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PhD thesis

METHODOLOGY FOR AN OPTIMAL DEPLOYMENT OF THE RECHARGING INFRASTRUCTURE FOR ELECTRIC VEHICLES

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Larraitz, Mikel eta Ilargirentzat, tesi honek etorkizun hobea izaten lagun diezaien

Y para Lorea, por ocuparse del presente mientras yo miraba al futuro

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More than ten years ago, I thought I was prepared to face the challenge of doing a PhD. Thesis about business models analysis, after having spent 6 years in such field of expertise. I never imagined how hard it would be, but neither how much I would learn in the process.

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“There are no problems we cannot solve together, and very few we can solve by ourselves”

Lyndon B. Johnson

“It’s a dangerous business, Frodo, going out your door. You step onto the road, and if you don’t keep your feet, there’s no knowing where you might be swept off to”

J.R.R. Tolkien

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LIST OF ACRONYMS

AC	Alternating Current
B2B	Business to Business
BEV	Battery Electric Vehicle
BRP	Balancing Responsible Party
CBA	Cost-Benefit Analysis
CO_2	Carbon dioxide
CS	Charging Station
CSO	Charging Service Operator
DC	Direct Current
DER	Distributed Energy Resources
DSO	Distribution System Operator
EBIT	Earnings Before Interest and Taxes
EMSP	Electro-Mobility Service Provider
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GHG	Greenhouse gases
GTC	Grid Transfer Capacity
ICE	Internal Combustion Engine
ICT	Information and Communication Technology
IRR	Internal Rate of Return
JRC	Joint Research Centre
KPI	Key Performance Indicator
LCOE	Levelised Cost of Energy
MIRR	Modified Internal Rate of Return
MS	(European Union) Member State
NPV	Net Present Value
O&M	Operation and Maintenance
PHEV	Plug-in Hybrid Electric Vehicle
POI	Point of Interest
RES	Renewable Energy Sources
RFID	Radio Frequency Identification
R&D	Research and Development
TCO	Total Cost of Ownership
TOU	Time of Use
TSO	Transmission System Operator
T&D	Transmission and Distribution
UCM	Use Case Maps
UK	United Kingdom
US	United States
V2G	Vehicle to Grid
VAT	Value Added Tax
ZEV	Zero-Emission Vehicle

CHAPTER 1

INTRODUCTION

1 INTRODUCTION

1.1 BACKGROUND

Transport is one of the largest energy consumers worldwide, since it accounts for about 30 % of global primary energy use [1]. Most of the energy is used in road transport (90 %) with passenger cars taking the leading role (64 %) [2].

Transport has been dominated by the internal combustion engine (ICE) vehicles during the last 100 years [3]. These vehicles use the combustion of a fuel, typically oil products like petrol or diesel, for propulsion [4]. As a result, about 25 % of all energy-related carbon dioxide (CO_2) emissions are due to transport, three quarters of which are originated in the road sector [5]. There are more than 1.3 billion cars in the world and it is expected to have 2 billion in 2050 [2], [6]. Therefore, the CO_2 emissions per car must be dramatically reduced, in order to allow such a big increase in car population, while at the same time mitigating climate change. In this sense, the Paris Agreement established the objective to limit the increase in the global average temperature to "*well below 2 ºC above pre-industrial levels*", also trying to limit the temperature increase to 1.5 ºC [7].

On the other hand, the use of ICE vehicles results in a high energy bill, which affect the trade-balance of non-oil-producer countries. The transport system of the European Union (EU) is strongly dependent on oil (94 %), most of which is imported (87 %), leading to an expenditure of about EUR[1] 187 billion [8]. Furthermore, the fear of oil supply disruptions due to political instability in oil-producing countries resulted in price spikes which e.g. cost additional EUR 50 billion per year between 2010 and 2013 [9]. Likewise, imports of oil and its products in the United States (US) accounted for about USD 388 billion in 2008, i.e. more than half of the US trade deficit, most of which (70 %) is used in the transport sector [10]. Although recent improvements in shale oil extraction have dramatically reduced this figure (it accounted for about 10 % of the trade deficit in 2016), the US still spent almost USD 58 billion in 2016 in importing oil and its products [11].

One of the alternatives to reduce CO_2 emissions from the transport sector and to reduce import dependency and the corresponding energy cost is to electrify the transport sector, especially in urban environments, due to its advantages in terms of lack of local emissions and noise reduction [4], [10]. An electric vehicle (EV) can be defined as a vehicle which [4], [12], [13]:

1) uses at least one electric motor as part of its drive train,
2) is equipped with an electric rechargeable energy storage system, which can be recharged externally, and
3) is manufactured primarily for use on public streets, roads or highways.

EVs are more fuel efficient than ICE vehicles, they reduce oil consumption and decrease energy dependence from oil producing countries, they do not emit pollutants while driving and they have a fully CO_2-emission-free operation, as long as they are charged by using renewable energy sources (RES) [14], [15], [16], which improves air quality, especially in

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[1] All the currencies in this report are presented according to their ISO 4217 code.

cities [10], [17]. They also provide a number of benefits for the electric power system, including a better integration of intermittent RES and a more efficient and reliable operation of distribution grids, since EV charging and discharging (feeding back electricity to the grid when needed) can be controlled [18]. Additional benefits for EV users are a significant reduction in maintenance (e.g. no oil changes, no exhaust repairs and reduced brake replacement) [3], a smoother operation due to the lack of clutch, very low noise emissions [19], high torque (power is delivered to the wheels as soon as the drivers steps on the accelerator) and lower cost per driven kilometre (without considering vehicle purchase cost) [16].

On the contrary, main drawbacks of EVs are high initial cost, short driving range, lack of charging infrastructure and reduced passenger and cargo space, which increase potential users' scepticism towards electro-mobility [3], [15], [20], [21].

Until 2015, the country with the highest EV stock was the US, but China took the lead in 2016. Each of them accounts for about one third of the global EV stock, as shown in Figure 1.

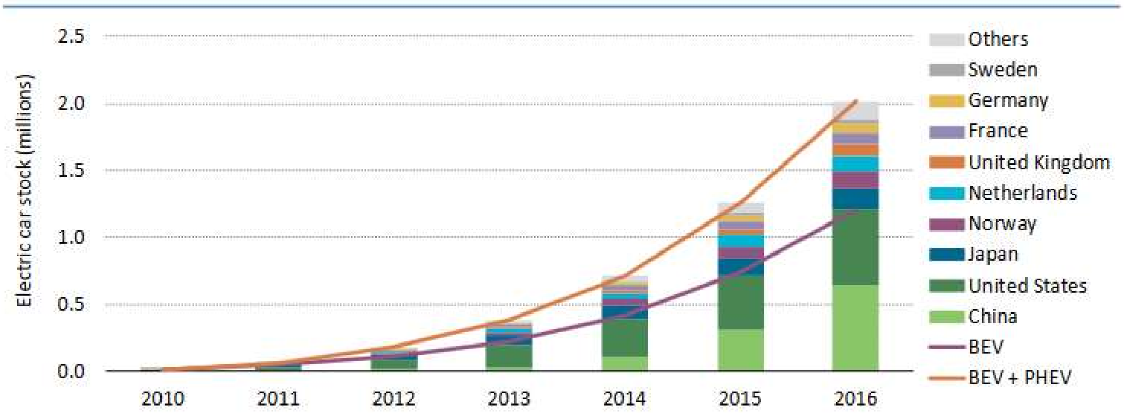

Figure 1: Evolution of the global electric car stock (2010-16) [22]

Although the EV car stock is not so big in European countries, many of them are leading the EV share in new car registrations: Norway has an impressive 29 %, the Netherlands 6.4 %, Sweden 3.4 % and both France and the United Kingdom are close to 1.5 % (the same as China). Based on the positive trend of EV adoption, EVs are expected to reach between 9 million and 20 million in 2020, and between 40 million and 70 million in 2025 [22].

1.2 AIMS OF THE THESIS

Due to the number of advantages presented above, public bodies around the world are creating a regulatory framework which favours the shift in the transport, from a system which is dominated by the use of fossil fuels to a new environment where electricity is widely used. In fact, the current EV uptake is the result of the positive policy environment at different levels, including regional (EU), country and local levels.

The regulatory framework to be set up by public bodies must ensure the success of electro-mobility, while guaranteeing a fair competition between stakeholders, and avoiding unnecessary costs to the consumers (e.g. too high/poorly designed subsidies to EVs). A good design of the regulatory framework is of paramount importance, because it will strongly affect the roles and the business strategies of existing and new stakeholders.

In addition to the difficulties of regulating any sector, electro-mobility has, at least, two additional challenges as a result of its novelty. On the one hand, there is no previous experience with EV use, so regulators can only use the experience of regulating similar sectors (including the historical evolution of regulation for ICE vehicles) and monitor closely their performance in this new environment. On the other hand, electro-mobility is evolving from an incipient status to a consolidated, mass-market situation, so the regulatory requirements will also need to evolve.

Under the existing technological and regulatory conditions, there might be some niche markets (fleets, technology geeks, environmentally conscious and/or wealthy customers, users with specific driving patterns e.g. long annual mileages but daily trips within the battery range, etc.) where electro-mobility can have a role to play. Although technological development can help solve most of the barriers for EV adoption, mass-market EV adoption requires the existence of publicly accessible charging infrastructure[2] (both for EV users who cannot charge at home and for EV users who need to sporadically increase their driving range before returning home), together with a good economic performance for EV users. Such good economic performance includes both a comparable total cost of ownership (TCO) with ICE vehicles and an affordable upfront cost.

However, the high investment required to build such a network and the uncertainty about its usage make quite difficult to build up an economically sustainable business model around it [23], [24], [25]. In addition, the development of this kind of charging infrastructure requires the coordination and the collaboration of different stakeholders, performing different roles, since electro-mobility is structured as an ecosystem of stakeholders, who must collaborate with each other so that it can survive and, hence, they can make a profit. Moreover, the roles for stakeholders are not completely defined yet, which provides different alternatives for regulatory options (see subsection 2.2.3). Additionally, and despite the standardisation efforts which reduced the number of potential solutions in the last years, there are still thousands of potential choices regarding charging alternatives (type of power supply, charging power, ownership and accessibility of the charging infrastructure, roaming possibilities, etc.), most of which require a dedicated analysis.

The literature review (detailed in section 4.3) revealed the need for an integrated approach to analyse the economic performance of the ecosystem around publicly accessible charging infrastructure:

- Some authors perform quantitative analyses, while some others only focus on qualitative approaches.

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[2] According to [12], publicly accessible charging infrastructure is the one "*which allow private users physical access with an authorisation or a subscription*". It includes privately owned infrastructure accessible to the public through registration cards or fees, car-sharing schemes which allow access for third party users by means of subscription or infrastructure in public parking areas.

- Some authors consider the whole value chain, but only few perform the analysis for the complete chain and the rest just focus on one or two actors (mainly on the operator of the charging infrastructure).
- In some cases, a public sector view is considered instead of a fully commercial perspective as required by the publicly accessible charging infrastructure.
- In general, each charging technology is analysed as a stand-alone option and private home charging is only included in few cases into the analysis for publicly accessible infrastructure.

However, none of them performs a complete quantitative analysis, which considers and analyses the whole value chain with a business perspective, and which merges all different charging alternatives into the same analysis.

This thesis presents a new methodology to optimise the decision-making process for the deployment of a publicly accessible EV charging infrastructure, while taking into account the complexity of the electro-mobility ecosystem. This way, this thesis aims at defining a methodology to enlarge the scope of the analysis (compared to existing methods) to help business developers find potentially interesting business cases.

This thesis presents three main contributions:

1. **Enlarged scope for analysing complex business cases to account for the different, interrelated dimensions of the business cases at the same time**: existing methodologies represent the relationships between business stakeholders through models, but only consider one charging alternative or business case at the same time. However, when the business ecosystem is so complex that different value propositions co-exist and interrelate with each other, as in the case of electro-mobility and the different charging alternatives (no single EV customer will always use private home charging and no single EV customer will only use fast charging), the single-business-case approach is not enough. On the one hand, the relationships between the different actors for each single charging alternative must be assessed, but, on the other, the relationships between different charging alternatives for each single actor must also be considered.
2. **Awareness of the crucial need to embed adequate representatives of the different stakeholders in the analysis to obtain data, make assumptions and validate results**: Even if the creation of an expert group from different expertise fields to select the alternatives, the data and the assumptions for the analysis cannot be regarded as a contribution to the state of the art, being able to make the participants fully understand the essence of the methodology and the added-value of such understanding is new. It is an innovative way to gather data (for future prospects) from a market where existing data are scarce (and not relevant for the mass market), but with a huge growth potential, as in the case of electro-mobility.
3. **Orientation of the analysis to provide results as break-even values for profitability**: The traditional method to approach an economic assessment is to make some assumptions, consider different data values, perform the calculations to obtain the results and carry out a sensitivity analysis to check the break-even values for the most relevant parameters. The methodology presented in this thesis goes a step beyond this approach by performing the most important part of the sensitivity analysis within the calculations themselves. For that purpose, the most critical parameters (significant impact and/or high uncertainty) for the different

stakeholders are identified and the break-even value for profitability is obtained for each of them.

1.3 STRUCTURE OF THE THESIS

This thesis is structured in 7 chapters, complemented with an additional chapter for bibliography.

The first chapter presents the background and the aims of the thesis, together with the structure of the document.

The second chapter describes EV technology and the whole electro-mobility ecosystem. The aim of this chapter is to describe the complexity of the electro-mobility ecosystem, including aspects such as the relevant stakeholders, regulatory options, charging alternatives, barriers and promotion schemes. After such description, the reader will be able to understand that such a complex ecosystem cannot be analysed through traditional business models analysis methods.

The third chapter focuses on the economic theory and introduces basic concepts, such as cash-flow, discount rate and present value, before describing different investment valuation methods, cost-benefit analysis methodologies and business models assessment approaches. The objective of this chapter is to present the different methods to perform economic analyses with a broad view, not just focusing on their applicability to the electro-mobility ecosystem. Economic analyses are performed with the aim of obtaining the required information to make a judgement or a decision and are often used in strategic planning and policy making. In general, they assess the interest of making an investment, so the investor must assess the expected costs and benefits and must take into account both the time value of money and uncertainty.

The fourth chapter links the previous two chapters and reviews the different approaches taken for analysing innovative business models related to electro-mobility. This chapter includes a literature review and a description of the main advantages and disadvantages of the different approaches. The enumeration and analysis of the different existing methods uncovers a gap in the economic analysis of business models for the deployment of publicly accessible charging infrastructure and shows the need for an integrated approach as the one described in this thesis.

The fifth chapter describes the new solution proposed in this thesis and its main contributions to the state of the art, which is the core of this work. Although the main reason for developing the methodology described in this thesis is the lack of suitable methodologies for analysing business models for the deployment of publicly accessible charging infrastructure, the described methodology can be used in many other applications.

The sixth chapter presents an example of the practical application of the proposed new solution. The target of this example is to demonstrate the applicability of the methodology described in this thesis by developing a use case linked to a potential situation in the future, where EVs become widespread and there is the need to develop a publicly accessible charging infrastructure to avoid range anxiety.

The seventh chapter describes the conclusions and novelties of the proposed new solution and identifies potential future research topics related to the work described in this thesis.

This document is complemented by the most relevant bibliography in relation to the research developed in this thesis.

CHAPTER 2

ELECTRIC VEHICLES AND ELECTRO-MOBILITY ECOSYSTEM

2.1 - ELECTRIC VEHICLE TECHNOLOGY
2.2 - ELECTRO-MOBILITY ECOSYSTEM
2.3 - CONCLUSIONS

2 ELECTRIC VEHICLES AND ELECTRO-MOBILITY ECOSYSTEM

2.1 ELECTRIC VEHICLE TECHNOLOGY

As defined in section 1.1, an EV uses (at least) one electric motor as part of its drive train, is equipped with an electric (externally) rechargeable energy storage system and is manufactured primarily for use on public streets, roads or highways. Different types of vehicles fall within this definition of EV [2]:

- Battery electric vehicle (BEV): It is an autonomous road vehicle exclusively with an electric powertrain drive and without any on-board electric generation capability. It needs to be charged by plugging into an electric socket.
- Hybrid electric vehicle: It is a vehicle with at least two different energy converters and two different on-board energy storage systems for the purpose of vehicle propulsion, as long as at least one of the energy stores, sources or converters delivers electricity. It usually uses an ICE and an electric motor either in series or in parallel. If the hybrid electric vehicle can be plugged to charge the battery from the main grid, it is called a plug-in hybrid vehicle (PHEV). Typically, the ICE is the primary source of energy and the battery, which provides a much shorter range than in BEVs (e.g. about 50 km), is charged through regenerative braking. The exception to this configuration is the range-extended electric vehicle, which is equipped with a plug-in (bigger) battery and whose ICE is used as a generator to recharge the battery when it is depleted.
- Fuel cell electric vehicle: It is a vehicle with an electric powertrain which obtains electricity from a fuel cell. It needs to have an on-board hydrogen storage, which can be complemented by an electric storage or not.

Since this thesis focuses on EV charging infrastructure, BEV is the most relevant type of EV, although PHEVs also fall within its scope.

Regarding the nomenclature for the EV charging infrastructure, there is a decoupling in terms between technical language in standards and the colloquial language: according to IEC 61851-1 [26] and ISO / IEC 15118-1 [13] standards, the electric vehicle supply equipment (EVSE) is composed of conductors, including the phase(s), neutral and protective earth conductors, the vehicle connector and inlet, attachment plugs, and all other accessories, devices, power outlets or apparatuses, installed specifically for the purpose of delivering energy from the premises wiring to the EV and allowing communication between them (if required). On the contrary, the term Charging Station (CS) is commonly used instead of EVSE in colloquial language. However, these two terms are describing two different technological units: a CS is a physical grouping of one or more EVSEs, which share a common enclosure and, usually, other components, such as EV user identification interface and communication interface towards the Charging Service Operator (CSO) [27]. In other words, the EVSE can be seen as the outlet and all its internal wiring, whereas the CS is the whole charging, identification and communication structure.

There are three main ways to have the battery of an EV charged:

- Conductive charging: The EV is connected to the alternating current (AC) supply network through a cable. Therefore, there is a physical connection between the battery and the mains. This is the most widely used solution, due to its simplicity (similar to any other electric device charging), efficiency (compared to inductive charging) and low cost. However, it is the least convenient one from the EV user point of view, because the EV must be parked, the user needs to plug-in the cable into the CS and/or the EV and, depending on the charging power, it may take a long time to fully charge the battery.
- Inductive charging: The EV is charged by using magnetic coupling devices instead of standard plugs in charging stations [28]. An electromagnetic field is established between the CS and the EV, so that energy can be sent through inductive coupling. An induction coil creates alternating electromagnetic field in the CS and another induction coil in the EV takes power from that electromagnetic field, in order to convert it into electric power to charge the battery [29]. This charging method is more convenient for the EV user, since it does not need to use cables to charge the EV, which can even be charged while driving. On the contrary, induction coils need to be very close for the charging to occur, since efficiency decreases as the distance between the EV and the CS increases. Moreover, inductive charging is more complex and expensive than conductive charging and, although research and technological development can mitigate its disadvantages, it is not likely to happen in the near future.
- Battery swap: The battery of the EV is replaced by another, fully-charged battery, usually in an automatic manner. The main advantage of this method is that the EV user obtains a fully-charged battery within minutes, so the user experience is very close to filling a petrol tank. On the contrary, it requires that EV manufacturers and battery swapping station owners collaborate to standardise the dimensions and location of the batteries, so that they can be easily removed and replaced. Furthermore, the battery is usually the most expensive component of the EV [29], [30], so having spare batteries can be a very expensive business for battery swap station operators under low usage conditions, as demonstrated by the bankruptcy of the pioneer in battery-swapping stations Betterplace [31] or the abandonment by Tesla Motors of this type of charging [32].

