	Gas oil
TRA_ROA_***_GPH_N	Gasoline plug-in hybrid-electric (GPH) vehicle	Gasoline + electricity
TRA_ROA_***_DPH_N	Diesel plug-in hybrid-electric (DPH) vehicle	Gas oil + electricity
TRA_ROA_***_FCE_N	Fuel cell (FCE) vehicle	Gaseous hydrogen

Figure 3.7: Road transport fuel technologies included in TEMOA-Europe [11].

The vehicle technologies of the various transport modes have different initial availability date according to the expected commercialization year [11]. For instance, fuel cell cars are already available on the market, while fuel cell trucks are projected to become more present within the next 5-10 years [11].

3.2.2 Non Road transport

Non-road transport technologies are categorized into 6 transport modes, as shown in Figure 3.8.

Road transport mode	**Code**
Domestic aviation	TRA_AVI_DOM
International aviation	TRA_AVI_INT
Passenger train	TRA_RAIL_PAS
Freight train	TRA_RAIL_FRG
Domestic navigation	TRA_NAV_DOM
International navigation	TRA_NAV_INT

Figure 3.8: Non-road transport modes included in TEMOA-Europe[11]

Figure 3.9 outlines the road vehicle technologies currently present in the database for the different transport modes. It is important to note that full-electric vehicles are not taken into consideration in aviation and navigation due to the intricate challenges associated with covering large distances. For this reason, non-road transport will not be included in this research.

Transport mode(s)	Technology	Description	Fuel(s)
Domestic aviation	TRA_AVI_DOM_JTK_N	Jet kerosene vehicle	Jet kerosene
	TRA_AVI_DOM_LH2_N	Liquid hydrogen-powered internal combustion engine vehicle	Liquid hydrogen
International aviation	TRA_AVI_INT_JTK_N	Jet kerosene vehicle	Jet kerosene
	TRA_AVI_INT_LH2	Liquid hydrogen-powered internal combustion engine vehicle	Liquid hydrogen
Passenger train / Freight train	TRA_RAIL_***_DST_N	Diesel vehicle	Gas oil
	TRA_RAIL_***_ELC_N	Full-electric vehicle	Electricity
	TRA_RAIL_***_GH2_N	Fuel cell vehicle	Gaseous hydrogen
Domestic navigation	TRA_NAV_DOM_DST_N	Diesel vehicle	Gas oil
	TRA_NAV_DOM_LNG_N	LNG vehicle	LNG
	TRA_NAV_DOM_DUAL_N	Dual fuel vehicle	Heavy fuel oil + ammonia
	TRA_NAV_DOM_AMM_N	Ammonia vehicle	Ammonia
	TRA_NAV_DOM_MTH_N	Methanol vehicle	Methanol
	TRA_NAV_DOM_LH2_FCE_N	Liquid hydrogen-powered internal combustion engine vehicle	Liquid hydrogen
	TRA_NAV_DOM_AMM_FCE_N	Ammonia fuel cell vehicle	Ammonia
International navigation	TRA_NAV_INT_HFO_N	Heavy fuel oil-fueled vehicle	Heavy fuel oil
	TRA_NAV_INT_LNG_N	LNG vehicle	LNG
	TRA_NAV_INT_DUAL_N	Dual fuel vehicle	Heavy fuel oil + ammonia
	TRA_NAV_INT_AMM_N	Ammonia internal combustion engine vehicle	Ammonia
	TRA_NAV_INT_MTH_N	Methanol vehicle	Methanol
	TRA_NAV_INT_LH2_N	Liquid hydrogen-powered internal combustion engine vehicle	Liquid hydrogen
	TRA_NAV_INT_AMM_FCE_N	Ammonia fuel cell vehicle	Ammonia

Figure 3.9: Non-road transport fuel technologies included in TEMOA-Europe [11]

Since the TEMOA model is constructed as an energy network in which technologies are linked to the flow of energy commodities, a network graph can perfectly represent a way to visualize the energy system relations present in the database. Figure 3.10 in particular shows the network diagram for the commodity TRA_ELC, which represents the electricity specifically used for the transport sector. As can be seen from the figure, the electricity used in the transportation sector comes in the model from different sources (i.e. solar panels, hydro, oil, etc.)

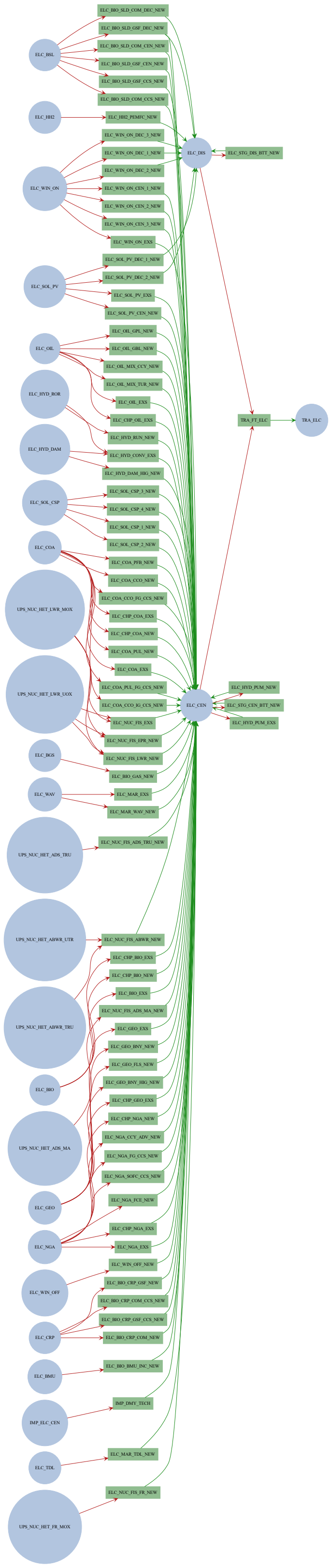

Figure 3.10: Network diagram electricity for transport (illustration made by the author through TEMOA-Europe