Therefore, this thesis focuses on conductive charging. Different standards apply for conductive charging in the US [33] and in Europe [26], which define different levels for EV charging. In the European standard, there are four types of charging modes [26]:

- Mode 1: connection of the EV to the AC supply network using standardised socket-outlets[3], rated up to 16 A[4], at the supply side, single-phase or three-phase, and using phase(s), neutral and protective earth conductors. The use of Mode 1 charging depends on the presence of a residual current device on the supply side. Where the presence of a residual current device on the supply side cannot be ensured by national codes, Mode 1 charging is not permissible. Voltage on the supply side

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[3] These standards refer to IEC and/or national standards. For example, in Europe, EN 60309 (industrial) [34], [35] and IEC TR 60083 (domestic) [36] standards apply.

[4] This 16 A-limitation for Mode 1 charging does not apply in France, Germany and Italy.

cannot exceed 250 V in single-phase circuits or 480 V in three-phase circuits (typically, 3.7 kW – 11 kW). There is no extra control pin in the connector. Due to the lack of guarantee of protection on the infrastructure side and the limited capacity of standard plugs to provide high power for long periods, this charging mode has certain limitations. For example, it requires a connector and cord built and listed specifically for the EV (including a ground fault circuit interrupter integrated into the cord set) in the US [37] and it is limited to small sized EVs (bicycles and motorbikes) in Europe.

- Mode 2: connection of the EV to the AC supply network using standardised socket-outlets, single-phase or three-phase, and using phase(s), neutral and protective earth conductors, together with a control pilot conductor between the EV and the plug or in-cable control box. Same voltage limitations as in Mode 1 apply, but charging power can be higher and reach 22 kW. The connector on the EV side has a control pin, but not on the supply side.
- Mode 3: direct connection of the EV to the AC supply network using dedicated EVSE, where the control pilot conductor extends to equipment permanently connected to the AC supply network. In single-phase charging, current cannot exceed 70 A and voltage cannot exceed 250 V (typically, 16 kW), while three-phase charging allows up to 63 A and 480 V (typically, 50 kW). The EVSE includes all the required protection systems and implements the control pilot functionality. There are control pins on both sides of the connector.
- Mode 4: indirect connection of the EV to the AC supply network using an off-board direct current (DC) charger, where the control pilot conductor extends to equipment permanently connected to the AC supply. Maximum current is 400 A and voltage can reach 1000 V (400 kW), on the supply side. The DC charger, which performs the AC/DC conversion, includes all the required protection systems and implements the control pilot functionality.

Although different types of connectors have been used for EV charging, standardisation efforts are progressively improving the interoperability of systems, which result in easier interchangeability of components and lower costs. For example, [38] defines different types of plugs for AC charging: Type 1 (“Yazaki”) which is commonly used in North America, Type 2 (“Mennekes”) which is mainly used in Europe, and Type 3 (“Scame”) which is progressively losing relevance in favour of Type 2. The most common standards for DC charging are “Combo 2” [39] and CHAdeMO [40]. In Europe, the CSs to charge at power above 3.7 kW must be equipped, at least, with Type 2 connectors [41] for AC charging and “Combo 2” for DC charging [12].

The connection cable may be attached to the EV, to the CS or to none of them, depending on the connection case [26]:

- Case “A”: connection of an EV to the AC supply network, by using a supply cable and plug permanently attached to the EV (the cable is attached to the EV and can be plugged in into the CS).
- Case “B”: connection of an EV to the AC supply network, by using a detachable cable assembly with a vehicle connector and AC supply equipment (the cable can be plugged into both the EV and the CS).
- Case “C”: connection of an EV to the AC supply network, by using a supply cable and a vehicle connector permanently attached to the supply equipment (the cable is

attached to the EVSE and can be plugged into the EV). This is the only case allowed for Mode 4 charging.

Additionally, there are a number of other standards to define the technical requirements for the CS, connector types, electrical installations, etc. (such as IEC 61851, IEC 60364-7-722 or IEC 60884-1 standards), but those concepts fall out of the scope of this thesis. More information about interoperability in electro-mobility can be found in [27].

2.2 ELECTRO-MOBILITY ECOSYSTEM

2.2.1 Business ecosystems

A business ecosystem is "*an economic community supported by a foundation of interacting organizations and individuals – the organism of the business world. The economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors and other stakeholders. Over time, they coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies. Those companies holding leadership roles may change over time, but the function of ecosystem leader is valued by the community because it enables members to move toward shared visions to align their investments, and to find mutually supportive roles*" [42]. The term refers to "*communities of economic actors whose individual business activities share in some large measure the fate of the whole community*" [43].

In other words, a business ecosystem is a community of actors who must collaborate with each other so that all of them benefit: end users obtain valuable goods or services at prices they are willing to pay and business actors can create profitable business models. All the actors in the ecosystem are directly or indirectly connected, which has two important results. On the one hand, all of them must contribute to the success of the ecosystem, regardless of their size, strength or role in the ecosystem. This means that they must establish relationships with customers, suppliers and even competitors. On the other hand, business ecosystems result in a dense network of relationships, so they cannot be analysed from the point of view of individual companies, but a holistic view is required.

Electro-mobility matches with this definition of ecosystem, as it is a complex network of stakeholders, which interrelate with each other in order to create the conditions for the success of the change of paradigm in the transport sector, so that they can obtain a positive business case[5]. Although some studies [44] consider a completely selfish behaviour of individual stakeholders, they recognise that such approach "*cannot yield a social optimal*

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[5] This thesis takes this definition of ecosystem into account, in opposition to the statement in [2]: "*An EV ecosystem defines the total infrastructure system required to support the operation of EVs. This system includes interfaces with "hard infrastructure," such as recharging technologies, energy grids, buildings, and transport systems. It also requires the provision of "soft infrastructure," such as regulation, information and communication technologies, commercial services, skills, and community engagement programs."*

solution". For the purpose of this thesis, it is assumed that stakeholders collaborate, at least until the required change in paradigm occurs.

2.2.2 Stakeholders and roles

Stakeholders in the electro-mobility ecosystem may be new entrants, who want to create a new business, or established companies, either of regulated nature or playing in competitive environments. Depending on the regulatory option (see section 2.2.3) and their business strategy, they may perform different roles or they may combine some of them. In order to differentiate between stakeholders and roles, the definitions in [45] will be used:

- A **party** is a legal entity, i.e. either a natural person (people) or a legal person (organisation). Parties can bundle different roles into a single business model.
- **Responsibilities** define external behaviour to be performed by parties.
- A **role** represents the intended responsibility of a party. Parties carry out their activities by assuming roles, which cannot be shared among more than one party. Roles describe external business interactions with other parties in relation to the goal of a given business transaction.
- An **actor** represents a party that participates in a business transaction. For that purpose, the actor performs tasks in a specific role or a set of roles within the business transaction.

Therefore, the actor, on behalf of a party, performs one or several roles in a business transaction. As a result, stakeholders can be defined as parties, their employees or automatic control systems as actors, and the activities they perform as roles.

The most important roles in the electro-mobility ecosystem are described below:

- EV user: They use an electric vehicle to satisfy their mobility needs. They may also perform the role of EV customers and/or EV owners (see below). For example, in the case of a parcel delivery company which uses rented EV, the EV users would be the drivers (employees), the EV customer would be the delivery company (employer) and the EV owner would be the renting company.
- EV customer: They consume electro-mobility services, including electricity and charging services [46].
- EV owner: They buy and own the EV.
- Electro-mobility service provider (EMSP)[6]: It sells electro-mobility services to EV customers [46], so that it is the entity with which the EV customer has a contract for all services related to EV operation [13]. Although the main service provided by the EMSP is EV charging, it may also offer some other services, such as CS search & find, routing, parking, CS reservation, roaming… The EMSP is owner of the data of the EV customers in its portfolio.

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[6] It is also called e-mobility service provider [46], e-mobility operator [13], electric vehicle service provider or EVSP.

- CSO[7]: It has the role of operating the physical equipment to complete the charging process of the EV. Moreover, it is responsible for the management of the charging session, as well as for monitoring, maintaining and controlling a certain CS. The CSO offers charging services (access to charging infrastructure, including energy) to the EMSP, based on a business-to-business (B2B) relationship, either directly or through an agreement with a third party. It is the owner of all the data related to the CS. It may also perform the role of CS owner (see below) or not, e.g. a municipality may own a number of CSs but it outsources their operation to another party (which acts as the CSO).
- CS owner: It owns the CS.
- Electricity customer: It is a natural or legal person purchasing electricity for the purpose of resale inside or outside the system where it is established (wholesale customer) or for its own use (final customer) [47].
- Distribution system operator (DSO): It is the operator of the high voltage, medium voltage and low voltage distribution networks required to deliver power to electricity customers, but it does not sell electricity. It is responsible for connecting all loads to the electric system and maintaining a stable, safe and reliable network for the supply of electricity to all customers [46]. In particular, it is "*responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity*" [47]. It is a fully regulated monopoly which only provides network services and which is legally unbundled from generation, transmission and, particularly, from supply and retail, so it cannot trade energy [14].
- Electricity supplier[8]: It is responsible for selling electricity to final customers. For that purpose, suppliers and final customers have power contracts with fixed locations for the supply [46]. Electricity supply is a non-monopolistic activity, performed in a competitive manner.
- Metering operator: It is responsible for installing, maintaining and certifying physical meters (meter operator) and for meter reading and quality control of the reading (metered data collector) [48] to allow electricity customers to purchase electricity. In most countries, this role is played by the DSO [46].
- Marketplace operator: The marketplace operator represents all administration activities performed by the marketplace. The marketplace is a virtual B2B environment for services related to electro-mobility, which is accessible through the internet and hosted in a cloud environment. Participants in the marketplace operate an electro-mobility business and, hence, EV customers do not have direct access to the marketplace, even if they use services from participants who offer and access services on the marketplace. All business partners may offer their services in the marketplace, which can then be bought by any other business partner. In addition, the marketplace offers clearing services to business participants, including contract clearing (EV user authentication and authorisation), collecting transaction data,

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[7] It is also called charging station operator [46], EVSE operator [13] EVSEO or EV charging point manager [14].

[8] It is also called electricity retailer, electricity supply retailer [46], supplier or retailer.

financial clearing of the transaction (CSOs forward the charge detail record so that the corresponding EMSP pays for the charging session), monitoring and reporting, or storage of CS and EV customer data (including the possibility to register, update and delete new contracts or CSs). Therefore, it includes the functionalities of a data clearing processor [46], or an electro-mobility operator clearing house [13].

Figure 2 below presents the different roles, their physical connections and their contractual connections (in dashed lines).

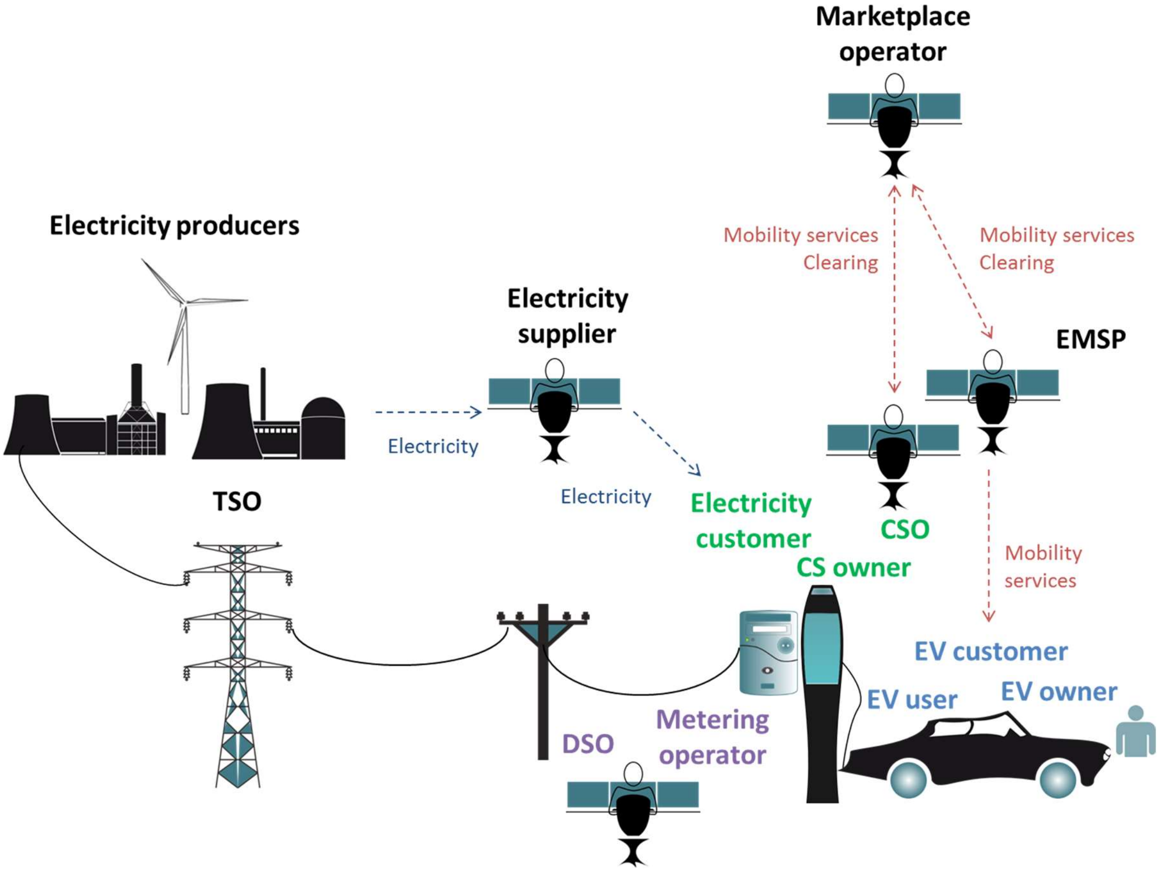

Figure 2: Roles in the electro-mobility ecosystem

Within the context of this thesis, it is assumed that EV users are also EV customers and EV owners and, thus, the three terms will be used interchangeably (and the three roles are highlighted in blue in Figure 2). Likewise, the CSO is the CS owner. Even if CSOs (and, depending on the regulatory options described in section 2.2.3, EMSPs) do not strictly buy electricity for their own use, but to provide charging services to EV customers, they are considered to be final electricity customers (highlighted in green in Figure 2).

2.2.3 Regulatory options

A regulatory option describes the minimal set of requirements and agreements between all relevant stakeholders in the electro-mobility ecosystem, which are needed to deliver a well-functioning market for them to compete on a level playing field, and which creates the conditions for a massive adoption of electro-mobility [46]. Hence, the regulatory option describes the roles, responsibilities and relationships between the agents of the electro-mobility ecosystem and, more specifically, the regulatory principles governing the ownership and operation of CSs. Therefore, “market model”, i.e. the set of rules by which a market (e.g. the market for ancillary services or the day-ahead market) functions, should not be used to describe a regulatory option [14] (as in [46]). There are three main regulatory options[9]:

1. **The DSO owns and operates the CS**. In this case, the DSO installs and operates the CS network, which becomes part of the distribution grid. This way, the access to CSs is open to any EV user (regardless of their EMSP) and the costs of the CS network are paid both by the EMSPs through regulated access fees and by all electricity consumers e.g. included in the transmission and distribution (T&D) fees.
2. **CS is operated by an independent entity.** Under this regulatory option, the DSO keeps managing the distribution grid and the EMSP is only responsible for providing electro-mobility services (including charging) to EV users, while the installation and operation of CSs is responsibility of the CSO, which is independent from any other role described in section 2.2.2. Therefore, the CSO decides which EMSPs’ customers may have access to the CSs. The CSO has an electricity grid access contract with the DSO and may have or not an electricity supply contract with an electricity supplier.
3. **The EMSP owns and operates the CS**. The EMSP is responsible for providing electro-mobility services (including charging) to EV users, but also for installing and maintaining the CSs. It behaves like any other final electricity customer for the DSO and for electricity suppliers. EMSPs install their own private networks of CSs to charge the EVs of their own EV users and may give access to other EV users or not. The costs of the CS network are paid by EV users.

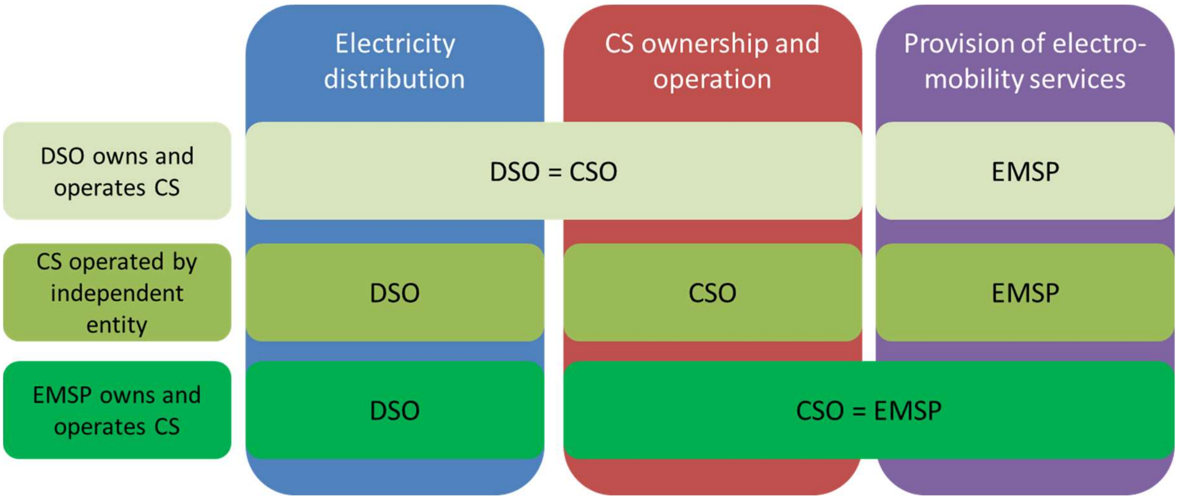

Figure 3: Regulatory options for deploying EV charging infrastructure

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[9] The regulatory options presented here are the “integrated infrastructure”, the “separated infrastructure” and the “independent e-mobility” models defined as market models in [46], respectively. The “spot operator owned charging station” model is not presented here, because the CSO does not own the CSs, which is against the considerations in section 2.2.2.

All these options, even with more specific limitations, are in place at the moment. For example, the DSO is the owner and operator and the CSs and EV users select the EMSP they have the contract with at the time of charging their EV (option 1) in Ireland. In Portugal, the CSO is an independent entity (option 2), but it has a monopoly in the country (similar to option 1), so the cost of the CS network is paid by EV users, but through regulated access fees. In Spain, each CS must be linked to an EMSP (option 3), but the EMSP does not need to own them. In Germany, CSs are installed by both EMSPs (option 3) and independent actors (option 2) [46].

Regardless of the regulatory option to be considered, when an EV user, having a contract with an EMSP for charging services, is able to charge at a CS not operated by that EMSP, a B2B roaming agreement between the EMSP and the CSO must exist [46], or each of them may have a B2B roaming agreement with a central clearing actor, such as the marketplace operator. Therefore, roaming is required in options 1 and 2, and even 3, if the EMSP allows that other EMSPs' customers charge in their CSs. There are two main roaming alternatives[10]:

- The charging service includes electricity: the electricity supplier is selected by the CSO and sells a bundled service to the EMSP. The CSO has both the grid access contract with the DSO and the electricity supply contract with an electricity supplier. This is the common approach in options 2 and 3.
- The charging service does not include electricity: the electricity supplier is selected by the EMSP and the CSO only has the grid access contract with the DSO. This alternative is more common in option 1, in order to ensure that the DSO does not distort competition between EMSPs.

In order to adopt the most generic case, the unbundled regulatory option is considered, so that all actors are independent from each other, i.e. the case where the DSO, the electricity retailer, the EMSP and the CSO are different legal entities. This generic case is selected because it is easier to make the analysis for the completely unbundled market model and, then, assess any other market model by adding the results of the required roles (also taking into account cost synergies) than analysing any other market model and trying to estimate the results components for the different roles performed by a single actor.

Under this regulatory option, the different actors have contracts (either bilateral or with a central clearing actor) to allow EV customers to buy electro-mobility services from an EMSP, including the possibility to charge at the CSs of a CSO. Therefore, roaming is required. It is assumed that the charging service includes electricity.

2.2.4 Charging alternatives

The sections above have already presented a number of alternatives for performing the EV charging process, including the type of vehicle, the type of charging, the charging mode (which is linked to the charging power and information flow) or the regulatory option (which affects roaming). Another important characteristic of the charging process is the location of the CS, which, in general, has four possibilities:

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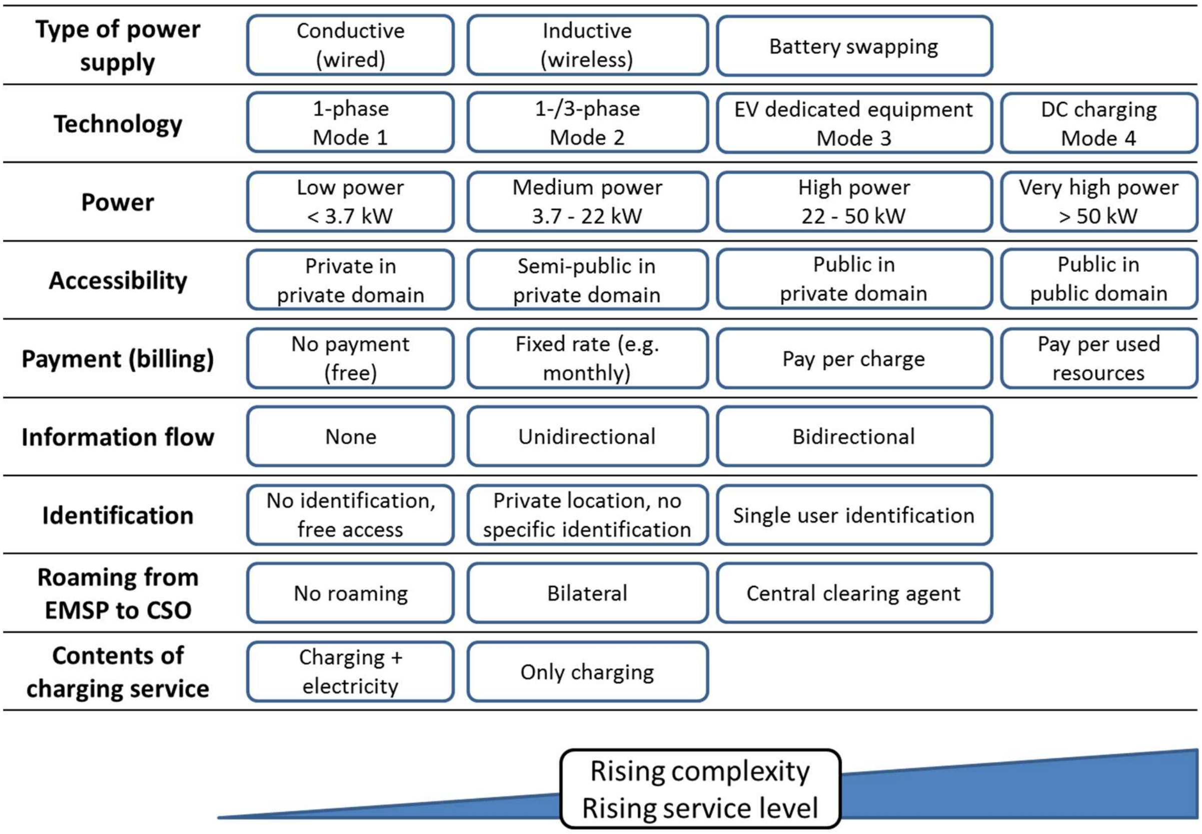
[10] These options are called "Roaming of charging service" and "Roaming of electricity and service", respectively, in [46].

- Private access in private domain: only the owner of the property where the CS is located can charge the EV. The typical case is the private home charging.
- Semi-public access in private domain: the access to the property where the CS is located is restricted. Typical examples are workplaces for charging employees' private EVs or for charging fleets of EVs (parcel delivery, etc.).
- Public access in private domain: any EV user can access the CS, although it is located in private property. Examples include malls, airports, parking lots, restaurants…
- Public access in public domain: any user can access the CS, which is located in public property, e.g. charging the EV while it is parked on the curbside.

The type of access also influences the way for EV identification. On the one hand, both private access and semi-public access in private domain may restrict the access to the property and, hence, EV users may not need to identify themselves afterwards (they can only physically access the CS after they have previously identified themselves). On the other hand, publicly accessible CSs, either in private or public domain, may provide free access (no restriction to have physical access to the CS) and, thus, they may not require identification. This lack of identification requirement does not mean that charging is for free, since a direct payment system may exist, which avoids the need for previous EV user identification.

The different alternatives described so far can be presented by the morphological box method [49]. The idea of this method is to approach complex problems, by identifying all the parameters which might enter into its solution, and constructing different solutions by using different configurations. Figure 4 builds upon earlier applications of the morphological box to electro-mobility [15], [23], [50], but considering only the relevant options for this thesis.



Type of power supply	Conductive (wired)	Inductive (wireless)	Battery swapping	
Technology	1-phase Mode 1	1-/3-phase Mode 2	EV dedicated equipment Mode 3	DC charging Mode 4
Power	Low power < 3.7 kW	Medium power 3.7 - 22 kW	High power 22 - 50 kW	Very high power > 50 kW
Accessibility	Private in private domain	Semi-public in private domain	Public in private domain	Public in public domain
Payment (billing)	No payment (free)	Fixed rate (e.g. monthly)	Pay per charge	Pay per used resources
Information flow	None	Unidirectional	Bidirectional	
Identification	No identification, free access	Private location, no specific identification	Single user identification	
Roaming from EMSP to CSO	No roaming	Bilateral	Central clearing agent	
Contents of charging service	Charging + electricity	Only charging		

Figure 4: Morphological box for the different charging alternatives for EVs

2.2.5 EV integration in electricity grids

An important aspect to be considered when analysing the potential advantages of EVs for the society as a whole is the impact that a mass roll-out of EVs can have in existing power systems.

The impact of EVs in power systems strongly depends on the changes in the load curve, on the flexibility of the power system and the ability to modify the charging behaviour of EVs. The changes in the load curve will stem from EV users' charging behaviour (location, frequency, energy charged per event, time of charging, etc.). An example of the variability of start time and energy consumption per charging event for different locations is presented in Figure 5.

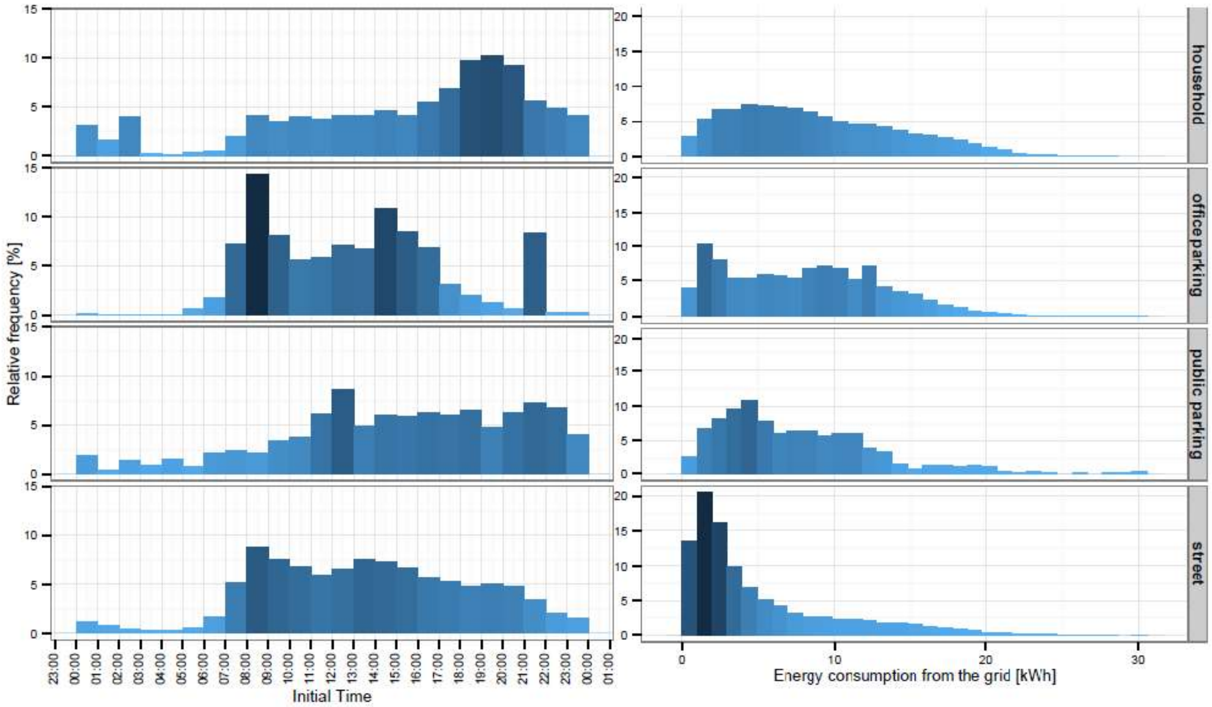


Figure 5: Start time and energy consumption in different locations [51]

If EV users do not have any incentive or obligation to accommodate the conditions for charging their EVs to the requirements of the power system, they will simply charge their EVs when they have a CS available. Depending on the driving behaviour of EV users and on the number of EVs in the system, this uncontrolled charging is likely to result in high electricity demand increases at certain times of the day. Since home charging is expected to be the first alternative [14], the uncontrolled EV charging is expected to increase the electricity demand almost at the same time as the evening peak of the system (as shown in Figure 5).

Therefore, an uncontrolled EV charging will result in an increase in line losses and CO_2 emissions (as less efficient power plants are required to satisfy the new demand), higher energy prices and power quality issues, especially in distribution grids.

However, the power system can also benefit from EVs if an appropriate charging strategy is selected, i.e. if EV charging behaviour can be modified. The increasing penetration of DER and RES creates a number of challenges for the management of transmission and distribution networks, but EVs can become an important tool to tackle them.

There are different potential control strategies for EV charging, with different aims and characteristics. The most important characteristics of the control strategies are [18]:

- Direction of the energy flow: the most common way of controlling EV charging is by controlling the power supply from the grid to the EV, which is also known as unidirectional flow. However, if equipped with the appropriate control equipment (charger, meter and control system), EVs can also return electricity from the battery to the grid if needed, which is known as vehicle-to-grid (V2G) or bi-directional flow.
- Control capacity for grid operators: depending on the services to be procured from EVs, the number of potential service providers and the criticality of the services for grid operators, the control over the charging process may be performed by the grid operators themselves (direct control) or by service providers, i.e. either the EMSP or EV customers themselves (indirect control). In direct control strategies, grid operators manage the charging equipment so that the charging process follows the energy profile they desire, while in indirect control strategies, EV customers are offered variable prices and they decide themselves (or outsource such decision to the EMSP) whether to react to those signals or not. Typical examples of indirect control strategies include:
    - Time of Use (TOU) tariffs: instead of having a single price for electricity for all the hours within the year, certain periods are defined in advance (e.g. two periods per day for the whole year, three periods per day but with seasonal differences…) and different prices apply to each of them.
    - Hourly pricing: electricity prices vary every hour and they are known in advance (e.g. the day before).
    - Real-time pricing: electricity prices vary every hour, but their amount is unknown until very close to the consumption time (e.g. 1 hour or 15 minutes in advance).
    - Critical peak pricing: in combination with any one of the alternatives above, there may be certain times in a year (e.g. twenty hours per year, three hours per month…) in which electricity prices are very high to reflect shortage conditions in the power system. The maximum number of times within the year may be fixed, as well as the maximum allowable price, but the application of the prices may only be known very close to real-time.

The different charging strategies can be used to obtain different services from EVs. A non-exhaustive list of potential services that EVs can provide to power system can be found below [52]:

- Ancillary services for electricity networks:
    - Frequency regulation: The transmission system operator (TSO) is responsible for keeping the power system frequency within the established limits. For that purpose, it uses three main types of frequency regulation services:
        - Primary regulation: immediate and automatic response (few seconds) by using built-in frequency-sensitive protection devices.

        - Secondary regulation: fast activation (within 30 seconds to 2 minutes) to be maintained during some minutes (e.g. 15). The charging process of the EV is controlled to follow the required charging/discharging profile.
        - Tertiary regulation: response within some minutes (up to 15) to be maintained during few hours (typically, at least 2 hours). The charging process of the EV is controlled to follow the required charging/discharging profile.
    - Load balancing and deviation management: The Balancing Responsible Party (BRP) must keep the scheduled programme (as a result of the energy traded in different markets, such as day-ahead, intraday…) for its whole portfolio of generation and/or consumption units. If the scheduled programme is not met in real-time operation, the BRP will be creating imbalances in the system and the TSO will charge the BRP for them. The charging process of EVs can be controlled to compensate variations in the expected production or consumption within the portfolio of a BRP, either in medium-term (by modifying the expected EV charging profile e.g. some hours ahead) or in real-time.
    - Voltage regulation: Both the TSO and DSO must keep the voltage in their networks within defined limits. In transmission networks, voltage is mostly affected by reactive power injection and consumption, but active power takes a more important role in voltage regulation as the voltage in the network decreases. Since EVs are expected to be connected mostly to low-voltage feeders, controlling the EV charging process can help DSOs to solve voltage issues within distribution networks.
    - Intertrips: automatic disconnection of EVs when a specific event occurs in the grid.
- Services for improving power system sustainability:
    - Deferral of grid extension: the extension of the grid may be deferred (or even avoided) by managing the EV charging process to reduce system peaks or by flattening the load profile.
    - RES integration: the fluctuating nature of RES and other distributed energy resources (DER) may require the curtailment of production during off-peak periods to avoid operational risks within electricity networks. By controlling the charging process of EVs, RES curtailment can be minimised, while V2G capabilities can support the grid in case of a sudden loss of RES generation.
- Services to improve power quality: These services are mainly related to features achieved during the design stage of devices and systems. They include:
    - Phase balancing
    - Harmonic and flicker reduction
    - Voltage dip compensation

2.2.6 Barriers to widespread electro-mobility adoption

Psychology research shows that customer preferences are driven by their own experience [53]. As a result, potential EV users tend to use their experience with ICE vehicles as a reference when defining their expectations about EVs. Therefore, the barriers for EV adoption stem from the aspects in which the performance of EVs is worse, but also from the aspects in which potential EV users *think* that EV performance is not satisfactory. For that reason, it is important to make potential customers familiar with EV usage, so that their attitude towards EV is based on their real experience and needs, and that the EV technology they use is the best available one. As shown in [53], EV users who drove early-market EVs were concerned about issues such as top speed, which have been solved by the EVs already existing in the market. The main drawbacks of EVs are listed below:

- High vehicle purchase cost: this is usually mentioned as the single most important barrier for EV adoption by potential EV users, as they are "*particularly sensitive to the purchase price of the EV*" [54] and a common recommendation in literature is that both the purchase price of the EV and its total cost of operation are comparable to that of the ICE vehicle [55] (some studies [56] go further and ask EVs to outperform ICE vehicles by 15-30 %). However, there have been huge improvements in the last years. In 2010, EV and PHEV list prices were between USD 6 000 and USD 16 000 to twice the price of equivalent ICE vehicles, being the battery by far the most expensive component of the EV (between 50 % and 80 % of the total cost [29], [30]). Although real figures are difficult to get, due to the secrecy of manufacturers, technological development has brought a steep decline in battery cost in the recent years: [57] estimate a 60 % reduction between 2007 and 2014 (USD 1 000 per kWh in 2007, USD 700 per kWh in 2010 and USD 410 per kWh in 2014) and [58] almost 80 % between 2010 and 2016 (USD 1 000 per kWh in 2010 to USD 227 per kWh in 2016). There are government subsidies in many countries (see section 2.2.7), which contribute to reducing the price difference and some manufacturers also offer the possibility to rent the battery, instead of buying it, in order to facilitate the acquisition of EVs. For example, the Renault ZOE has a EUR 7 500 discount in the list price if the 22-kWh battery is rented and the renting price (and the maximum renting contract duration) is affected by the annual mileage, e.g. a renting for an annual mileage of 12 500 km/year costs EUR 89.36 per month, but rises to EUR 99.37 per month if mileage is increased to 15 000 km/year (with a maximum duration of 84 months in both cases) and to EUR 159.36 per month (and a maximum duration of 72 months) if mileage rises to 30 000 km/year [59].
- Short driving range: EVs already existing in the market have batteries in the range of 20 or 25 kWh, i.e. an autonomy of about 130 km [60] without additional battery charging, which is more than enough to cover most drivers' daily driving needs [53], [61], [62]. Taking into account that the battery is one of the main contributors to the high vehicle purchase cost, an extension of the driving range (i.e. an increase in battery size) would also mean a more expensive EV. Hence, although EV users would be willing to pay about EUR 50 for each additional kilometre they could drive [54], having a driving range of 500 km would mean about additional EUR 20 000 in the EV purchase price, which, as shown above, is actually the biggest barrier for EV deployment[11].

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[11] The reason for the success of Tesla Model S may be that it is an EV for EV users who are sensitive to the driving range (it provides more than 400 km), but not to purchase price (USD 80 000) [63].

- Lack of charging infrastructure: together with the limited driving range, the lack of charging infrastructure makes many potential EV users suffer from "range anxiety" i.e. the fear of being stranded if they run out of battery. There are multiple experiences that demonstrate the importance of the availability of refuelling infrastructure for the adoption of different mobility technologies [4], [10], [64]. The choice of different alternative fuels for transportation is strongly linked to the availability of refuelling stations. In fact, the adoption of the ICE was largely facilitated because "*relatively cheap gasoline distribution points, made possible by the expansion of the automobile, became the norm and drove the industry forward through a reinforcing feedback*" [10]. In the field of electro-mobility, there are also experiences of customers who have made more intensive use of EVs when publicly accessible charging infrastructure has been deployed. Additionally, the overall costs of the transportation system could be lower if investments were made in EV charging infrastructure rather than in increasing battery capacity [37].
- Slow charging rate: the charging rate that can be expected in private home charging is in the range of 3.7 kW (Mode 1 or Mode 2, single-phase charging), which, for a 20-25 kWh battery, would take between 5.5 and 6.75 hours for a full charge. Obviously, this is not acceptable for publicly accessible charging infrastructure, so the expected charging power is quite higher, i.e. 22-50 kW (Mode 2 or Mode 3, three-phase; or Mode 4). Although these charging power values can reduce the charging time to 30-60 minutes, it still spans over a much longer time than the usual refuelling time at petrol stations (2-5 minutes). This aspect, added to some other differences during the charging process, makes the user experience while charging completely different to fuelling an ICE vehicle [23].

The need for a dense enough network of publicly accessible CSs to avoid range anxiety, together with the need for relatively short charging times, makes the deployment of charging infrastructure very expensive. One of the issues to be taken into account is that estimating EV charging demand is a challenging task, because there are few realistic vehicle travel data, because the required time for public charging is different from ICE vehicle refuelling and because there is the possibility for charging at home. As a result, traditional approaches for refuelling demand estimation (e.g. traffic flow and vehicle ownership density) may not appropriately represent the demand for EV charging in public locations [17].

Another issue is that the publicly accessible CS network is required from a behavioural point of view, but it may not be that much from a technical point of view: EV users want to see the charging infrastructure, but they will not use it as long as they can use their own private charging system [4], [10], [15]. This likely mismatch of demand and infrastructure can lead to under-used charging stations, which makes the commercial viability of operating publicly accessible CS doubtful, as demonstrated by the literature approaching this issue [4], [10], [14], [15][12]. In addition, too few CSs may result in long queuing issues [19], leading to a high station balking-fraction, i.e. EV users that forgo refuelling because the queue is too long, and the corresponding unfavourable word of mouth [10], which may prevent potential EV users from adopting electric mobility.

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[12] A more detailed literature review can be found in section 4.3.

Additional barriers for EV adoption include the uncertainty about battery lifetime, high battery replacement cost [65], uncertainty about EV resale value, reduced passenger and cargo space [3] and safety concerns, including both for the EV itself (risk of the EV catching fire [4]), for people recharging the EV (risk of electrocution [29]) and for pedestrians (due to the lack of noise [66]).

2.2.7 Electro-mobility promotion measures

As described in the introductory chapter, transport is one of the largest energy consumers, with almost one third of all the primary energy use worldwide [1]. In order to improve their trade balances and to mitigate climate change, many countries are adopting measures to promote the use of EVs. This subsection summarises the measures in the most relevant EV markets in the world: Europe, US and China.