3.3 Inclusion of Social Acceptance criteria in TEMOA-Europe

3.3.1 Business As Usual (BAU)

The Business As Usual scenario is used in ESOMs (Energy System Optimization Models) to make a forward analysis to understand the trends if nothing changes from now on. It can also be a benchmark useful to compare the impact of new alternative policies. In this study, it will be the reference for the comparison of the other scenarios.

3.3.2 Purchase cost

Generally, electric vehicles have a higher upfront cost compared to traditional internal combustion engine vehicles. A recent Pew study found that while 67 percent of Americans say electric cars and trucks are better for the environment, 66 percent view EVs as more expensive than fuel-powered cars [52]. This factor influencing Social Acceptability, as found in 2, was chosen to be inserted in TEMOA-Europe and modeled via *Investment Cost*, called in the database as *CostInvest*.

Electric Cars Cost Scenario (ECCS)

Many governments promote incentives and subsidies to enhance the adoption of electric vehicles. These incentives can significantly reduce the upfront cost of purchasing an electric vehicle and may include tax credits, rebates, grants, and exemptions from certain taxes or fees [52]. In this scenario, it has been decided to consider the upfront cost (investment cost) of an electric car equal to the upfront cost of a fossil fuel car (gasoline, diesel, natural gas, and liquefied petroleum gas) considering the difference in the cost as government subsidies.
Figure 3.11 shows the original values of electric cars investment costs and the new values calculated as mean values of the investment costs of gasoline, diesel, natural gas, and liquefied petroleum gas present in the database. Figure 3.12 illustrates the vales of ICE car prices (investment costs) present in TEMOA-Europe from which the new EVs costs were calculated.

Type of Vehicle	Period [year]	EV Cost [Meur/Bvkm]	
		Old Value	New Value
Electric Vehicles*	2010	3190	1884
	2020	2870	1878
	2030	2070	1872
	2040	1940	1872
	2050	1850	1872

* [TRA_ROA_CAR_ELC_NEW]

Figure 3.11: New values (inserted in ECCS) of EVs investment costs in comparison with the old ones.

Period [Year]	Gasoline*	Diesel*	Liquefied petroleum gas*	Natural gas*
2010	1800	1920	1908	1908
2020	1764	1908	1920	1920
2030	1764	1908	1908	1908
2040	1764	1908	1908	1908
2050	1764	1908	1908	1908

*All values are in MEUR/Bvkm

Figure 3.12: Values of ICE cars from which have been calculated the new mean values for ELC cars prices as shown in 3.11.

3.3.3 Risk perception and environmental concern

Risk perception and environmental concern (the other two criteria resulted from the Literature review and chosen for being modelled in TEMOA-Europe) can seem to be qualitative factors difficult to translate into economic values to be included in a mathematical model. However, there is an economic parameter that acts as a sort of bridge between the perception of people (qualitative factor) and the cost (quantitative factor): the *discount rate* (or *hurdle rate*). The discount rate is defined as "the interest rate used to determine the present value of future cash flows in a discounted cash flow (DCF) analysis" [53]. It takes into account the time value of money and the level of risk involved in an investment or project that can create volatility in future cash. The discount rate is one of the most important parameters to model the financing costs of a project [54]. The investment risk can be represented as the weighted average of the expenses incurred by a company to fund a project, given by equity and dept [54]. In ESOMs the traditional objective function to be minimised is the total system cost, which is defined as the total cost of energy supply in the system under analysis . In TEMOA open-source modelling framework, the total system cost is calculated as follows:

$$C_{tot} = C_{loans} + C_{fixed} + C_{variable}$$

where C_{tot} is the total cost of the system, C_{loans} is the total system investment costs computed aggregating the investment costs occurring when technologies are installed, and C_{fixed} and $C_{variable}$ are the total system fixed and variable costs computed aggregating the fixed and variable annual costs of technologies. In the objective function, the total cost of the system is discounted to the initial year of the model time horizon through the social discount rate (*Global discount rate*). However, in TEMOA-Europe a modeler may also specify a *technology-specific discount rate* in addition to the *Global Discount Rate*.

Hurdle Rate Scenario (HRS)

It is plausible that during the next years, the perception of people towards electric vehicles will positively change, both in environmental terms and in safety terms, while the perception towards fossil fuel vehicles will get worse. Thanks to what affirmed in 3.3.3, this can be traduced in a lower discount rate for electric vehicles and a higher discount rate for fossil fuel vehicles. The values of discount rate for electric (ELC) cars were originally set in the database equal to 10% from 2010 until 2050, while the value of discount rate for CFVs was 15%. Figure **??** shows the new set of discount rates for electric cars and conventional fuel cars. These new values were taken from [54].

Period [year]	**Electric Vehicles***		**ICE Vehicles****	
	Old Value	New Value	Old Value	New Value
2010		0.1		0.2
2020		0.02		0.2
2025	0.1	0.02	0.15	0.3
2030		0.02		0.3
2040		0.02		0.3
2050		0.02		0.3

* [TRA_ROA_CAR_ELC_NEW]

** TRA_ROA_CAR_GSL_NEW, TRA_ROA_CAR_DST_NEW, TRA_ROA_CAR_LPG_NEW, TRA_ROA_CAR_NGA_NEW.

Figure 3.13: New and old values of discount rates for conventional fuel and electric cars.

3.4 Influence of Social Acceptability factors

Once answered to the first research question (*Is it possible to include Social Acceptability of new transport technologies in ESOMs?*) affirming that Social Acceptability can be included in ESOMs but only partially, we shall now proceed to address the second research question: *Is it possible to use ESOMs as a tool to evaluate the importance and influence of Social Acceptability factors*? To answer this question, the car sector share in the three aforementioned scenarios has been first analyzed. Starting from the BAU scenario, Figure 3.14 shows the car sector share. The illustration highlights that in the future years, starting from 2030, plug-in hybrid cars will catch on and become the most used one (just followed by hybrid cars.

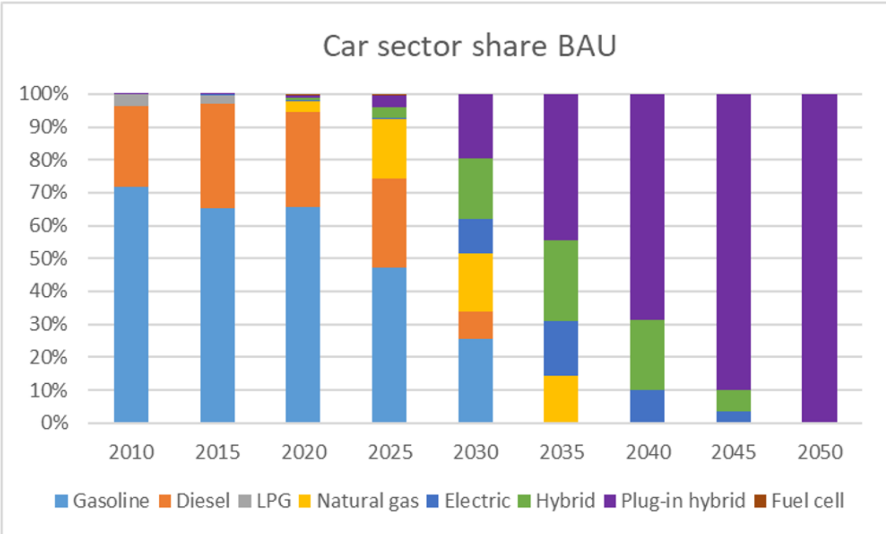

Figure 3.14: Car sector share in BAU scenario.

Figure 3.15 shows the car sector share in the ECCS scenario. Even if in this case it has been added the hypothesis of electric car cost is equal to fossil fuel car cost, plug-in cars will remain the most adopted ones in the future. The only difference from BAU scenario is that if in the former case the second type of adopted car was the hybrid one, in this case, the percentage of electric cars increases becoming the second adopted type of car just after the plug-in hybrid one.

The difficulty for the model to shift to electric cars is because electricity is a very limited commodity (considering the phase-out trend of nuclear in Europe in the next years) and crucial for other sectors (in particular industry, residential and commerce) as can be seen in Figure 3.16.

This particular outcome (the stack in plug-in hybrid vehicles and therefore the The difficulty for the model to shift to electric cars) can be straightforwardly clarified by better analyzing the upstream sector taking into account the electricity cross-sectoral competition as an energy source. Electricity is a very limited commodity (considering the phase-out trend of nuclear in Europe in the next years) and crucial for other sectors (in particular industry, residential, and commerce) as can be seen in Figure 3.16. Merely incentivizing electric vehicles is insufficient to make the system transition to EVs, given the limited total electricity production.

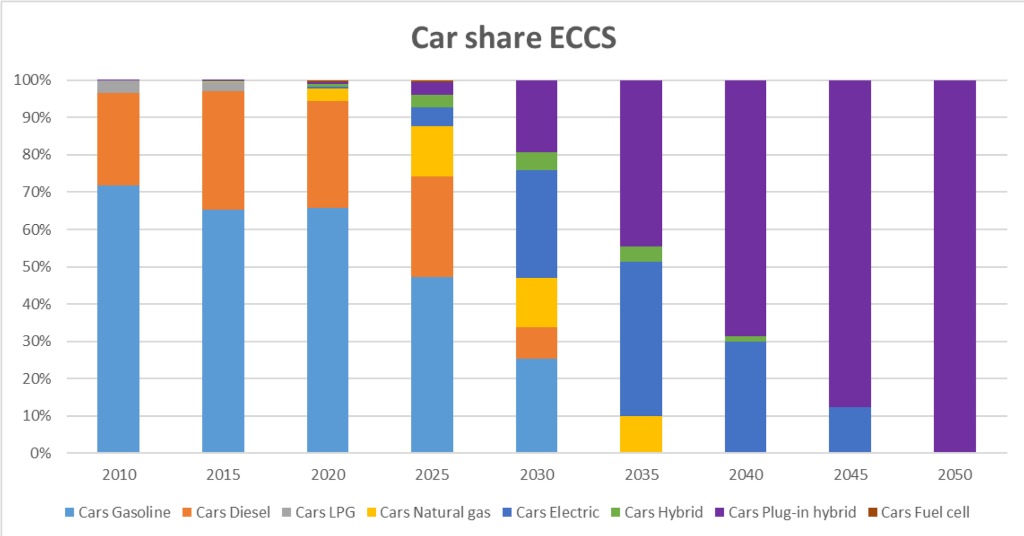

Figure 3.15: Car sector share in ECCS scenario.