2.2.7.1 Europe

The largest energy consuming sector in Europe is transport, with a 28 % share of total energy consumption [67]. This sector is strongly dependent on oil (94 %), most of which is imported (87 %). In order to revert this increasing trend of oil dependence, the European Commission adopted a Directive to deploy the infrastructure for alternative fuels, including electricity, hydrogen, biofuels and natural gas, among others [12]. Some of the main objectives established in such Directive include the reduction of 80-95 % of greenhouse gases (GHG) emissions by 2050 (compared against the 1990 levels). This objective will require a reduction of about 60 % of emissions from transport, and a contribution by RES, including electricity and biofuels, of 10 % in transport fuels by 2020. The contribution of first generation biofuels (biofuels that grow on land and which come from cereal and other starch-rich crops, sugars and oil crops and from crops grown as main crops primarily for energy purposes on agricultural land) has been capped to 7 %, so the remaining 3 % must come from second generation biofuels and EVs using electricity produced from RES [68]. In July 2016, the European Commission presented a package of measures to accelerate the shift to low-carbon emissions in all sectors of the economy in Europe, including transportation and fixed intermediate targets for CO_2 reductions by 2030 [69].

The Directive explicitly mentions that "*Electricity has the potential to increase energy efficiency of road vehicles and to contribute to a CO_2 reduction in transport. It is a power source that is indispensable for the deployment of electric vehicles* (…)*, which can contribute to improving air quality and reducing noise in urban/suburban agglomerations and other densely populated areas* (…). *Electro-mobility is an important contributor to meeting the Union's ambitious climate and energy targets for 2020*" [12].

Member States (MSs) must adopt a national policy framework for the deployment of the market for alternative fuels in the transport sector, which should define the national targets and objectives (for 2020, 2025 and 2030), as well as the promotion measures to reach such objectives. Each MS must have communicated such policy framework to the Commission by 18 November 2016 (but not all of them did [70]).

The European Commission encourages MSs to ensure that there is enough coverage of publicly accessible charging points, especially in densely populated areas and, if needed, in connection networks to be established by MSs. For that purpose, the policy framework must establish an appropriate number of publicly accessible CSs, which must be put in place by the end of 2020. As an indication, the Directive proposes to have one publicly accessible charging point per 10 electric cars, but leaves to MSs the decision on the appropriate number, also taking into account the type of EVs, the charging technology (see section 2.1) and the availability of private charging of EVs. Publicly accessible CS should be prioritised in public transport stations (passenger terminals in ports, airports and railway stations), while public authorities may impose obligations on site developers and managers to build private CS in apartment blocks, offices or business locations. The European Commission will monitor the application of the Directive and, if needed, further requirements will be imposed as a target for 2025.

Moreover, the Directive defines the rolling-out and operation of CSs as an activity to be developed as a competitive market with open access to all parties, and it imposes the obligation on DSOs to cooperate on a non-discriminatory basis with other CSOs. In addition, all publicly accessible CSs must allow EV users to recharge their EV without entering into a contract with the electricity supplier, the EMSP or the CSO of the CS, i.e. it requires that a direct payment system is made available. As an additional requirement, the Directive establishes the obligation to use standardised plugs, so that all CSs installed in the EU from 2017 onwards must have, at least, a Type 2 (as defined in [38]) connector for AC charging and a “Combo 2” (as defined in [39]) connector for DC charging.

On the other hand, the European Commission has set CO_2 emissions performance requirements for new passenger cars in the EU, establishing averaged emissions targets per manufacturer of 130 g CO_2/km by 2015 and 95 g CO_2/km by 2021. In order to meet those targets, manufacturers may reduce the emissions of their petrol and diesel vehicles, but they may also receive credits for producing vehicles with very low emissions (below 50 g CO_2/km) [71]. Even if EVs may not be needed to reach the 2020 goals, they will play an important role to reach the overall GHG emissions reduction targets by 2050 [55]. Therefore, further EV promotion schemes at the EU level are likely to exist in the future.

Although the general framework is established by the EU, specific promotion schemes are implemented by MSs, which lead to different EV adoption rates per MS. Figure 6 shows the total EV registrations (left) and their share (right) per MS.

After having more than doubled in 2015 compared to 2014 [72], EV sales had a modest growth in 2016 (+7 %), with 75 % of the new registrations being concentrated in the same four countries as in earlier years [73]. A summary of the main incentives for EV ownership in all EU countries can be found in [74], but the main promotion schemes in place in the countries where electro-mobility is facing the highest success are described below:

1. The Netherlands: EVs have benefitted from an exemption on the registration tax and on the annual circulation tax in recent years. Since both taxes are quite high in comparison to other MSs, it has been a strong incentive for potential EV buyers, which resulted in an important uptake, especially for PHEVs. After 2015, all zero-emission vehicles (ZEVs), such as BEVs, are still exempt from both taxes, but PHEVs must pay registration tax and the exemption from annual circulation was removed in 2016 (examples about the calculation of the registration tax can be found at [75] and [76]).

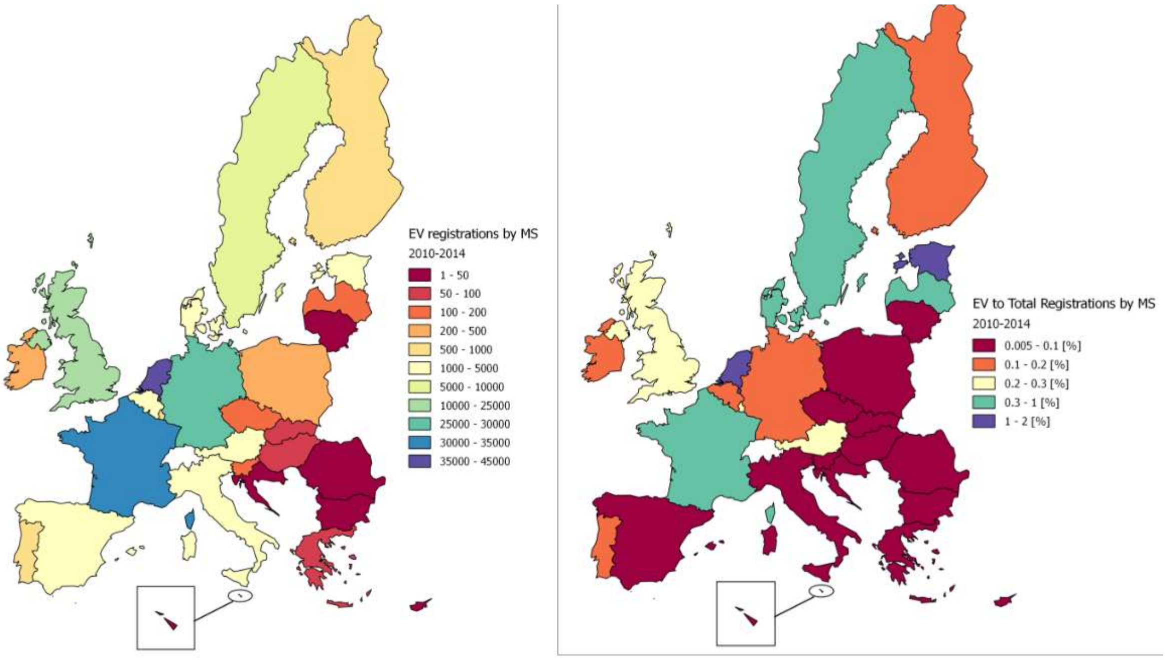

Figure 6: Map of EV registrations in EU Member States (2010-2014) [77]

2. United Kingdom (UK): the main incentive is also a monetary incentive, through a premium on the purchase price (35 % of the value of the new car, up to GBP 4 500, i.e. about EUR 5 240, depending on the model [78]) and an exemption from the annual circulation tax [79]. Another incentive which proved to increase EV sales is the exemption from the congestion charge (GBP 11.50 per day) in Greater London [80]: although it applied to other vehicles in the past, it was restricted to BEVs and PHEVs in mid-2013, just before the EV market started to boom in 2014.
3. Germany: the incentive in Germany is an exemption in the annual circulation tax (few hundred euros) and, since July 2016, a subsidy of EUR 4 000 for BEV (and EUR 3 000 for PHEV). However, most new cars sold in Germany are company cars (62 %) [81], i.e. the company offers a car (which can be used for private purposes too) to its employees and pays all related charges, usually including fuel costs. Then, the company claims vehicle costs as business expenditures and can reduce its profit tax [82]. More details and additional measures can be found at [83].
4. France: the registration cost puts a penalty on high CO_2 emitting cars and provides a premium for low CO_2 emitting cars, including EVs. The premium is up to EUR 6 000 for BEVs (not applicable to PHEVs after 1 January 2017), but capped at 27 % of the vehicle purchase price including value-added tax (VAT). The premium can be combined with a EUR 4 000 subsidy for scrapping a more-than-10-years-old diesel vehicle [84].

In addition to these two main support schemes (tax exemptions, e.g. in registration and circulation tax, and direct premiums for EV purchase), some other promotion schemes include exemption from road toll payment, access to free parking in publicly-owned parking lots or access to driving in bus lanes. In the long term, there might also be a prohibition to access the inner city areas to ICE vehicles, which can be a strong incentive for potential EV buyers to adopt electro-mobility [85].

Promotion measures can also focus on the CSOs, rather than on the EV buyer. A non-exhaustive list of potential measures can be found in Table 1 [25].

Measure	Description
Extended private grid connection	The CS is connected to an existing grid connection. The ideal condition for this measure is when the CS requires low power (3.7 kW) and the existing grid connection is strong (e.g. three-phase supply for domestic consumers, as in Germany or the Netherlands).
Simplified metering	The metering requirements are relaxed, so that some CSs can share the DSO meter (meters must be precise to invoice for EV charging, but they do not need to be smart meters with communication capabilities).
CSO as meter owner	Regulation allows CSOs to own the meter. This way, investment costs are increased, but no rent must be paid to the DSO.
Large-scale consumer	Regulation allows that a network of CSs (in a limited geographical area) belonging to the same CSO is considered as a single consumer. This way, the allocated network capacity can be shared between the CSs and, hence, some costs (depending on the electricity bill structure defined in each MS, it could include capacity payment, fixed payment, energy tax…) can be consolidated. Under present regulatory conditions (one connection point = one consumer), it is not possible, but widespread adoption of smart meters could permit evolving towards this kind of implementations.
New connection category	The establishment of specific T&D access fees which take into account the particular conditions of EV charging can help reduce the electricity bill costs for CSOs, e.g. the “super-valley” tariff made available for private charging of EVs in Spain [86]. Its impact can be further improved if they also consider the benefits that smart EV charging can provide to the electricity system operation [87].
Discounted interest rate	The government guarantees the investment. This way, the financing cost can be reduced by 3 % to 5 %.
Revolving fund	The government provides soft loans to CSOs. Public bodies provide funds for capital investments, which must be paid back by CSOs in 4 to 5 years, but without (or very low) interests.
Public subsidy	Public parties subsidise capital expenditures of CSOs. The subsidy can be either a share of total cost or a fixed amount per CS or per CSO.
DSO as CSO	Regulation establishes that the DSOs must be the CSO. This way, CSs become distribution grid assets and, hence, their costs are recovered through the T&D access fees paid by all electricity consumers (not only users of publicly accessible CSs). This measure results in a monopoly in CS operation for the DSO, which may be against the spirit of the European Directives on alternative fuels or internal energy market.

Table 1: Potential measures to promote CS installation

In any case, these measures need to be based on a previous study to determine costs and benefits, in order to avoid increasing public debt [82], as shown in Figure 7 [88]. In this sense, it is also important to consider the effects of fuel taxation.

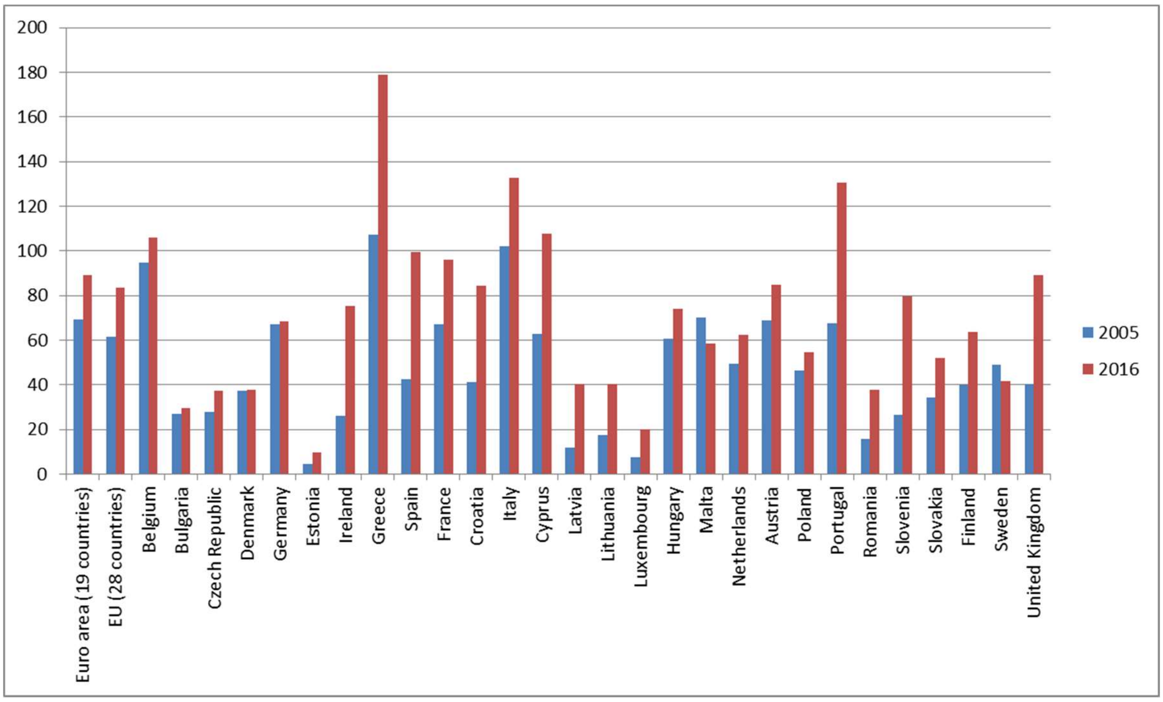

Figure 7: Government gross debt as percentage of Gross Domestic Product (2005, 2016)

An alternative for MSs to promote electro-mobility is to increase the excise duty rates for petrol and diesel, so that the TCO for ICE vehicles increases and, hence, EVs become more competitive in economic terms. For example, Spain could increase the taxes for unleaded petrol in about EUR 0.2 per litre and still have a similar tax rate as its neighbouring countries (Portugal and France). If such increase was applied, by considering a petrol-fuelled car which meets the 130 g CO_2/km EU-target for 2015 (5.6 l/100 km [89]) and an annual mileage of 14 000 km/year [55], the annual cost for the car would rise in about EUR 157. For a 15-year lifetime and at a 5 % discount rate, its impact in the TCO difference between ICE vehicles and EVs would be equivalent to a direct purchase subsidy for EVs of about EUR 1 575.

On the one hand, there are minimum taxation requirements set up by the Energy Directive 2003/96/EC, but MSs are free to apply higher rates, as shown in Figure 8 for unleaded petrol[13]. On the other hand, excise duties on petrol and diesel represent an important source of income for MSs. Therefore, if electro-mobility becomes widespread, MSs will need to look for additional taxation schemes [55], as current taxes on electricity are relatively low (due to the public service guarantees established in the electricity directive [47]).

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[13] The figure based on the data available in [90]. Where more than one taxation value is present (due to different types of unleaded petrol), the average value is presented. The value in Portugal corresponds to 2016 (EUR 617.51 per 1 000 litres) because there is no data available. The minimum taxation requirement is depicted as a red line.

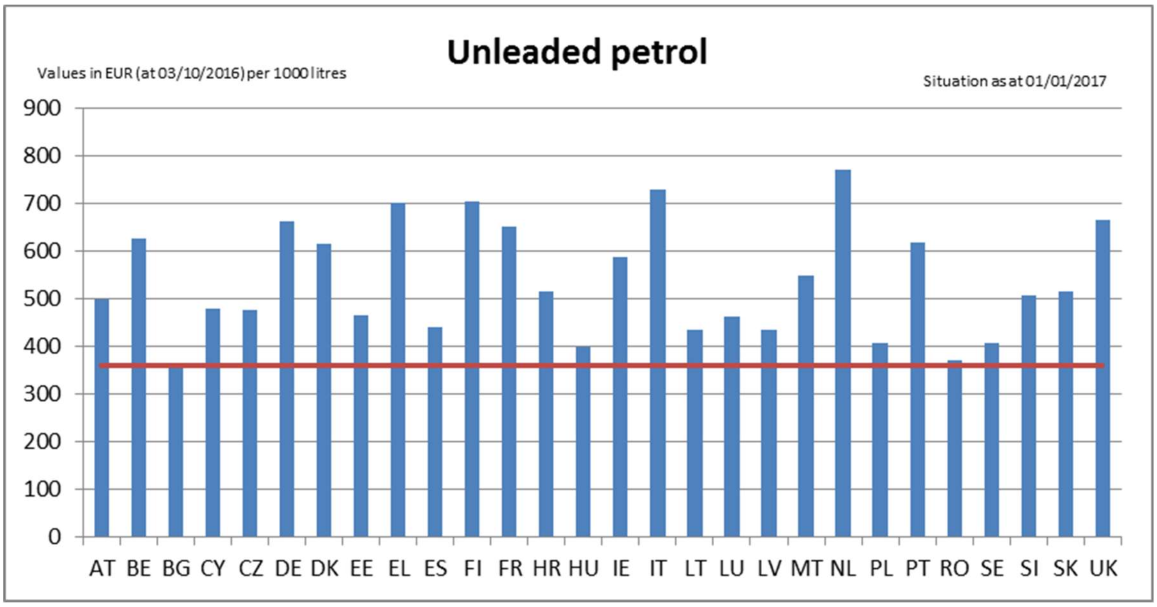

Figure 8: Excise duty rates for unleaded petrol in EU MSs in EUR per 1 000 litres

However, the main EV market in Europe is not within the EU, but in Norway, with more than 168 000 EVs (about 118 600 BEVs and almost 50 000 PHEVs) in 2017 [91]. The main incentives are: no purchase/import taxes (since 1990), exemption from 25 % VAT on purchase (since 2001), low annual road tax (since 1996), no charge on toll roads or ferries (since 1997 and 2009 respectively), free municipal parking (since 1999), access to bus lanes (since 2005), 50 % reduced company car tax (since 2000) and exemption from 25% VAT on leasing (since 2015) [92]. Yet, the main reason for the EV success in Norway is the high taxation on ICE vehicle purchase, which does not apply to EVs. For example, the Volkswagen Golf costs NOK 238 000 (about EUR 25 300) in Norway but only GBP 16 285 (about EUR 19 100) in the UK, while the Nissan Leaf in Norway costs NOK 240 690 (about EUR 25 575) and GBP 23 490 (about EUR 27 500) in the UK [93].

2.2.7.2 United States

The umbrella for the promotion of EVs in the US is “EV Everywhere”, one of the “Clean Energy Grand Challenges” announced by President Obama in March 2012. The aim of the initiative is “*to enable companies in the United States to be the first in the world to produce a 5-passenger affordable American electric vehicle with a payback time of less than 5 years and sufficient range and fast-charging ability to enable average Americans everywhere to meet their daily transportation needs more conveniently and at lower cost*” [94]. The initiative focuses on three main aspects: technology-push to reduce cost of electric drives, market-pull to increase consumer acceptance, and charging infrastructure development to enable fuelling convenience. Technology-push focuses on research and development (R&D) in specific areas, to reduce [95]:

- Battery cost, from USD 500 per kWh to USD 125 per kWh, while reducing size to half and more than doubling energy density from 100 Wh/kg to 250 Wh/kg.

- Electric drive system cost, from USD 30 per kW to USD 8 per kW.
- Vehicle weight by about 30 %.

Market is pulled through financial incentives, by offering federal tax credits between USD 2 500 and 7 500 for EV purchase [96]. Last, enabling charging infrastructure works on areas such as CS siting and permitting, standardisation and grid integration.