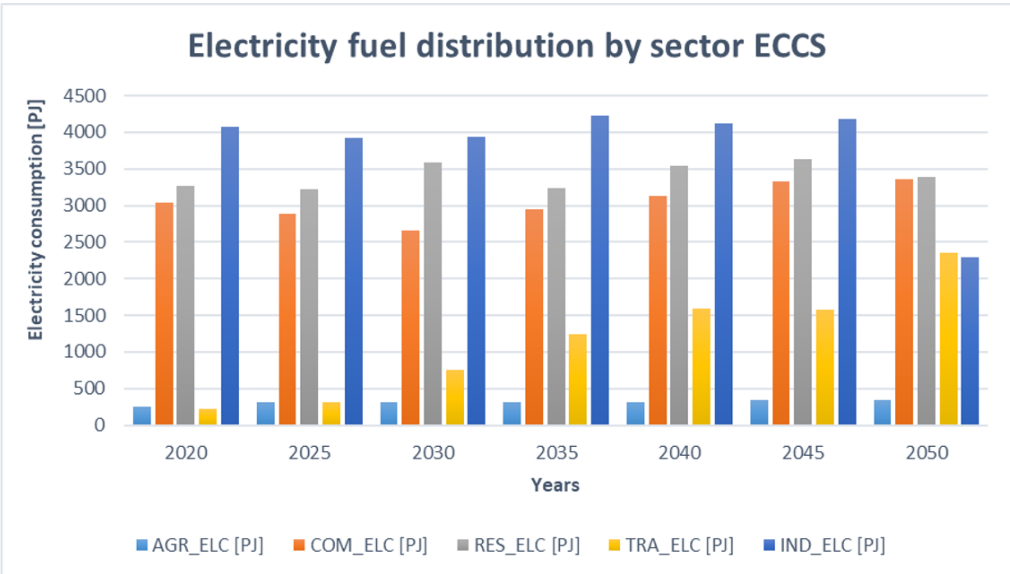

Figure 3.16: Electricity fuel distribution in ECCS scenario.

In the case of HRS scenario, results are quite different. Figure 3.17 illustrates the car sector share. In this case, it can be easily noticed how electric cars become in the future years the most adopted type of cars, followed only by plug-in hybrid cars.

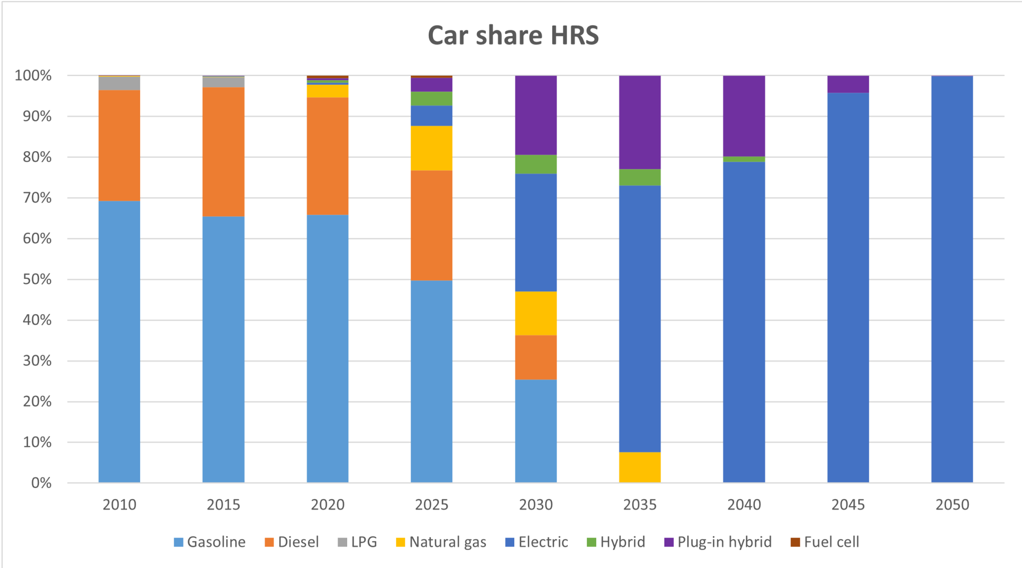

Figure 3.17: Car sector share in HRS scenario.

These results highlight that risk perception and environmental concern (traduced in TEMOA-Europe in *discount rate*) are more influential than purchase cost.

Chapter 4

The Role of Social Acceptability in the Decarbonization Path

4.1 Phase-out of Internal Combustion Engine vehicles

Over the last two decades, there has been a high surge in oil demand. A significant portion of this increase can be attributed to the growing demand in road transport. During this period, there has been a rise of 600 million vehicles in the worldwide automobile fleet [12]. The road freight activity witnessed almost a 65% increase [12]. Presently, road transport accounts for the largest part to global oil demand, constituting approximately 45% of the total. The petrochemicals industry, the second-largest consumer of oil, accounts for 15% of total oil demand [12]. The remarkable increase in electric vehicle (EV) sales is beginning to influence the demand for oil in road transportation. Sales of gasoline and diesel cars, as well as two/three-wheelers and trucks, peaked in 2017, 2018, and 2019, respectively (see Figure 4.1). If in 2020 EVs constituted 4% of total global car sales, projections indicate that they are on track to reach by 2023 the 18% of the market share, predominantly in China and advanced economies [12]. Supported by the implementation of phase-out schedules for internal combustion engine (ICE) vehicles and the introduction of incentives for electromobility, EVs will reach almost 20% of the total road vehicle kilometers by 2030 [12].