In addition, the “Clean Power Plan” [97] aimed at reducing CO_2 emissions in 2030 by 32 % from 2005 levels through, among others, the increase of the contribution by RES to electricity demand by 30 %. The Environmental Protection Agency set a rate-based approach (which places a CO_2/MWh limit on power plants), but States could also use a mass-based approach (which considers the total tons of CO_2 from the electric power sector). Although EVs will increase electricity demand and, hence, may hinder the achievement of the goals in the plan, States which opt for the rate-based approach could benefit from a controlled EV charging, which matches renewable energy production to increase the total share of renewable energy in the State’s electricity supply (which was the objective of the plan). The plan was in force until 28 March 2017, when President Trump requested to review it [98].

An additional initiative at Federal level is the establishment of the “Fuel Economy and Environment Label” [99], which is compulsory for new cars since 2013. The label allows potential buyers to compare vehicles in terms of energy use (how much fuel or electricity is needed to drive 100 miles), savings/expenditures on fuel during 5 years compared to the average new vehicle, emissions, driving range and charging time of plug-in vehicles.

The environmental benefits of EVs are strongly linked to the electricity generation mix used to power them, so there are huge differences in the US. As shown in Figure 9, the adoption of EVs would provide higher benefits both in the Atlantic and the Pacific coasts.

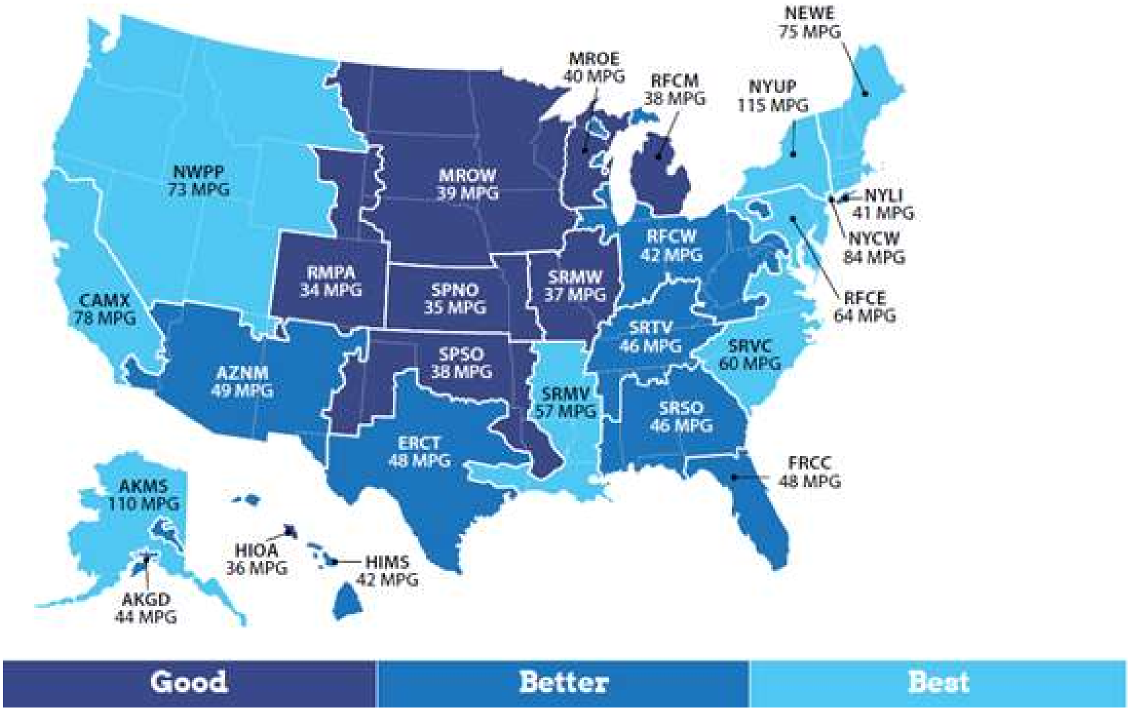

Figure 9: Environmental impact of EV adoption per State in the US [100]

One of the states with the biggest potential impact (78 miles per gallon, mpg) is California. California is also the most populated state (39.25 million inhabitants [101]) and a very big market for vehicles, with more than 35.3 million vehicles registered (about 24.5 million of which are cars) in 2016 [102], i.e. almost 0.90 vehicles per inhabitant.

Although there is no specific target for EVs, California has ambitious GHG emission reduction targets, with the "ZEV Mandate": it aims at having the same CO_2 emissions in 2020 as in 1990, cutting them in 40 % by 2030 and in 80 % by 2050. According to the California Environmental Protection Agency, the state is on the good track to reach the 2020 objective, but further efforts will be needed to meet the mid- and long-term goals. One action to reach such goals is to cut petroleum use in half by 2030, as it accounts for about 50 % of GHG emissions, which can be made by reducing the expected increase of vehicle-miles travelled to 4 %, increasing on-road fuel efficiency of cars to 35 mpg (6.72 l/100 km) and doubling the contribution of alternative fuels, including electricity [103].

The mandate established targets for ZEV sales from large-volume car manufacturers. In first stages, only BEV were eligible as ZEV, but a review of the battery technology development and the pressure made by manufacturers extended the scope to fuel cell electric vehicles and to partial ZEV, such as ultra-clean ICE vehicles and PHEV. On the other hand, the share of ZEV sales was set to be increasing until 10 % in 2003. This first stage of the mandate raised interest in EV technology and contributed to mitigating climate change effect, but it also brought criticism about "compliance cars" (cars that were made by car manufacturers just to comply with the regulation, but which they were not very eager to promote) and about linking the programme to a specific technology, as the success (and the cost) of the programme strongly depended on the technological development [55].

Therefore, the "ZEV Program" was revisited and a technology-neutral approach was introduced. Now, the "ZEV Program" is part of the "Advanced Clean Cars Program", whose objective is to have, by 2025, new vehicles emitting 34 % fewer GHG and 75 % fewer smog-forming emissions [104]. The "ZEV Program" in force between 2015 and 2017 requires manufacturers to have 14 % of their sales from ZEV, with fines of USD 5 000 per missing credit and the obligation to acquire the missing credits in the following years [105], [106]. After 2018, there will be a new calculation method for the share, but it will be increasing from the 4.5 % (under the new calculation) share in 2018 to 22 % in 2025 [107].

In addition to Federal and State governments, local governments can also provide incentives for EV adoption. In order to guide potential investors when asking for incentives, the California Air Resources Board (which is part of the California Environmental Protection Agency) has a website [108], where the available incentives are summarised and updated regularly.

Some of the incentives for installing EV charging infrastructure are listed below, where Los Angeles downtown has been taken as an example:

- ChargePoint offers in all the US the "Net+ Purchase Plan", a lease plan for CSOs, which includes installation, service and warranty, during the contract duration (between 3 and 7 years) and the possibility to buyout at no cost at the end of the lease. ChargePoint also envisages flexible payments aligned to CS usage.
- Fuelling equipment for electricity (among other alternative fuels) installed between January 1, 2015, and December 31, 2016, were eligible for a Federal tax credit of 30 % of the cost, not exceeding USD 30 000 (permitting and inspection fees not

included in covered expenses). CSOs who installed qualified equipment at multiple sites were allowed to use the credit towards each location. Consumers who purchased qualified residential fuelling equipment prior to December 31, 2016, may receive a tax credit of up to USD 1 000. Unused credits may be carried backward one year and carried forward 20 years.

- The "California Capital Access Program", created by the California Energy Commission, facilitates loans for the design, development, purchase, and installation of CSs for EVs at small business (up to 1000 employees) locations, as long as they meet some technical requirements and the CSs are accessible to the business owner's employees, the general public or to the tenants of a multi-unit dwelling. It may provide up to 100 % coverage to lenders on certain loan defaults. Borrowers may be eligible to receive a rebate of 10-15 % of the enrolled loan amount.
- For residential EV charging, the California Energy Commission offers the "Property-Assessed Clean Energy" financing, which allows property owners to borrow funds to pay for energy improvements, including purchasing and installing CSs. The borrower must repay over a defined period of time through a special assessment on the property.
- For a limited time, NRG EVgo is wiring eligible apartment buildings and workplaces with up to ten charge-ready parking spaces for free. They'll also manage the charging stations and cover the electricity costs through each driver's usage fee. This programme is available to buildings with 10 or more units that are located in areas served by the utility companies Pacific Gas & Electric, Southern California Edison or San Diego Gas & Electric.
- Different utilities offer rebates on their customers' electricity bill if they install a Level 2 (240 V) CS for EVs. Pasadena Water & Power offers USD 400 for business (if they install a CS for employees' EV charging) and residential customers (who will also receive up to USD 200 worth of LED lights for their homes), Burbank Water & Power offers up to USD 1 000 in similar conditions and Los Angeles Department of Water and Power offers USD 500 for eligible CS purchases. These rebates are usually available for limited time, as e.g. Glendale Water & Power also had rebates, but they are no longer available.

There are also incentives for vehicle purchase in Los Angeles downtown:

- Many private companies (California hotels, Bank of America, Google, Integrated Archive Systems, Clif Bar & Co., Timberland, Patagonia, AT&T and many more) help employees to purchase hybrid or alternative fuel vehicles, with incentives in the range from USD 1 000 – 5 000. Many other companies are offering workplace charging, such as Google, Facebook, Microsoft, Netflix, Ebay, 3M, Apple, Dell, Adobe, SAP, Sierra Nevada, Warner Brothers, Mattel, Symantec, Intuit and Pixar.
- There is a Federal tax credit for acquiring new PHEV for final use (including lease, but not resale) of up to USD 7 500 since 2010. The credit begins to phase out for vehicles at the beginning of the second calendar quarter after the manufacturer produces 200 000 eligible plug-in electric vehicles (i.e., plug-in hybrids and EVs) as counted from January 1, 2010 [109]. At the end of 2016, Ford had cumulative sales of 88 335 vehicles, Mercedes of 9 947 vehicles and BMW of 39 525 vehicles [110].
- The "Clean Vehicle Rebate Project", funded by the California Environmental Protection Agency's Air Resources Board, provides rebates of up to USD 5 000 for the

purchase or lease of zero-emission and plug-in hybrid light-duty vehicles (in addition to the Federal tax credit). On top of the standard rebate, qualifying, low-income households may receive an additional USD 1 500 rebate.

- A consumer may retire a qualified vehicle and receive USD 1 000. Consumers meeting low income eligibility requirements may receive USD 1 500. This incentive is for retiring any type of vehicle, but it may help in the transition from fossil fuelled transport to electric mobility.
- The “Public Fleet Pilot Project” offers up to USD 15 000 in rebates for the purchase of new, eligible zero-emission and plug-in hybrid light-duty vehicles. The “Public Fleet Pilot Project” is administered by the Center for Sustainable Energy for the California Air Resources Board and replaces standard “Clean Vehicle Rebate Project” rebates, with increased incentives for public agencies operating in California’s most vulnerable and pollution-burdened areas (such as Los Angeles downtown[14]). Private vehicle owners residing in the South Coast Air Basin who met income and vehicle requirements can also ask for a rebate of up to USD 9 500 to replace an older, high-polluting vehicle with a newer vehicle, upgrade to a hybrid or electric vehicle, or get vouchers for rideshares or public transit passes.

In addition, several utilities offer TOU for EV charging:

- Azusa Light & Water. For qualifying residential customers, the price for electricity consumed between 10 p.m. and 6 a.m., in excess of 50 kWh, shall be discounted by 5 cents per kWh from the “All excess kWh” contained in their respective rate schedule. The amount of the discounted electricity shall not exceed 500 kWh per billing period.
- LA Department of Water and Power. Customers who choose to install an optional, dedicated TOU meter will qualify for a discount of 2.5 cents per kWh, plus receive an additional USD 250 credit on their electricity bill. This dedicated service adds cost to the installation process, but yields lower electricity costs for base charging.
- Southern California Edison. Two special EV rate plans for charging in off-peak hours are available:
    - The “Home & Electric Vehicle Plan” uses a single meter to measure the electricity usage of both home and EV.
    - The “Electric Vehicle Plan” requires a separate meter for charging the EV, while household usage remains on its own meter and its current rate plan.

On the other hand, public bodies also offer special permits for EV drivers:

- California law allows single-occupant use of “High Occupancy Vehicle” lanes by certain qualifying clean alternative fuel vehicles. Three different decals have been issued, at different periods in time and for different eligible vehicles. The “White Clean Air Vehicle” decals are available to an unlimited number of qualifying Federal Inherently Low Emission Vehicles, such as pure ZEVs. The expiration date for the white stickers has been extended to 1 January 2019.

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[14] One of the main driving forces in California is poor air quality, but this is not expected to be a major driver in e.g. Europe [55].

- The City of Los Angeles is offering instant online EV Home Charger, permitting approval and expedited charger inspection and meter installation.
- Free metered parking for 100 % alternative fuel vehicles is available in downtown Hermosa Beach and Santa Monica. Free parking is also available in a number of hotels in California for EV and PHEV drivers.

In the case of Los Angeles International Airport, parking is not free, but there is free charging for EV owners. Insurance discounts of about 10 % (Farmers Insurance, Travelers Insurance) are also available for EV drivers in California.

2.2.7.3 China

Despite China's world leadership in EV sales, it is difficult to find official sources of information in English, so the information in this paragraph is based on pieces of news [111], [112], [113], [114], [115], [116], reports [117] and translations form official sources [118], [119] by using Google Translator. In some cases, information does not completely match among sources and, thus, the different approaches are described.

In China, the government plans to promote EVs have the main goal of creating the world-leading industry to produce jobs and exports and the side-goal of reducing urban pollution and oil dependence. Incentives focus on specific city areas and, depending on the vehicle range, can reach up to CNY 60 000 (about EUR 7 800). After 2017, subsidies by the central government will be reduced by 20 % and local subsidies by 50-60 %.

Although EV subsidies date back to 2009, the market did not have a significant growth until 2014 (Figure 10), just after a regulatory change in mid-2013, but its real impact is uncertain. By comparing the amount of the subsidy, it seems to be the same before and after the change, so there was criticism that "*the new policy is basically the same as the previous one*" [112]. However, there were differences in the sources used, so it seems that there have been changes both in terms of the receiver of the subsidy (the car manufacturer was the one receiving the subsidy, but now it seems to be the EV customer) and in terms of barriers for foreign brands (subsidies were only available for local producers[15], but the government apparently removed all of them).

In September 2015, the government announced a plan to develop a nationwide CS network, although it first focuses in big cities like Beijing, Shanghai and Shenzhen. The objective of the plain is to serve 5 million EVs and to have, at least, one public CS for every 2 000 EV. During 2016, more than 100 000 public CS were built (ten times the figure in 2015).

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[15] According to [115], "*foreign automakers are generally required to establish a joint venture with a Chinese company to produce cars domestically*".

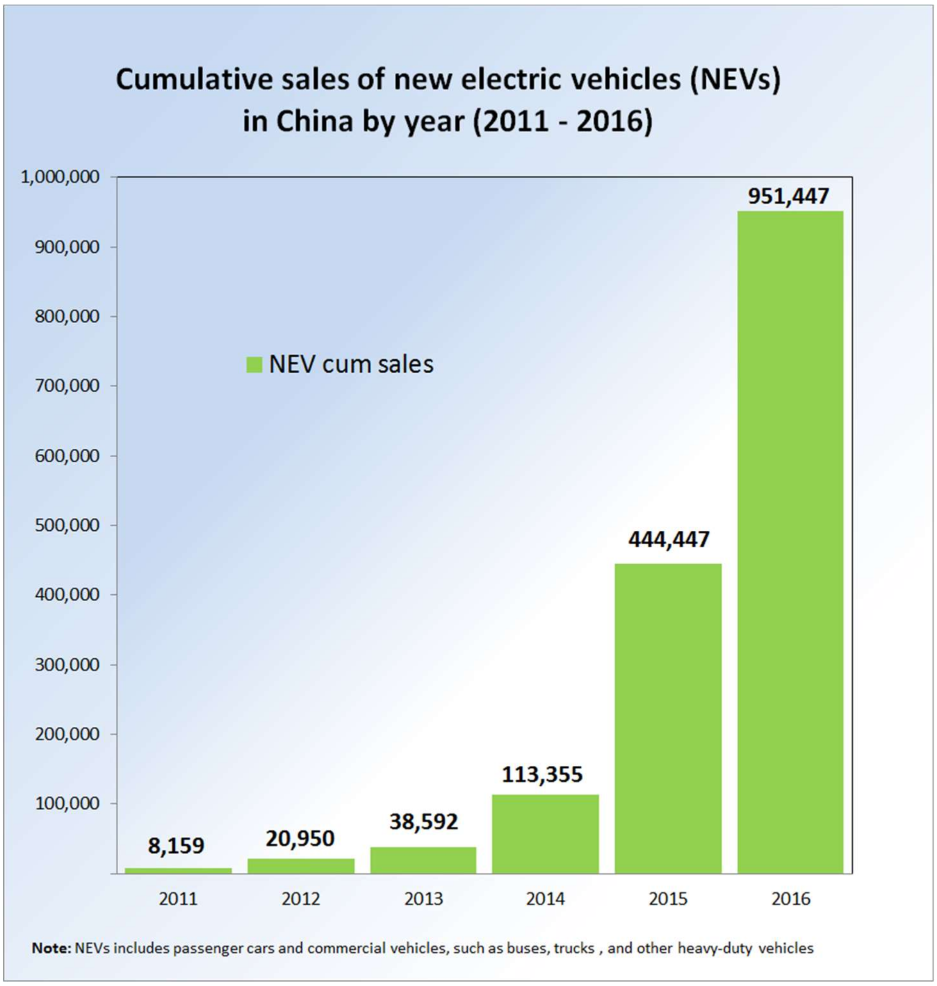

Figure 10: EV cumulative sales in China (2011-2016) [120]

2.3 CONCLUSIONS

Electro-mobility is a complex ecosystem, with many stakeholders interrelating with each other. The roles for them are not completely defined yet, which provides different alternatives for regulatory options.

Despite the standardisation efforts in the last years, which led to some reduction of potential solutions, the wide variety of charging alternatives (including the type of power supply, the charging power, the ownership and accessibility of the CS and roaming possibilities) result in thousands of potential choices, most of which require dedicated analysis.

An additional advantage of standardisation has been cost reduction, but the main barriers for electro-mobility still remain, i.e. high EV purchase cost, short driving range, lack of publicly accessible charging infrastructure and slow charging rate. Technological development is improving both driving range and charging speed, but at the cost of not being able to reduce EV and CS expenditures. Public support focused in reducing EV acquisition cost (either by subsidising EV purchase or by offering tax rebates), which allowed EV market to speed up in the recent years. However, investment in publicly accessible CS has not been given that much priority yet.

The methodology described in this thesis aims at guiding the approach to improving the economics of publicly accessible CS, while taking into account the complexity of the electro-mobility ecosystem.

CHAPTER 3

BUSINESS MODELS ANALYSIS

3 BUSINESS MODELS ANALYSIS

3.1 INTRODUCTION TO ECONOMIC ANALYSIS

This section aims at providing an introduction to the basic concepts needed to perform an economic and/or financial analysis. The objective of an economic analysis is "*to provide the information needed to make a judgement or a decision*" [121].

An investment can be seen as a means to allocate different resources (money, time, efforts…) to obtain incomes in the future. The investor makes the investment in order to create enough incomes to obtain a benefit. Therefore the investor needs to make an assessment of the expected costs and benefits before deciding whether to make the investment or not.

In general, the economic assessment of a project must consider, for each year of the lifetime of the investment, direct costs, indirect and overhead costs, taxes, returns on investments and externalities, such as environmental impact or societal gains, which are *relevant* for the decision to be made. Consequently, the complexity of the analysis and its level of detail depend on the purpose and the scope of the analysis, which are linked to the point of view of the potential investor. Investor's perspective will influence different variables of the analysis, such as the discount rate to be used, the use of before-tax or after-tax cash-flows, financing costs, etc. However, it is important that all the potential different investment alternatives are compared from the same perspective.

The results of economic evaluations are often used in strategic planning and policy making, so uncertainty is an important consideration to be included in the analysis. In many cases, investment projects look into the future, where there are many uncertainties, such as future evolution of prices or the emergence of new technologies. In these cases, the use of average annual values can provide enough guidance as to avoid entering into full details. However, it is important to back up the analysis on sound and consistent data, and to compare alternatives on a level playing field, so that they are based on comparable characterisations. Moreover, it is important to identify those uncertain variables which may have the most important effect on the result of the economic assessment. Once the variables are identified, a sensitivity analysis (or a scenario analysis, if the variables are closely interrelated) is a very useful risk-hedging tool for investors.

Some of the most important concepts for economic assessments are presented in the subsections below.

3.1.1 Cash-flow

The cash-flow is the net amount of cash (or cash equivalents, i.e. assets that can be converted into cash immediately) moving into and out of a business during a given period. Cash-flows include revenues captured, operating and maintenance expenses, interest paid, income taxes paid, capital expenditures, repayment of debt principal and dividends. Only the first item represents cash moving into the business, while the remainders are movements of cash out of it.

When performing an economic analysis of a project with a long lifetime, it is not worthwhile to conduct detailed descriptions of the timing for the cash movements. In these cases, the common practice is to add the whole sets of cash movements for the same income or cost category into a single movement made at the end of the year. As a result, annual discount rates can be used to account for the depreciation of money along time.

Cash-flows can be expressed as before-tax cash-flows or after-tax cash-flows. Financial treatment of taxes is a very complicated subject, since they depend on a number of issues, as discussed in [121]. As any other cost, taxes are an important component of the cash-flow of a project, but they are just money transfers (except those to correct for externalities), when the analysis is made from the perspective of society. Therefore, a before-tax analysis may also be helpful in these cases.

3.1.2 Discount rate

Every asset has a value, but such value varies with time [122]. As a result, the value of money also varies with time. An investor will put a higher value on a euro today than within 10 years, because he can invest that euro today, receive a return and have more money within 10 years. Hence, the investor is putting a price on the time he must wait until he has a return on an investment, i.e. he considers a *time value*.

The discount rate acts as a measure of the time value and it is often used to consider the risk inherent to an investment too. Consequently, the discount rate is central to the calculation of the present value of any asset and, thus, to any economic analysis.

In addition, discount rate may also take into account the effect of inflation. Inflation is the rate at which the general level of prices for goods and services[16] is rising and, consequently, the purchasing power of currency is falling. Therefore, it is important to distinguish between current euros or in constant euros:

- Current euros represent the actual number of euros required in the year a cost is incurred.
- Constant euros represent the number of euros that would have been required if the cost had been paid in the base year.

An economic assessment may consider any of them, but it is important to keep consistency throughout the study. If a constant inflation rate (e) is considered, a cash-flow in year m (F_m) in current euros can be converted into a cash-flow in base year n (F'_n) in constant euros by using equation (1).

$$F'_n = \frac{F_m}{(1+e)^{m-n}} \tag{1}$$

For example, for an average inflation rate of 2 % within a 10-year period (e.g. 2007-2017), the value of EUR 100 (current) in year 10 will be the same value as for EUR 82.03 in year 0:

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[16] There are different inflation rate index, although the most common inflation index is the Consumer Price Index, which measures the average change in prices of a “basket” of goods and services and represents price trends at retail level.

$82.03 = 100 / (1 + 0.02)^{10}$. This means that the same things could be bought with EUR 82.03 in 2007 than with EUR 100 in 2017.

When the discount rate takes into account inflation it is called *nominal discount rate*, and when not it is called *real discount rate*. Consistency between usage of inflation or not must be kept along the study, so nominal discount rates are linked to current euros, while real discount rates are tied to constant euros. Discount rates can also be converted from nominal (d_n) to real (d_r) and vice versa according to equation (2).

$$(1 + d_n) = (1 + d_r) * (1 + e) \tag{2}$$

However, a reasonable approximation is given by equation (3).

$$d_n = d_r + e \tag{3}$$

For example, when inflation is 2 % and real discount rate is 7 %, nominal discount rate becomes 9.14 % (from equation (2)), which is very close to 9 % (as calculated according to equation (3)).

As the time value is not the same for all investors, the discount rate to be used in the economic study will depend, among others, on the investor's rate of return, risk premium and planning horizon.

If the economic analysis looks into the future, estimates of future inflation rates are required, so a sensitivity analysis may help hedge the high degree of uncertainty associated with such estimates. Likewise, a sensitivity analysis on the discount rate is also recommended. Based on [121] and [123], such sensitivity analysis may consider a base discount rate of 7 % and extreme values of 3 % and 10 % in the case of energy-related investments.

3.1.3 Time points and periods

Time points define the most relevant points in time for the analysis. They include the year to which all cash-flows are converted (base year) and the year in which the actual investment is made (investment year).

On the other hand, most important time-periods include the useful lifetime for the investment, the analysis period, the depreciation period (for tax purposes), the financing period and the levelisation period.

All projects have one initial investment, but additional investments may be required during the analysis period to replace parts of the main asset, e.g. the gearbox of a wind turbine may need to be replaced before the end of the lifetime of the rest of the components of the turbine. In general, the first investment year is set as the base year, where the time periods start, but these periods do not need to be the same. For example, an asset may have a lifetime of 20 years, be financed over a 10-year period, and be depreciated over 5 years. On the contrary, the analysis period is usually set to match the investment lifetime.

In any case, the assumptions made for time points and periods must be clearly documented in the economic study. In addition, the same study period must be considered when evaluating competing investment alternatives.

3.1.4 Present values

Present value is a measure of today's value of revenues or costs to be incurred in the future [121]. The present value (*PV*) of one euro paid or received in the future can be calculated by using a factor to discount future cash flows (F_n) to the present, as shown in equation (4).

$$PV = \frac{F_n}{(1+d)^n} \tag{4}$$

Where *d* is the annual discount rate.

3.2 INVESTMENT VALUATION METHODS

Investment valuation methods are metrics that allow investors to assess the economic interest of an investment. Investments can be financial (monetary assets which can generate future revenues, such as cash, stocks, bonds, or even the acquisition of a company) or non-financial. Non-financial investments, which are usually linked to industrial activities, are the focus of this thesis, so the rest of this chapter is devoted to the most common methods to evaluate them. A detailed description of valuation methods for financial investments can be found in [122].

There are different methods or measures to assess the economic value of an investment. Depending on the characteristics of the investment and the type of analysis to be carried out, the suitability of each method will be different, so it is strongly advisable to use several measures to evaluate an investment. Following subsections present the characteristics, advantages and drawbacks of each method.

3.2.1 Net Present Value

The Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows. Therefore, it allows considering both the revenues and the costs of an investment project, and to take into account the time value of money.

Based on the formula of the Present Value, the NPV of an investment after year *N* can be calculated according to equation (5).

$$NPV = \sum_{n=0}^{N} \frac{F_n}{(1+d)^n} \tag{5}$$

Where:

- F_n is the net cash-flow (difference between incomes and costs) in year *n*.
- *d* is the discount rate.

In the particular case in which the investment (*I*) is made only once and if the annual cash-flow is constant (*F*), the NPV of the investment in year *N* can be calculated by using equation (6).

$$NPV = -I + F * \frac{(1+d)^N - 1}{d * (1+d)^N} \tag{6}$$

An investment is considered to be economically attractive if the NPV in the analysis period is positive, because the incomes are worth more than the costs. If the NPV is zero, the investor will remain indifferent whether the investment is made or not, as costs and incomes are worth the same, and the investment is not attractive if NPV is negative.

As discussed above, the discount rate must be selected to be consistent with having considered either constant or current euros. The NPV for an investment is the same either it is calculated in constant or in current euros. An example of the calculation of NPV in current and in constant dollars can be found in [121].

In addition to the advantages already discussed, the NPV also reflects the size of the investment, which can be helpful for deciding on whether to invest in a larger project with a lower rate of return or in a smaller project with a higher rate of return. For example, an investor may need to select between two investment projects, with a 3-year analysis period:

- Alternative 1: The investment cost is EUR 1 000 and the annual benefit is EUR 600.
- Alternative 2: The investment cost is EUR 10 000 and the annual benefit is EUR 5 000.

The annual benefit per euro invested is higher in alternative 1, but the NPV (e.g. at a 10 % discount rate) is almost 5 times higher (EUR 2 434 vs. EUR 492) in alternative 2.

If a third alternative is considered, where the investment is EUR 10 000 and the annual benefits are EUR 9 000, EUR 5 000 and EUR 500 in the three years, its NPV is EUR 2 690. In this case, the NPV is higher than for alternative 2, even if the addition of annual benefits is lower. This is due to the impact of time value of money.

As can be seen, the NPV is a very useful valuation method, especially when comparing different investment alternatives. Consequently, NPV is almost always used when valuating investments, either as a primary or as a secondary valuation method. Moreover, it is also a good method when social costs (the costs incurred by the society as a whole, such as environmental costs) must be taken into account.

3.2.2 Internal Rate of Return

The Internal Rate of Return (IRR) represents the discount rate for which the NPV of an investment at the end of the analysis period is zero. Therefore, it allows assessing the profitability of an investment by establishing a minimum profitability threshold and checking whether the IRR is higher than such threshold or not. Only the investments with IRR higher than the threshold must be accepted by the investor.

The main advantage of the IRR is that it provides a way to make quick accept/reject decisions. However, it is not recommended to select among different alternatives, as it does not account for the size of the investment or the analysis period. In the example above, alternative 1 has an IRR of 36 %, alternative 2 of 23 % and alternative 3 of 31 %. If only the IRR criterion is considered, alternative 1 will be selected, although alternative 3 provides a higher profit in euros. Regarding the period, two alternatives may provide the same IRR for different periods (e.g. 4 years and 30 years), but the investor will prefer to have a sustained revenue stream over the longest period, which cannot be derived from the IRR.

Nevertheless, the main drawback of IRR appears when further investments are required after the initial investment started providing annual benefits. The IRR is the discount rate d which is obtained from equation (7).

$$0 = \sum_{n=0}^{N} \frac{F_n}{(1+d)^n} \tag{7}$$

This formula results in a polynomial function of degree *N*, which means that there are *N* different roots, or solutions to the equation. If the pattern of the investment is the usual one (one investment at the beginning of the project and cash inflows for the rest of the analysis period), there is only one valid solution, as the rest of the roots are either negative or imaginary. If not, there may be more than one valid solution.

A final problem of IRR is that it assumes that interim cash flows are reinvested at the IRR rate. This may be valid for IRRs in the upper range of usual discount rates (i.e. 10-15 %), but it is difficult to justify for higher IRRs (it is unrealistic to assume that cash-flows can be reinvested at 36 % in the example above).

Therefore, IRR should only be considered in accept/reject project assessments and not for comparison purposes.

3.2.3 Modified Internal Rate of Return

The Modified Internal Rate of Return (MIRR) is used to take into account different reinvestment rates and avoid one of the problems of the IRR. For that purpose, MIRR is calculated so that positive cash flows received during the project lifetime are reinvested at the discount rate (as the NPV does) until the end of the analysis period.

Then, the future cash flows are discounted back to the base year at a new discount rate. The new discount rate that equals the present value (in the base year) of future positive cash flows and the present value of negative cash flows (in general, investments) is the MIRR. The MIRR can be calculated through equation (8).

$$\sum_{n=0}^{N} \frac{F_n^n}{(1+d)^n} = \sum_{n=0}^{N} \frac{F_n^p * (1+d)^{N-n}}{(1+r)^n} \tag{8}$$

Where:

- F_n^n is the negative cash-flow in year *n*.
- F_n^p is the positive cash-flow in year *n*.
- *d* is the discount rate.
- *N* is the analysis period.
- *r* is the MIRR, which is calculated from equation (8).

The MIRR also allows considering investment projects with negative annual cash-flows (usually, resulting from requiring further investments).

The features of MIRR make it attractive to rank different alternatives and it can also be used to make accept/reject decisions (although IRR is used more often for this purpose). However, it is not recommended to select between mutually exclusive alternatives, as it does not consider the size of the investment (as in the case of the IRR, an alternative with a higher MIRR may result in a smaller amount of euros being obtained at the end of the analysis period).

3.2.4 Simple payback period

The simple payback period represents the minimum number of years to recover an investment, i.e. the number of years required for the addition of non-discounted (without considering present values) annual cash flows to exceed the required investment. The simple payback period can be calculated as the first year *N* in which equation (9) is met.

$$\sum_{n=0}^{N} I_n \leq \sum_{n=0}^{N} F_n \tag{9}$$

Where:

- I_n is the investment required in year *n*.
- F_n is the annual cash-flow in year *n*.

The main advantages of simple payback period are its simplicity, which allows a quick comparison of alternatives, and its importance for risk assessment, as it provides an idea of the time in which the money invested is at risk. When risk is an issue, an investor may prefer an investment with a smaller simple payback period if the yield (e.g. the NPV) of two investment alternatives is similar.

On the contrary, it does not account for the size of the investment, it does not consider the returns after payback and it does not take into consideration the time value of money.

3.2.5 Discounted payback period

The discounted payback period solves one of the problems of the simple payback period, as it does consider the time value of money, as equation (10) illustrates.

$$\sum_{n=0}^{N} \frac{I_n}{(1+d)^n} \leq \sum_{n=0}^{N} \frac{F_n}{(1+d)^n} \tag{10}$$

However, this method does not either consider the size of the investment, nor the returns after payback.

3.2.6 Annualised value

The annualised value is the representation of the equivalent annual cash-flow of a series of cash-flows. In order to calculate it, all the annual cash-flows (F_n) in the analysis period (*N*) are discounted to their present value and, then, they are annualised by using the uniform capital recovery factor. The annualised value is calculated through equation (11).

$$Annualised\ value = \frac{d * (1+d)^N}{(1+d)^N - 1} * \sum_{n=0}^{N} \frac{F_n}{(1+d)^n} \tag{11}$$

The annualised value is a very useful tool when the annual cash-flows are constant (or if they increase by a constant annual rate, which can be considered as an inflation rate and, hence, can be easily taken into account when selecting the discount rate) and there is only one investment to be made at the beginning of the analysis period. In that case, the investment is economically attractive if the annual cash-flow (*F*) is bigger than the investment (*I*) multiplied by the uniform capital recovery factor, as described in equation (12).

$$F > \frac{d * (1+d)^N * I}{(1+d)^N - 1} \tag{12}$$

3.2.7 Revenue requirements

Revenue requirements represent the total revenue that must be collected from customers to compensate for all the expenditures of a specific project (not a firm). This metric is often used in regulated businesses, such as the electric power industry.

It is usually calculated as the before-tax total life-cycle cost, according to equation (13).

$$Revenue\ requirements = \frac{I - \left(T * PV_{Dep}\right) + PV_{O\&M} * (1-T)}{1-T} \tag{13}$$

Where:

- *I* is the initial investment.
- *T* is the income tax rate.
- PV_{Dep} is the present value of depreciation expenses.
- $PV_{O\&M}$ is the present value of operation and maintenance (O&M) expenses.

For residential customers, non-profit organisations or government bodies, income taxes do not apply, so the formula can be simplified to equation (14), where OM_n represents the O&M expenses in current value (not in present value, see subsection 3.1.2).

$$Revenue\ requirements = I + PV_{O\&M} = I + \sum_{n=0}^{N} \frac{OM_n}{(1+d)^n} \tag{14}$$

These revenue requirements can be calculated on an annual basis, by using the annualised value described in equation (11).

$$Annual\ revenue\ requirements = \frac{d * (1+d)^N}{(1+d)^N - 1} * \left[I + \sum_{n=0}^{N} \frac{OM_n}{(1+d)^n} \right] \tag{15}$$

3.2.8 Levelised Cost of Energy

The Levelised Cost of Energy (LCOE) is the cost to be assigned to every unit of energy produced (or saved) by the project over the analysis period, so that it equals the total life-cycle cost discounted back to the base year. It is calculated by using equation (16).

The LCOE was defined to be able to compare competitive alternatives with different scales of operation, levels of investments and operational time periods. It is a good metric to rank alternatives when there is a limited budget, but it is not recommended to select among mutually exclusive alternatives, because it does not consider the sizes of the investments.

$$\sum_{n=1}^{N} \frac{Q_n * LCOE}{(1+d)^n} = \frac{I - \left(T * PV_{Dep}\right) + PV_{O\&M} * (1-T)}{1-T} \tag{16}$$

Where Q_n is the energy produced or saved in year n.

When taxes are not considered, the LCOE can be calculated according to equation (17).

$$LCOE = \frac{I + \sum_{n=0}^{N} \frac{OM_n}{(1+d)^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d)^n}} \tag{17}$$

3.3 COST-BENEFIT ANALYSIS METHODS

The different investment valuation methods presented in section 3.2 have the aim to assess the economic interest of a potential project. However, it is not always easy to determine which costs and benefits are relevant for the investment project under analysis. Moreover, the assessment of projects in business ecosystems is not easy to perform, so some kind of guidance is needed.

In order to overcome such barriers, different Cost-Benefit Analysis (CBA) methods have been proposed. This section presents the most relevant CBA methods to be used in the electricity sector in general and in the smart grids field in particular. Although electro-mobility is not the focus of these methodologies, they can be used to assess EV-related investment projects.

3.3.1 Multi-criteria assessment versus CBA

The evaluation of different investment alternatives needs to define a set of criteria and a set of weights to determine the relative importance of each criterion. Defining the criteria (and their respective indicator) is critical in order to ensure that they are complete, non-overlapping, applicable, system-oriented, simple, reproducible, realistic, objective and documentable. Furthermore, defining the weights is even more critical and controversial, since it needs to consider the whole conception of values, which is inherently subjective. In general, multi-criteria analyses convert all the indicators into one-only, non-dimensional (in per unit) utility-value, which expresses the level of satisfaction of the society as a whole, in order to perform a weighted, linear combination of utility values to obtain the total value for society.

On the contrary, CBAs aim at converting all the indicators into a monetary unit. This approach permits avoiding the need to define weights, as all indicators are converted into a single, understandable unit. However, the difficulty here is the monetisation (i.e. the transformation into monetary values) of the different criteria. In any case, this monetisation is not deemed to be more difficult than quantifying the right utility value needed to perform the multi-criteria analysis. Moreover, the use of the monetary unit is expected to be more understandable by the business developer.

3.3.2 CBA methodology by the Joint Research Centre

The Joint Research Centre (JRC) is the science and knowledge service by the European Commission. Its mission is to support EU policies with independent evidence throughout the whole policy cycle [124], so it also acts as the in-house science service for the European Commission.

In 2011, the JRC conducted a comprehensive study about the different smart grids projects in Europe, both past and ongoing. The main outcomes of such study were:

- CBA was only considered in few projects.
- The lack of an established CBA methodology for smart grids project seemed to be among the reasons for it (other reasons included confidentiality issues and focusing on evaluating technologies, applications and solutions rather than on performing a CBA).

Therefore, and taking the work performed by the Electric Power Research Institute for the US as a basis, the JRC prepared a report describing the *Guidelines for conducting a cost-benefit analysis of Smart Grids projects* [123], which is also known as the JRC CBA methodology.

The JRC provides a methodological approach to estimate the costs and benefits of smart grids, by means of a step-by-step assessment framework, guidelines and best practices that fit the European context. The experience of one project for smart grids is also presented in the report, with the aim to link the proposed guidelines with a real implementation experience. The report builds upon several fundamental assumptions to perform the CBA:

- The best way to promote investments is to make a fair allocation of short-term costs and long-term benefits among the different stakeholders. In fact, smart grids projects are typically characterised by high initial costs and uncertain and, often, long-term benefit streams. As a result, the proposed CBA goes beyond the costs and benefits incurred by the actor(s) carrying out the smart grid project, by considering the project's impact on the entire value chain and on society as a whole.
- A smart grid project must be viable not only in economic terms, but also from social and environmental points of view. However, the impact of smart grid projects goes beyond what can be captured in monetary terms. Hence, the economic analysis (monetary appraisal of costs and benefits on behalf of society) is integrated with a qualitative impact analysis (non-monetary appraisal of non-quantifiable impacts and externalities, e.g. social impacts or contribution to policy goals).
- Local conditions have a significant impact on the CBA. Consequently, a comprehensive analysis of smart grids projects must be tailored to local conditions, such as geography, grid topology, typology of consumers and regulation. However, the CBA presented in the report provides a structured set of suggestions, as a checklist of important elements to consider in the analysis, which can be useful for a first assessment of the project, which must then be refined by considering local specificities.