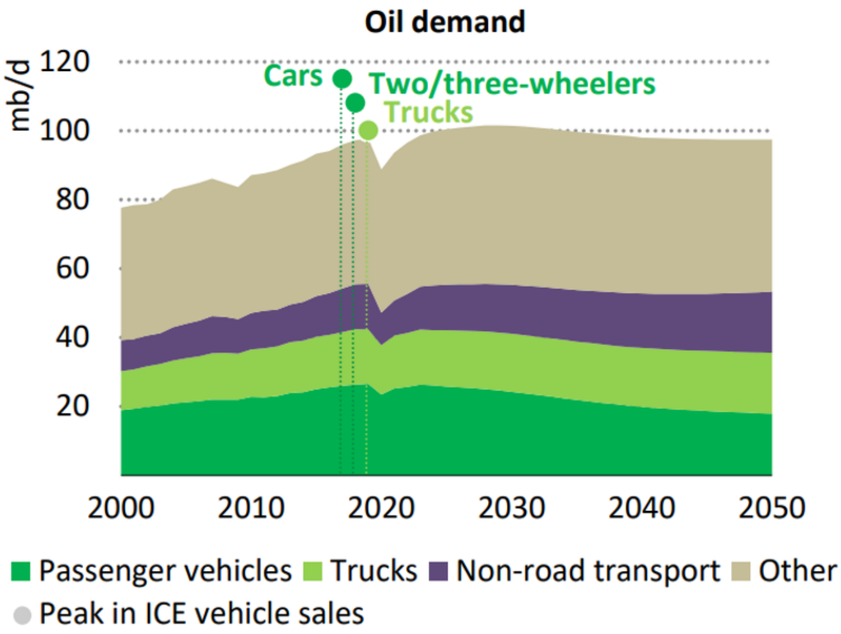

Figure 4.1: Global oil demand by type of road vehicle. Note: mb/d = million barrels per day. [12]

Figure 4.2 shows the key energy demand policies for transport by region. The process of electrification of trucks so far has been slower than the electrification of cars. This is partially because it has attracted less policy support. Approximately 30 countries have set deadlines to phase out ICE vehicles, with several other nations considering comparable actions [12] (see Figure 4.3).

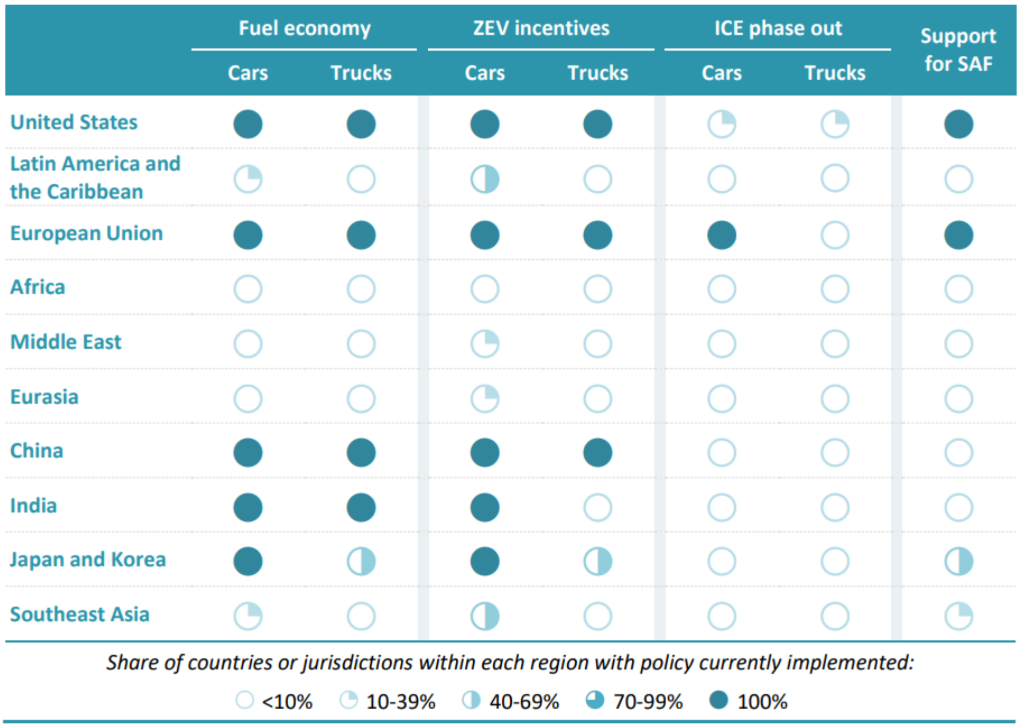

Figure 4.2: Key energy demand policies for transport by region. Note: Notes: ZEV = zero emissions vehicles including EVs and fuel cell vehicles with zero emissions at the tailpipe. ICE = internal combustion engine. E-fuels-powered vehicles = conventional vehicles which run on electro fuels. SAF = sustainable aviation fuels. In regions with only one country, unless there is a national policy in place, shares are shown for subnational jurisdictions. In the European Union, the ICE vehicle phase-out policy exempts e-fuels-powered vehicles. [12]

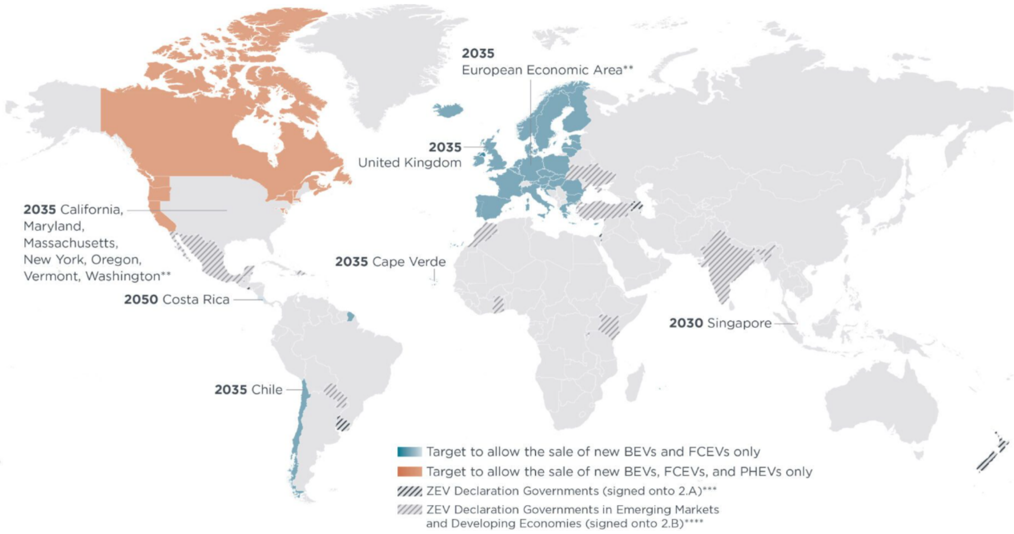

Figure 4.3: The map displays official phase-out targets set by national and sub-national governments with the aim to end the sale or registration of internal combustion engine (ICE) light-duty vehicles. Note: BEVs = Battery Elctric Vehicles, FCEVs = Fuel Cell Electric Vehicles, PHEVs = Plug-in Electric Vehicles. Zero-Emission Vehicle (ZEV) Signatories to 2.A committed to phase-in targets by 2035 for leading markets and by 2040 globally. Zero-Emission Vehicle (ZEV) Signatories to 2.B committed to work intensely toward accelerated proliferation and adoption of zero-emission vehicles. [13]

In 2022, Parliament approved the new CO2 emissions reduction targets for new passenger cars and light commercial vehicles, part of the "Fit for 55" package. The legislation effectively ban the sale of new internal combustion vehicles by 2035 [55]. This banning measure can be considered an extreme tool to reduce European Union net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and to achieve climate neutrality in 2050 [27].
In this chapter, it has been examined the role of Social Acceptability in the EU's decarbonization path, aiming to determine if there are alternatives to the aforementioned banning measure.

4.2 Decarbonization Scenario (DS)

Since the main aim of TEMOA-Europe is to provide a tool for insights into the development of European strategies in the framework of the Green Deal, the fundamental hypothesis in this scenario is achieving Net Zero Emissions (NZE) by 2050 following the *Fit for 55* targets. In the model CO2 emissions together with CH4 and N2O emissions are considered. They are aggregated based on their global warming potential (GWP) over 100 years. The model considers not only CO2 emissions but also CH4 and N2O emissions, which are aggregated based on their global warming potential (GWP) over a 100-year period, following the guidelines provided in a specific source. The CO2 emissions per unit of activity (output) for each technology is determined by the parameter *EmissionActivity* in TEMOA. The maximum yearly CO2 emission levels are constrained in the model through the values saved as *EmissionLimit*. They are sed such as to allow net-zero emissions by 2050, as already performed by IEA in the World Energy Outlook 2021 [56] at the global level.

Figure 4.4 reports the implemented emission limits and the relative reduction with respect to 1990 levels. It is important to note that the emission limit is considered for the entire energy system, and not specified according to different sectors. In this way the model can choose which sector to prioritize in the decarbonization process.

Period	Emission limit (Gt)	Reduction with respect to 1990 (%)
2030	2.25	55
2035	1.50	70
2040	0.75	85
2050	0.00	100
2060	0.00	100
2070	0.00	100
2080	0.00	100
2090	0.00	100
2100	0.00	100

Figure 4.4: Emission reduction trajectory implemented in TEMOA-Europe. [11]

4.3 ECCSplus Scenario

In this scenario, it has been decided to consider both the risk perception (and environmental concern) and the purchase cost. In this way both the investment costs and the discount rates have been modified following the values and prescriptions explained respectively in Chapter 3.3.2 and Chapter 3.3.3. It is important to note that no other constraints on emissions are set. To make the discussion clearer, Table 4.5 shows the relative hypothesis for each scenario.

Acronym	Type of Policy	EV Cost	Hurdle Rate	Net-Zero
BaU	Reference			
ECCS	Bottom-up / pull policy	✓		
HRS			✓	
ECCS+		✓	✓	
DS	Top-down / push policy			✓

Figure 4.5: Summary of the Hypothesis for each scenario.