The overall assessment of a smart grids project is then composed of the combination of an economic analysis and a qualitative impact analysis. Such qualitative impact considers both the entire value chain and the society as a whole and it also takes into account local and project-specific conditions. Both analyses are detailed in the following subsections.

3.3.2.1 Economic analysis

The goal of the economic analysis is to extract the range of parameter values enabling a positive outcome of the CBA and define actions to keep these variables in that range. It consists of three main parts, as presented in Figure 11.

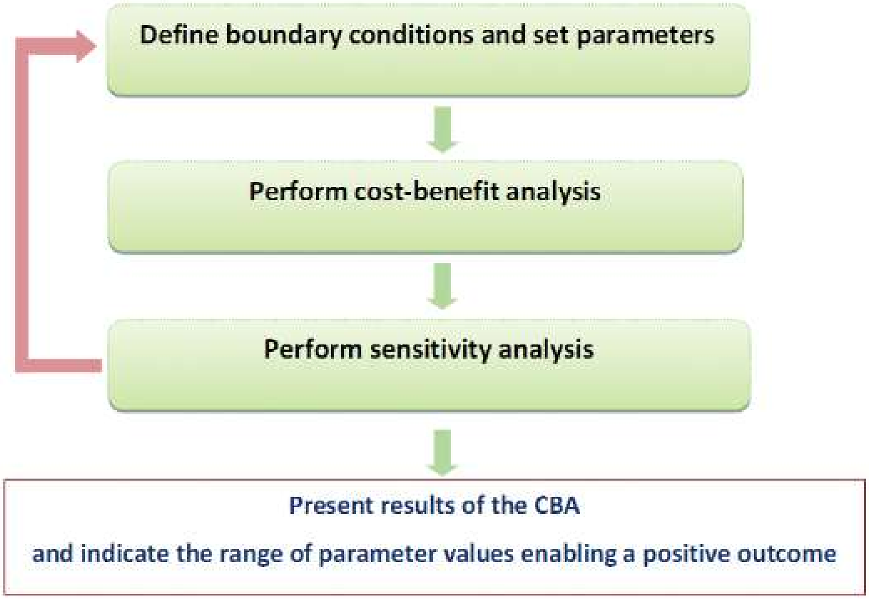


Figure 11: Framework for the economic CBA proposed by the JRC [123]

First, the boundary conditions must be defined and the parameters to be considered must be set, i.e. the main variables and assumptions must be stated. It is important to adapt them both to the specific project to be considered and to local conditions, but also to substantiate their validity. For this purpose, the data sources must be identified and their level of uncertainty should be expressed. For those variables or assumptions with high or moderate level of uncertainty and which may have a significant impact on the result of the CBA, a sensitivity analysis should be performed. Some of the typical parameters to be defined in this step include:

- The discount rate. For smart grids projects, the use of a “social discount rate” (the discount rate to reflect the value that a project can provide to society as a whole) is recommended. Hence, it should be in the range of 3.5 % - 5.5 % and subject to a sensitivity analysis.
- The time horizon for the CBA. Energy infrastructure projects are generally assessed during a period of 20 to 30 years.
- The schedule of implementation. It is especially important when the project will be implemented in multiple phases, as either the costs or the benefits may increase or decrease as the implementation rate increases. Some of the most important aspects to be considered (and which should also go through a sensitivity analysis) are the deployment time frame, the expected lifetime and the number of installed assets and their composition (urban vs. rural, concentrated vs. scattered).

- The impact of regulatory framework. The impact of regulations on the assumptions and, if needed, on benefits or costs, must be clearly stated. In particular, the roles of the different stakeholders must be defined.
- Macroeconomic factors. Inflation rate or carbon costs may also need to be taken into account.
- Implemented technologies. Design parameters, system architecture and technology may impact the CBA. Forecasts on technology development (either to account for cost reductions or to include new facilitating/competing technologies) must be considered.
- Electricity system characteristics. Peak load transfer and consumption reduction capabilities, expected trends of electricity demand and electricity price trends are other parameters to be defined before entering into the CBA.

Then, the core of the economic assessment is carried out by following seven steps, as also shown in Figure 12:

Figure 12: Steps for the economic CBA proposed by the JRC [123]

1. Review and describe technologies, elements and goals of the project: the project must be clearly defined, in terms of scale and dimension (e.g. consumers served, energy consumption per year…), technologies to be adopted, local characteristics of the grid, relevant stakeholders (all the actors affected directly or indirectly by the project must be identified) and regulatory context (and its impact on the project). In addition, the project's objective and its expected socio-economic impact must be clearly stated.
2. Map assets onto functionalities: the smart grid functionalities activated by the assets proposed by the project must be determined. The report provides a list of 33 smart grid functionalities, grouped in six main smart grid services and a template to make the mapping. The six services are:
    a. Enabling the network to integrate users with new requirements.
    b. Enhancing efficiency in day-to-day grid operation.
    c. Ensuring network security, system control and quality of supply.
    d. Better planning of future network investment.
    e. Improving market functioning and customer service.
    f. Enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management.
3. Map functionalities onto benefits: once functionalities have been identified, they can be mapped onto the potential benefits they can provide. Again, a list of 22 potential benefits, divided into ten sub-categories of four main categories (Economic, Reliability, Environmental and Security), and a template are provided in the report. Although not all functionalities must necessarily contribute to a given benefit, each of them must be analysed to check whether it contributes to any benefit.

    The links between assets and benefits through functionalities are not straightforward and require taking time to think. This need to think is useful to ensure a more complete set of estimated benefits and to facilitate the evaluation of the impact of the project through specific Key Performance Indicators (KPIs) to be used in the qualitative assessment.

    Moreover, the identification of benefits may become difficult in smart grid projects because a single smart grid benefit can be provided by a variety of technologies, software programs and operational practices, while some elements can provide benefits for more than one smart grid objective in ways that often impact each other.

4. Establish the baseline: the baseline is the system condition which would have occurred if the project had not taken place (scenario A), which is then compared to the realised and measured conditions with the smart grid system installed (scenario B).
5. Monetise the benefits and identify the beneficiaries: after having defined the baseline and the rest of scenarios to be considered, their benefits must be compared. It is recommended to use incremental or marginal costs and benefits associated with the smart grid project, so that only the differences between scenarios A and B are considered. For that purpose, a number of tasks must be performed:
    a. Identify and compile the data.
    b. Quantify the benefits. In smart grid projects, control groups can be used to determine the conditions in scenario A. The report [123] provides some guidelines about how to establish control groups.

   c. Monetise the benefits. The report provides some guidelines on how to monetise some smart grid benefits.
   d. Identify the beneficiaries. The whole value chain must be considered (not only to the party responsible for the implementation) and the right benefits must be allocated to each party. Benefits for society as a whole must also be considered.
   e. Assess uncertainty. Not all the benefits can be estimated with the same degree of confidence. In order to reflect this, it is recommended to assign an uncertainty level (modest, significant, high or non-quantifiable) to each benefit.
6. Identify and quantify the costs: these are the costs incurred by the project. Again, it is recommended to use incremental or marginal costs and benefits associated with the smart grid project (differences between scenarios A and B) and to consider them for the whole value chain. A thorough analysis is required because, on the one hand, all the cost items need to be considered, while, on the other, only the costs necessary and sufficient for the purpose of the project must be considered. Usually, costs can be measured by investing companies or proxies can be obtained in the marketplace. Taxes should not be incorporated in the CBA.
7. Compare costs and benefits: the incremental (or marginal) benefits and costs must be considered for the whole value chain or, at least, for the party responsible for the implementation and for consumers. The most common methods to compare them are the annual comparison (by depicting either the benefits and the costs or the net benefit on an annual basis), the cumulative comparison (the same, but with aggregated figures for each year), the NPV (section 3.2.1), the IRR (section 3.2.2) or the benefit-cost ratio (either on an annual basis or in present value).

Then, the outcome of the CBA is refined through a sensitivity analysis, which aims to identify the range of critical variables for which the CBA outcome is positive. The sensitivity analysis allows accounting for variations in local conditions (which may lead to different CBA results for different countries or regions) and to reduce the inherent risk of making forecasts into the long-term future (as usually required for smart grid projects). This way, the sensitivity analysis shows how the profitability of the project (in terms of NPV or IRR) is affected by variations in key quantifiable variables. Some of the most common parameters in sensitivity analyses for smart grid projects are:

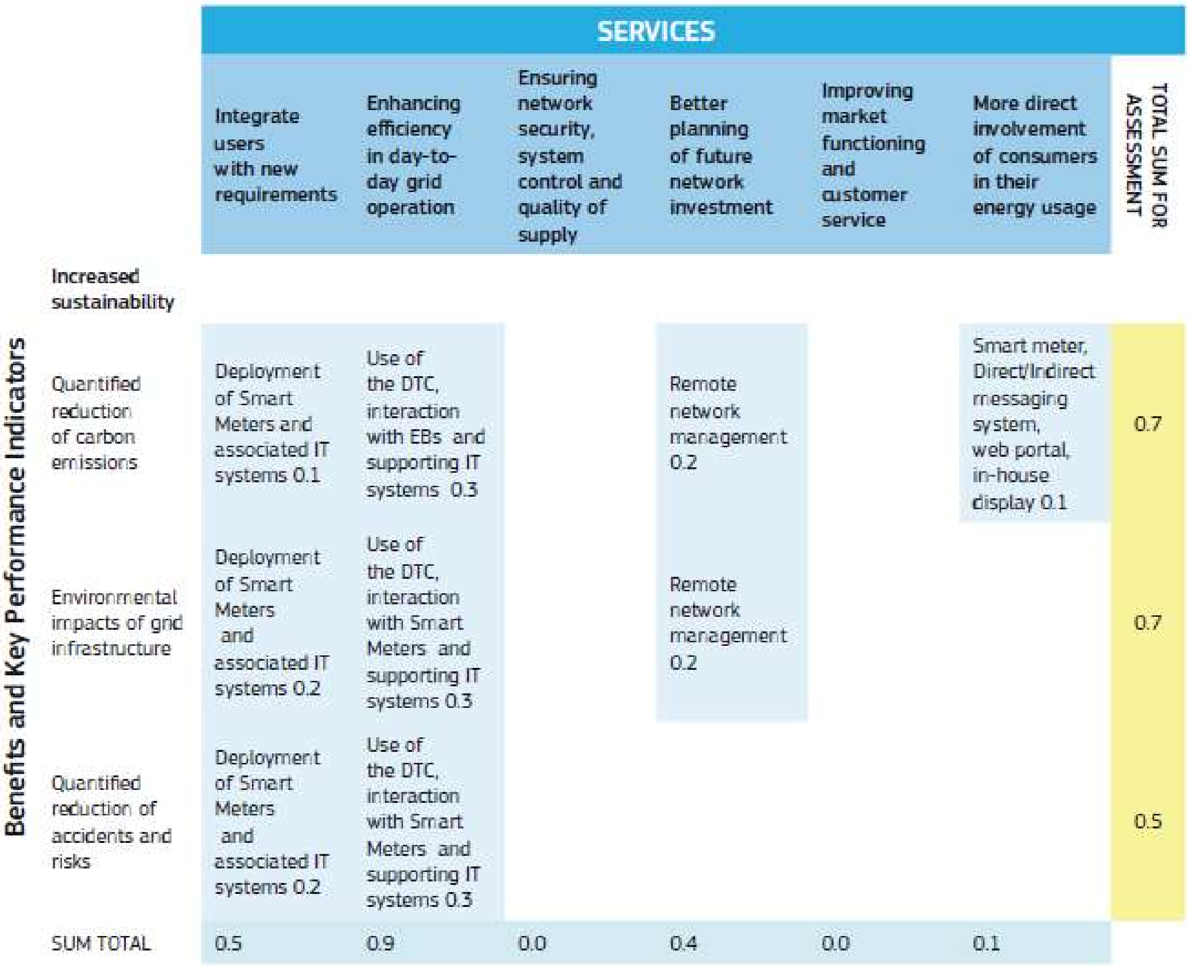
- Estimated growth rate of energy consumed and energy efficiency potential.
- Peak load transfer.
- Percentage of electricity losses at T&D level.
- Estimated number of non-supplied minutes.
- Value of lost demand.
- Discount rate.
- Implementation schedule.

3.3.2.2 Qualitative impact analysis

In addition to the impacts that can be expressed in economic terms, smart grids projects provide a number of benefits which are difficult to monetise, but which should be considered to provide the whole set of advantages of the project. However, these non-monetary impacts must be treated very carefully, especially if they are not supported by quantitative measures but on opinions or subjective judgements.

The non-monetary appraisal focuses on costs and benefits derived from broader social impacts like security of supply, consumer participation and improvements to market functioning. Such additional impacts can contribute to reach policy objectives and/or create externalities (either positive or negative) for society. Therefore, the analysis is made in two steps.

First, the performance of the project is assessed by capturing its deployment merit. For that purpose, the report provides both a list of KPIs to be linked to different potential benefits of smart grid projects and a merit deployment matrix, which combines KPIs (rows) and functionalities (columns). The matrix is used to identify the links between KPIs and functionalities and to give weights to quantify how strong each link is. The weights considered here must reflect the relative importance of each criterion for the decision-maker and must be suitable to combine the quantitative and qualitative analysis. By adding the impacts of the links in a column, the impact of the project in terms of functionalities can be estimated, while adding the impacts in a row shows the effect of the project in terms of benefits. An example is shown in Figure 13.



Benefits and Key Performance Indicators	SERVICES						
	Integrate users with new requirements	Enhancing efficiency in day-to-day grid operation	Ensuring network security, system control and quality of supply	Better planning of future network investment	Improving market functioning and customer service	More direct involvement of consumers in their energy usage	TOTAL SUM FOR ASSESSMENT
Increased sustainability							
Quantified reduction of carbon emissions	Deployment of Smart Meters and associated IT systems 0.1	Use of the DTC, interaction with EBs and supporting IT systems 0.3		Remote network management 0.2		Smart meter, Direct/Indirect messaging system, web portal, in-house display 0.1	0.7
Environmental impacts of grid infrastructure	Deployment of Smart Meters and associated IT systems 0.2	Use of the DTC, interaction with Smart Meters and supporting IT systems 0.3		Remote network management 0.2			0.7
Quantified reduction of accidents and risks	Deployment of Smart Meters and associated IT systems 0.2	Use of the DTC, interaction with Smart Meters and supporting IT systems 0.3					0.5
SUM TOTAL	0.5	0.9	0.0	0.4	0.0	0.1	

Figure 13: Example of merit deployment matrix in the CBA proposed by the JRC [123]

Then, as a second step, externalities (costs and benefits that a project creates for society) and social impact are taken into account. A complete list of externalities must be made and they should be expressed in physical terms, by using an indicator. In order to make the assessment as objective and rigorous as possible, the reasons for choosing and the way to calculate each indicator must be clearly stated. Moreover, the social impact must also be assessed, including the impact of the project in aspects such as jobs, safety, environmental impact, social acceptance, time lost/saved by consumers, enabling both new service or applications and market entry for third parties, ageing workforce, or privacy and security.

3.3.3 ENTSO-E guideline for CBA of grid development projects

The European Network of Transmission System Operators for Electricity (ENTSO-E) represents 43 TSOs from 36 European countries [125]. It was established and given legal mandates by the EU to facilitate the liberalisation and the creation of the internal electricity market [47]. One of the duties requested by the EU was the publication of a methodology for a harmonised energy system-wide CBA at EU-level for projects of common interest [126]. Such methodology, which is summarised in this subsection, was first published in 2015 [127] and it will be reviewed periodically. A second version of the CBA methodology [128] was expected to be released in spring 2017, but, by August 2017, it has not been delivered yet.

The objective of the CBA methodology by ENTSO-E is to establish a common framework for analysing all the candidate projects of common interest to become part of the pan-European Ten Year Network Development Plan. The report describes the common principles and procedures (including network and market modelling methodologies) required to perform the multi-criteria CBA, in order to compare the contribution of each candidate project to different indicators on a consistent basis. The aim is to characterise the projects both in terms of the added value they provide for the European society and in terms of costs. Some benefits and project impacts on society are difficult to monetise and, besides, the results of the assessment are highly dependent on the assumptions taken for scenarios and their time-horizons. Therefore, the methodology does not compare costs and benefits, but it provides all of them as information.

The CBA is designed to be used only with transmission (or storage) projects that affect transfer capabilities between individual TSOs or price zones (if they also affect the internal capability of one or more TSOs' networks, the affected TSO's internal standards would also apply). However, it is not intended to be used for cross-border cost allocation. Furthermore, it is intended to assess the impact of projects on a Europe-wide basis (or, at least, the ENTSO-E region and its closest neighbours), since the CBA is intended to identify the projects which are the best for the European power system.

Since the installation of new transmission infrastructure can take more than 10 years, the methodology uses scenarios (future trends) and planning cases (specific situations in certain points in time), in order to deal with the inherent uncertainty of long-term planning. ENTSO-E proposes to use both a top-down (to use ENTSO-E's System Outlook and Adequacy Forecast, so that scenarios present a common macro-economic and political view for the whole EU's electricity system) and a bottom-up (to look at the national legislations in force at the date of the analysis and/or formally consulting MSs and the organisations representing all relevant stakeholders) approach. Scenarios are a coherent, comprehensive and internally consistent description of a plausible future (in general composed of several time horizons) built on the imagined interaction of economic key parameters (including economic growth, fuel prices, CO_2 prices, etc.). Therefore, their main three components are the forecasts for the generation portfolio (installed power, type of generation, etc.), demand (rate of growth, impact of energy efficiency measures, shape of the demand curve, etc.) and the exchange patterns with the systems outside the region to be analysed. ENTSO-E recommends using scenarios which are representative of, at least, two time horizons of mid-term horizon (5 to 10 years), long-term horizon (10 to 20 years) and very long-term horizon (30 to 40 years). Intermediate points in time can also be used by interpolation techniques. Scenarios are aimed at constructing contrasting future developments which differ enough from each other to capture a realistic range of possible future pathways and, hence, different challenges for the grid. Consequently, the report proposes to define one reference scenario (created top-down by considering both the EU 2020 targets [129] and the European Energy roadmap 2050 [130]) and some variations (created either top-down or bottom-up) in different directions. For example, in the Ten Year Network Development Plan 2014, variations were assumed in the pace of implementation of energy decarbonisation and in the degree of integration of the electricity market, leading to four visions:

- "Slow progress": failure to meet decarbonisation objectives and low integration.
- "Money rules": failure to meet decarbonisation objectives but high integration.
- "Green transition": success in meeting decarbonisation objectives but low integration.
- "Green revolution": success in meeting decarbonisation objectives and high integration.

The methodology also provides the minimum set of technical and economic parameters which must be defined for each scenario. When selecting the number of scenarios to be analysed, a compromise must be met between robustness (the number of scenarios should be large enough to get a complete picture of the effects that a project may have under different possible future conditions) and workload (the calculations under each scenario must be sufficiently detailed and accurate).

Based on scenarios, market and network studies are performed to identify representative planning cases. Market studies are used to calculate the dispatch of generation units and load along the year on an hourly basis, by using a very simple model of the physical grid, where bidding areas are represented as nodes interconnected by single branches, without taking into account grid constraints within bidding areas. Network studies, on the contrary, contain full details of the physical grid and are used to calculate the actual flows that take place in the network under given generation/load conditions. Therefore, market studies reflect structural bottlenecks, while network studies show incidental bottlenecks, so they complement and provide feedback to each other. Through an iterative process, the Grid Transfer Capacity (GTC), i.e. the ability of the grid to transport electricity across a boundary[17], can be calculated on an annual basis. From this GTC calculation, the most

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[17] A boundary represents a bottleneck in the power system where the transfer capacity is insufficient to accommodate the likely flows that will need to cross them, so it can result from generation (generation accommodation), consumption (security of supply) or market-driven flows (market integration). Bottlenecks may appear between or within a country and they may be fixed or variable in time.

representative planning cases can be selected and used to determine the required grid development needs. Planning cases represent one specific point in time (winter/summer, peak/off-peak hour, year, etc.), with its corresponding generation (wind conditions, hydro inflows, forced or planned unavailability of power plants, etc., together with the scheduled dispatch programme), demand, power exchange with neighbouring regions (including international flows) and environmental conditions (temperature, which not only affects demand and generation, but also the technical capabilities of grid elements), as well as the detailed location of generation and demand and the expected grid development.