4.4 Results

4.4.1 CO2 emissions

Figure 4.6 highlights how the GHG emissions values of ECCSplus and DS are comparable. Both scenarios reach net zero emissions by 2050. On the contrary, the ECCS scenario CO2 emissions decrease until 2040 (having the first shift to EVs between 2030 and 2040), but then they increase again since the dominant car type adopted in those years is the plug-in hybrid electric one. It is important to note that the comparison only takes into account emissions from the car sector. This is because in the ECCSplus scenario modifications were exclusively made in the car sector, making a comparison of total model emissions meaningless.

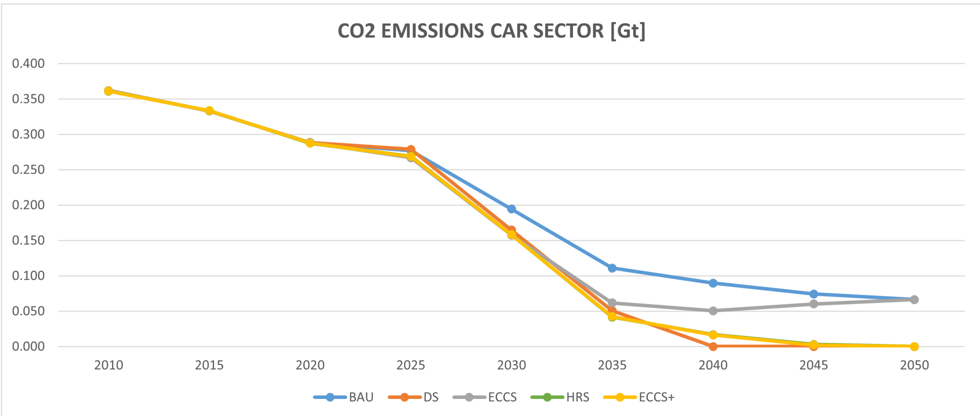

Figure 4.6: Comparison between the CO2 emissions in the car sector of all the scenarios (BAU, ECCS, HRS, ECCS+, DS.

4.4.2 Costs

Figure ?? and figure 4.7 illustrate the cost for the car sector individually and for the entire model. The DS scenario has the highest total system investment costs due to the decarbonization of the comprehensive model and therefore of all sectors. ECCS+ follows and then the BAU scenario (where there are no policies implemented). Conversely, if we consider just the car sector, the BAU scenario incurs in the highest investment costs, while the ECCSplus and DS scenarios show lower (and similar) costs. The fundamental assumption in the model (across all scenarios) concerning future excise taxes on fossil fuel usage is the main reason behind this reduction in costs in the ECCS+ and DS scenarios since taxes increase considerably operational and variable expenses. In particular, excises are set in the model according to the values published by the European Commission [57].

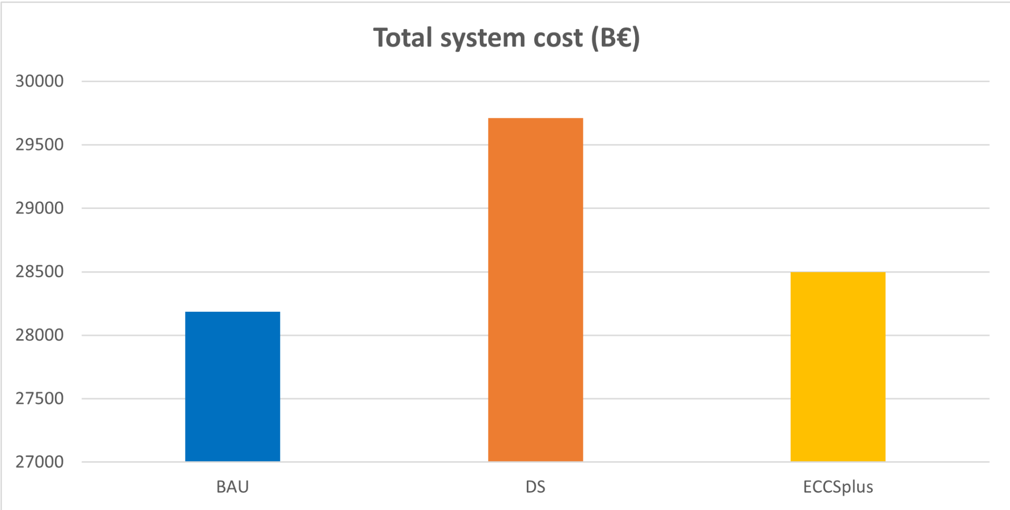

Figure 4.7: Comparison between DS, BAU, and ECCS+ total system costs.

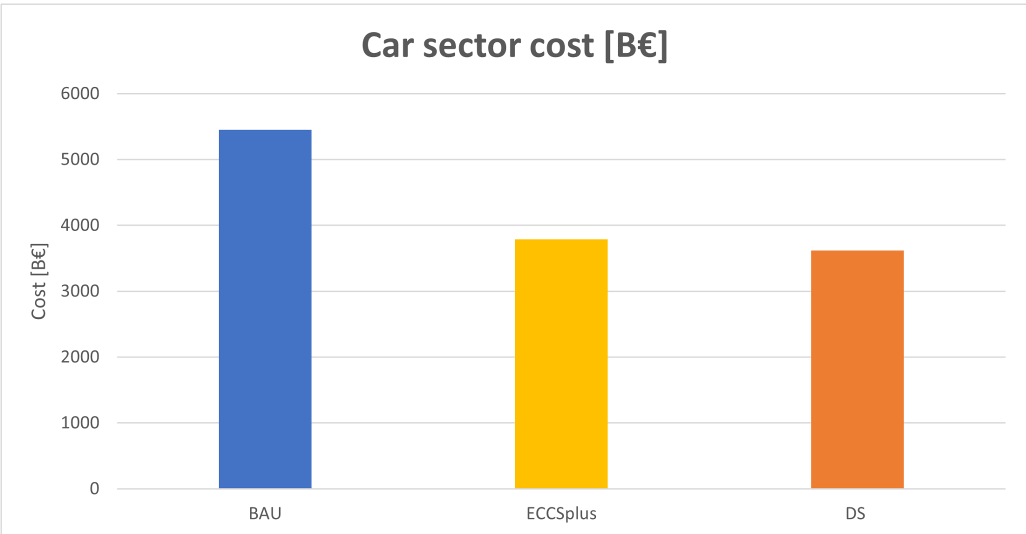

Figure 4.8: Comparison between the car sector costs in BAU, DS, and ECCSplus.

4.4.3 Push and pull measures

To answer the third research question, i.e. Can Social Acceptability have a pivotal role in the EU decarbonization path?, it is important to first have clear in mind

the distinction between push and pull measures. Push measures (i.e. penalties) tend to restrict individuals' freedom of choice, on the contrary, pull measures (i.e. rewards) generally enhance the range of available behavioral possibilities [58]. According to Steg [58], often pull measures result in being more effective in changing behavior. This is because this alteration in behavior is associated, thanks to the rewards, to positive feelings and attitudes. In this way, it is more probable that new behavior becomes a social norm. On the other hand, penalties can evoke negative feelings and attitudes and can lead to behaviors that contrast with the directive.
Following this explanation, the decarbonization scenarios (DS) can be considered a clear technology-push policy approach since it considers the assumption of zero-carbon emission technologies for transportation and the ban of ICE vehicles starting from 2035 (refer to Chapter 4.1. In contrast, subsidies or reduced investment discount rates for EVs (or other low-carbon vehicles for next research) represent a pull policy measure.

Looking at Figure 4.8, it is possible to note how the costs of ECCSplus and DS scenarios are comparable. They are also perfectly comparable in terms of emissions, too. The consequence of this is that the two policies are equivalent. The only difference is the type of measure adopted: in one case is a push measure (banning of ICE cars) and in the other case is a pull measure (incentives and subsides considering risk perception, environmental concern, and purchase costs). Knowing that pull measures are significantly preferable to push measures, the approach that considers Social Acceptability emerges as superior to the one that relies on a straightforward and similarly prone-to-failure measure such as banning ICE vehicles.

Chapter 5

Conclusions

The urgent challenge of climate change necessitates that decision-makers foresee and influence future developments across various scenarios. These scenarios should account for factors such as resource availability and pricing, technological advancements, demand expansion, as well as emerging energy and environmental strategies.

Energy System Optimization Models (ESOMs) are gaining relevance worldwide. They aim to get to the Reference Energy System optimized on a certain aspect. They are becoming more and more a reference for policymakers to make energy policies supported by solid scientific studies. They have emerged as key tools for the analysis of energy climate policies at the regional, national, and international scales.

There is a growing awareness within the scientific world about open science. It permits the unrestricted diffusion of data and results of scientific research, enhancing the spreading of knowledge without economic limitations. In the context of energy system modeling, the free dissemination of data and results, as well as the reproducibility of findings, are vital to ensuring the scientific robustness of results. In this way, external pressures on researchers is avoided, especially when evaluating potential legislative interventions, which are often subject to political evaluations. It is for this reason that the research has been made using Tools for Energy Model Optimization and Analysis (TEMOA-Europe).

Public perception is crucial for achieving national energy transitions and climate change targets and cannot be disregarded. Despite this imperative, sustainability scholars have largely overlooked the social acceptance of renewable energy technologies (RETs) and, in particular, transport sector sustainable technologies. The scarcity of information and attention to social acceptability can translate in ineffective policymaking and suboptimal strategies.

A complete Literature review process has been brought on to evaluate the existing knowledge about Social Acceptability of new transport technologies in the transport sector and a list of the main factors influencing it has been made. The outcome was a classification of all the factors in three categories: a. social- psychological factors (i.e., level of education, gender, awareness of electric vehicles, income level, environmental concern) b. technological features (i.e., driving range, charging duration, charging rate, perceived risks), c. economic and market aspects (i.e., economic benefits, purchase cost, battery cost, incentive-based policies).

Social Acceptability is not included in TEMOA-Europe yet. In this study, three criteria, coming out from the literature review process, have been traduced in economic objects insertable in TEMOA-Europe database. Risk perception and environmental concern have been traduced in hurdle rate and purchase cost in investment costs. Through the definition of two scenarios, it has been possible to understand that risk perception and environmental concern have a significantly higher influence on EVs adoption than purchase costs.

As said before, Social Acceptability has a fundamental role in achieving national energy transitions and climate change targets. This has been verified through the analysis of two additional scenarios, one characterized by NZE limits, equivalent to a ban of ICE cars, and one characterized by Social Acceptability measures (equal costs for ICE cars and EVs and lower hurdle rates for EVs and higher for ICE vehicles). Through the comparisons of these scenarios with the Business As Usual, it has been possible to understand that through the implementation of the Social Acceptability measures equivalent results in terms of costs and emissions can be reached, and these measures are preferable to the banning one since pull measures are known to be more efficient than push measures.

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