If transmission weaknesses are identified, grid reinforcement is needed. The transmission grid may be reinforced by means of projects or clusters of projects. A project is the smallest set of assets that effectively add capacity to the transmission infrastructure that can be used to transmit electric power, such as one transformer and one overhead line. Typical projects include reinforcement of overhead circuits to increase their capacity, duplication of cables to increase rating, extension and construction of substations, installation of reactive-power compensation equipment, etc., but not reallocation of generation, assumption of new demand-side services or generator inter-trips (even if generator inter-trips can be used in emergency situations, they should not be regarded as a structural measure). On the contrary, a cluster of projects is the combination of a main project which is built to increase GTC[18] and one or more supporting projects which must be developed in combination with the main project, so that the latter is able to increase GTC as intended. ENTSO-E establishes a number of conditions for projects to be clustered: they must achieve a common measureable goal (competitive projects cannot be clustered), their commissioning dates cannot be more than 5 years apart from each other and the secondary project(s) must contribute to obtaining at least 20 % of full potential of the main project. More than one additional project can be considered, as long as the first additional project did not help reach the full potential.

The project (or cluster of projects) is then assessed in terms of benefits, costs and impact on society, by using a combined cost-benefit and multi-criteria assessment. In order to comply with the requirements in [126], benefits are expected to contribute to EU network objectives (develop a single European grid to reach EU climate policy objectives, guarantee security of supply, complete the internal energy market and ensure technical resilience of the system), costs must be measurable (especially to check environmental and social viability) and indicators must be as simple and robust as possible (so some of them use simplified methodologies).

As in the case of the JRC methodology, ENTSO-E considers both monetary and non-monetary indicators to assess the economic, social and environmental viability of the project (Figure 14 [127]).

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[18] GTC increase is calculated for stressed network situations in order to highlight the contribution of the reinforcement. Since GTC may vary over the year, it can be provided as a range in MW (maximum and minimum), but the value obtained must be valid at least 30 % of the time. A project with a GTC increase of, at least, 500 MW is considered to have a significant cross-border impact.

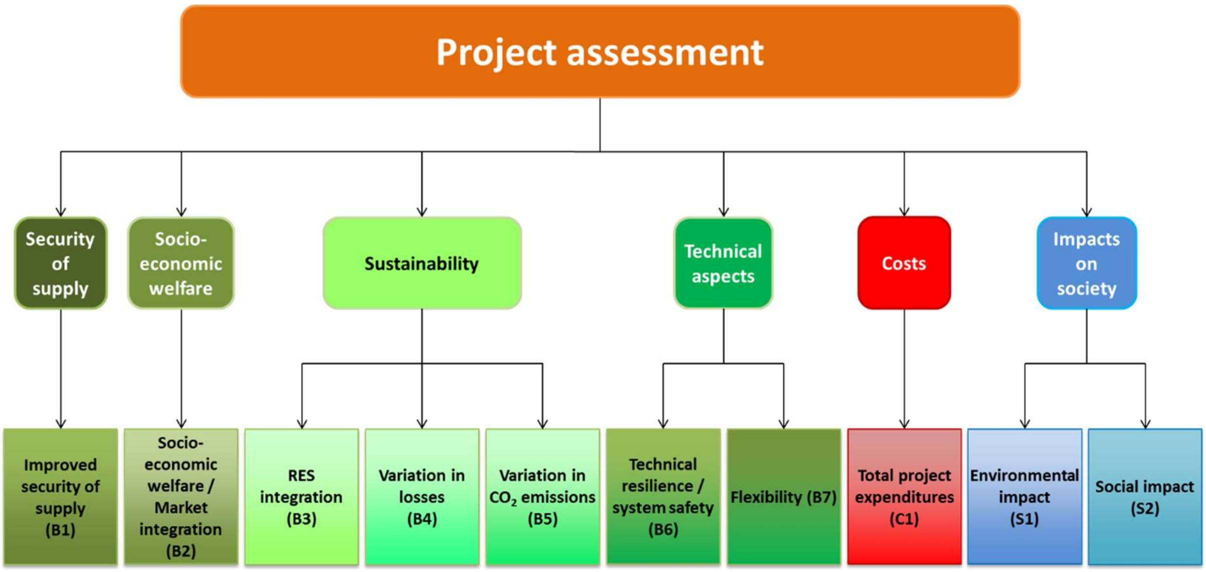

Figure 14: Main categories and indicators of the CBA methodology by ENTSO-E

Benefit (B), cost (C) and environmental and social impact (S) indicators are briefly discussed below:

- Improved security of supply (B1) is the ability of the power system to provide adequate and secure supply of electricity under ordinary conditions.
- Socio-economic welfare (B2) is the ability of the power system to reduce congestion and, as a result, provide adequate GTC so that electricity markets can trade power in an economically efficient manner.
- RES integration (B3) is the ability of the power system to allow the connection of new RES plants and unlock existing and future RES generation, while minimising generation curtailments.
- Variation in losses (B4) is the evolution of thermal losses in the power system.
- Variation in CO_2 emissions (B5) is the evolution of CO_2 emissions in the power system.
- Technical resilience / system safety (B6) is the ability of the system to withstand increasingly extreme conditions (exceptional contingencies).
- Flexibility (B7) is the ability of the proposed reinforcement to be adequate in different possible future scenarios, including trade of balancing services.
- Total project expenditures (C1) include material and assembly, temporary solutions needed to realise the project (e.g. building a temporary line to keep the supply, but which will be dismantled afterwards), dismantling at the end of the project lifetime, devices which have to be replaced within the project lifetime and maintenance.
- Environmental impact (S1) characterises the project impact assessed through preliminary studies and aims at giving a measure of the environmental sensitivity associated with the project.
- Social impact (S2) characterises the project impact on the population that is affected by the project, assessed through preliminary studies, and aims at giving measure of the social sensitivity associated with the project.

Some projects will contribute to all benefit categories, while others will only contribute significantly to some of them. In addition, other benefits may exists (e.g. increase of competition) but, since they are difficult to model, they are not included in the methodology. As the scope of the methodology is the whole ENTSO-E area, the same discount rate and lifetime are taken into account to calculate the benefits of all projects (regardless of the MS they are located in): 4 % and 25 years.

By building up different planning cases, the grid development needs for a certain scenario can be identified. In general, system planning studies are based on a deterministic analysis, which takes into account several representative planning cases. At least, two carefully considered macro-economic scenarios must be taken into account. Yet, the likelihood of risks of grid operation (and their uncertainties) can also be assessed through a probabilistic approach, where multiple cases are created, depending on the variation of some uncertain variables. In this case, the variables to be considered (demand, generation availability, RES production, exchange patterns, availability of network components, etc.) must be identified, their values and probability of occurrence must be estimated and a planning case must be built and analysed for each variable and value. Then, results must be analysed, which requires the use of a statistical tool, but critical cases not known in advance may be found.

3.3.4 SWOT analysis

SWOT analysis is a structured planning method to evaluate four elements of a project or a business venture: Strengths, Weaknesses, Opportunities and Threats. Each of these elements reflects internal or external factors which are favourable or unfavourable for the project or business under analysis:

- Strengths are internal advantages of the project.
- Weaknesses are internal disadvantages of the project.
- Opportunities are external advantages for the project.
- Threats are external disadvantages of the project.

In any case, these factors relate to the relative advantages or disadvantages of a project or a business venture, when compared to competitors (either projects or companies), in order to obtain a defined objective. The factors are usually represented as a 2x2 matrix, as shown in Figure 15.

Figure 15: SWOT analysis matrix

Candidate internal factors to become strengths or weaknesses include price, product, promotion (communication channels with customers, marketing), place (location), people (personnel capacities), process (manufacturing capabilities, etc.) and financing. As for external factors, macroeconomic trends, technological change, legislation, socio-cultural changes, competitive position and changes in the marketplace are usually considered in the analysis.

SWOT analysis can be used to define the strategy of the company, especially during the growth phase for the business. For that purpose, after the SWOT analysis is made, the most important factors should be selected and evaluated and relationships between them must be identified.

In some cases, the company may try to match strengths and opportunities to increase the value of the project or the business, while, in some others, weaknesses or threats can be converted into strengths or opportunities by e.g. finding new markets. However, it is not always easy to identify the actions to be taken after the SWOT analysis to define the strategy.

Another drawback of this method is that the analyst may only list the factors in each category, without a critical thinking of their importance. Moreover, making a critical analysis of the factors requires experience and introduces a subjective bias in the results, which may also reduce the appeal of this method.

3.4 BUSINESS MODELS ANALYSIS METHODS

In section 3.3, some of the main methods to analyse projects have been described. When the same principles are applied to whole companies, the analysis can focus on the business model for the company.

3.4.1 Business model definition

Although it is a widely used term in the business environment and in academia, there is no single definition of the term *business model* [14], [15], [16], [23], [66], [131], [132], [133]. In general, business model definitions include three common elements:

1) How value is created,
2) How value is delivered and
3) How value is captured.

Other usual elements in business model definition are the design of the content, structure and governance of transactions [66].

One of the reasons for such different understanding of the term may result from the different orientation of people using it: business-oriented people tend to focus on the value/customer-oriented approach (outward looking), while technology-oriented people are more prone to understand it with an activity/role-related approach (inward looking). Another reason for discrepancies is that, although most authors focus on the “business” part of the term, the degree of definition of the “model” part varies widely: some authors just refer to the way a company does business, while some others emphasise the model aspect and conceptualise that way of doing business. A third level of difference in the use of the term results from the level of abstraction or concretion that the author is considering [134]:

1. Level 1 – Overarching Business Model Concept: the business model is seen as an abstract concept that allows describing what a business does for a living. It may include just an idea of what a business model is or it may include meta-models to define what elements are to be found in a business model. Even within meta-models, different levels of conceptualisation can be found.
2. Level 2 – Taxonomies: the business model is classified into a type or a meta-model type, according to some common characteristics. As in the case above, different levels of conceptualisation are possible. Taxonomies may apply to businesses in general, but also to specific industries (WLAN, computing, mobile-games…).
3. Level 3 – Instance: the business model is a specific example of (or a conceptualisation, representation and description of) a real-world business. This approach is used to analyse specific companies.

The business model concept also evolved over time, starting from simple definition and classification of business models, then listing (not describing) the components of a business model, continuing with a detailed description and representation (as building blocks) of business models components and reaching a stage of conceptual modelling of business models components where business models ontologies[19] were created. Finally, reference models started to be used in real-life applications.

This thesis focuses on the last steps of the evolution of the concept, so it is based on the conceptual level (Level 1). Therefore, the “model” part of the term is emphasised and a value/customer-oriented approach (outward looking) is taken. This is also the approach of two of the most widely used business model analysis methodologies: Business Model Canvas [136] and e^{3}value [137], which are described in the following sub-sections. These authors state that “*a business model consists of a set of elements and their relationships and expresses the business logic of firms*” [135] and “*a business model describes the rationale of how an organization creates, delivers and captures value*” [136].

It is important to distinguish a *business model* from a *business plan*. According to [136], a business plan is aimed at describing and communicating “*a for-profit or non-profit project and how it can be implemented, either inside or outside an organization*” and has a the following structure:

1) The team. This component must highlight why the team is the right one to successfully build and execute the business model proposed, including their experience, knowledgeability and connections. It is therefore focused on the management team, but the rest of the team must also be taken into account.

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[19] An ontology is a theory of what exists, so a business models ontology describes what a business model actually is. Hence, ontologies aim at creating a shared, formal and explicit conceptualisation of a business model: they create a model of reality (concept) which is interpreted identically by all stakeholders (shared), which can be supported and analysed by a machine (formal) and which is written down (explicit) [135].

2) The business model. This component describes the vision, mission and values of the business idea, how it works, its target markets, the marketing plan and the key resources and activities.
3) Financial analysis. This component includes total cost, revenue and cash-flow projections, which determine the funding requirements for the company. The analysis should also include an estimation of how many customers can be acquired, break-even analysis, sales scenarios and operating costs, as well as capital expenditures.
4) External environment. This component describes the position of the business model with respect to the external environment and highlights its competitive advantages.
5) Implementation roadmap. This component shows how long it will take to implement the business model and which steps and milestones must be reached. An outline of the implementation agenda by means of e.g. a Gantt chart is also required.
6) Risk analysis. This component describes the limiting factors and obstacles, as well as critical factors. It can be derived from a SWOT analysis.

3.4.2 Canvas model

As described in section 3.4.1, there are many ways to understand what business models are. Consequently, there is no structured way to invent, design and implement business models. The main aim of an innovative business model may be:

- To satisfy existing but non-solved market needs.
- To bring new technologies/products/services to the market.
- To improve, disrupt or transform an existing market with a better business model.
- To create an entirely new market.

When a business developer identifies a business idea which may answer to one or several of the alternatives above, he or she may find it difficult to explain that business idea to investors or managers in their company. In order to help business developers in that process, [136] describes the Canvas model to present a business model in a direct and understandable way.

The Canvas model is composed of nine building blocks, which cover the four main areas of a business model, i.e. offer, customers, infrastructure and financial feasibility:

1. Customer segments. They are the different groups of people or organisations that the business model aims to reach and serve. A business model may target one or more customer segments. A group of customers becomes an independent customer segment if they have different needs which justify a distinct offer, they are reached through different distribution channels, they require different types of relationships, they provide substantially different profitability amounts and they are willing to pay for different aspects of the offer. Examples of customer segments include mass market, niche market, segmented customers (e.g. with incomes above certain threshold) or diversified customers (with the same resources, a company may offer different services to completely different customer segments).
2. Value propositions. It is the bundle of products and services that create value for a specific customer segment, i.e. it seeks to solve customer problems and satisfy customer needs with value propositions. A single business model may have one or more value propositions for different customer segments. The value proposition is the aggregation

of benefits that a company offers to customers, either through a new product/service or by an existing market offer but with added features and attributes. Novelty, performance, customisation, design and price are examples of value proposition.

3. Channels. Value propositions are delivered to customers through communication, distribution and sales channels. This building block describes how the company communicates with and reaches its customer segments to deliver the value proposition. Channels are the company's interface with customers and include functions such as raising awareness among customers about the company's products and services, allowing customers to purchase those products and services, delivering the value proposition to customers and providing post-purchase customer support. Different types of channels may be used during the different phases of value deliverance: awareness, evaluation, purchase, delivery and after-sales.
4. Customer relationships. They describe the types of relationships that the company establishes and maintains with each customer segment. Relationships may be personal or automated and may aim at acquiring customers, retain customers or boost sales (usually in early stages of business development). Some alternatives are personal assistance (generic or dedicated to each individual client), self-service, automated services, communities or co-creation.
5. Revenue streams. They result from value propositions successfully offered to customers, i.e. they represent the cash[20] that a company generates from each customer segment. Revenue streams may be one-time or recurring (when customers' loyalty is obtained or when a post-purchase customer support is provided). Revenue streams may be created by asset sales, usage fees, subscription fees, lending/renting/leasing, licensing and advertising. In addition, revenue streams depend on the pricing mechanism, which may be fixed (fixed list prices, product feature dependent, customer segment dependent, volume dependent…) or dynamic (negotiation, auctions, real-time market, yield management…).
6. Key resources. They are the assets required to offer and deliver previously described elements in order to make the business model work. Key resources can be physical (manufacturing facilities, buildings, vehicles, machines, systems, etc.), financial (cash, lines of credit, etc.), intellectual (brands, proprietary knowledge, patents, etc.) or human. In addition, they can be either owned or leased by the company, or even acquired from key partners (see bullet 8 below).
7. Key activities. They are the most important things that a company must do to make its business model work. Key activities can relate to production (designing, making and delivering a product), problem-solving (providing consultancy and other services, such as health, legal support, etc.) or platform/network (networks, matchmaking platforms, software and some brands).
8. Key partnerships. They describe the network of suppliers and partners that make the business model work. The main four types of partnerships are strategic alliances between non-competitors, strategic partnerships between competitors (coopetition), joint ventures to develop new businesses and buyer-supplier relationships to assure reliable supplies. These partnerships may intend to optimise the business model and to

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[20] It should not be confused with earning, which are obtained by subtracting costs from revenues.

benefit from economy of scale (non-critical resources and activities may be outsourced and some infrastructure may be shared), reduce risk (e.g. competitors may cooperate to create new products/technologies whose success is uncertain) or acquire resources (e.g. to acquire knowledge, licenses or access to customers).

9. Cost structure. It describes all costs incurred to operate the business model. Although all companies aim at reducing their costs, business models may be either cost-driven (the focus is to minimise costs as much as possible) or value-driven (the focus is to create value for customers, leaving cost as a second-order priority). Cost structure is composed of fixed costs (not depending on the volume of goods or services provided), variable costs (depending on the volume of goods or services provided), economies of scale (costs per unit can be reduced as the size of a business increases) and economies of scope (costs per unit can be reduced if more than one field of operation is used, e.g. if the same distribution channel can be used for different activities).

The graphical representation of the Canvas model is depicted in Figure 16.

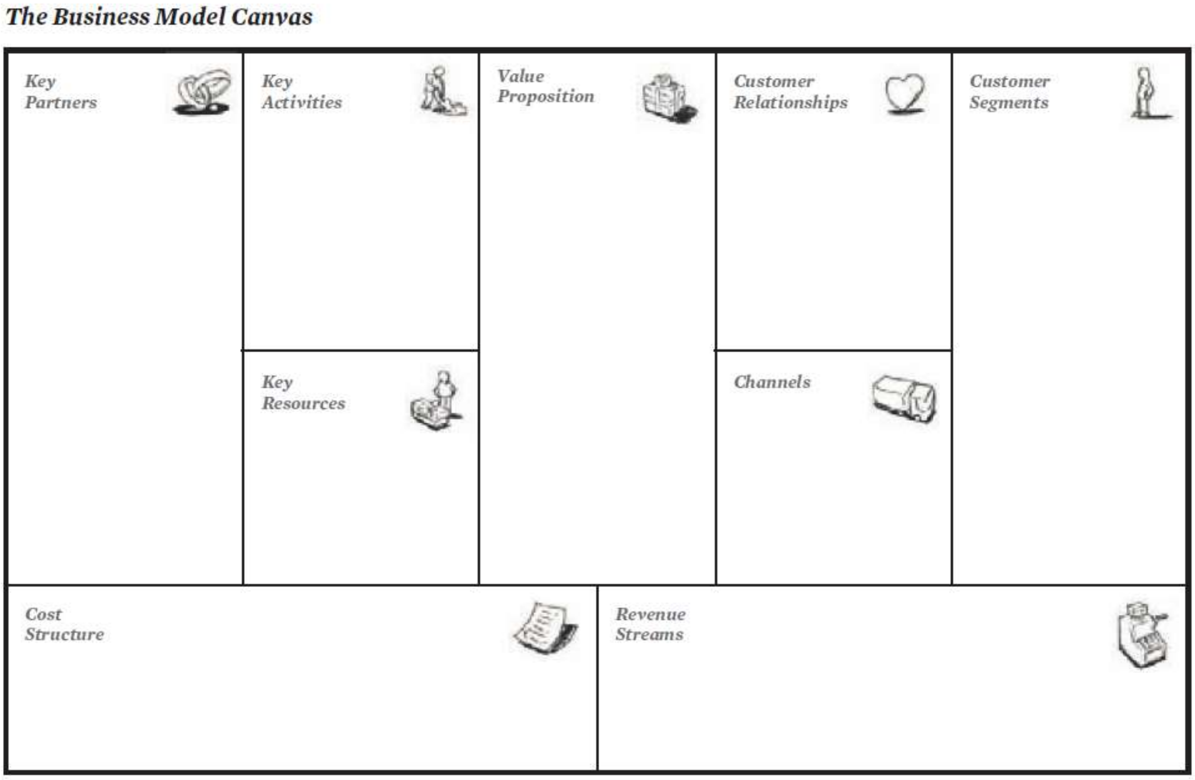

Figure 16: Canvas model [136]

The Canvas model can be very helpful in the early stages of business development. First, the business idea must be outlined, which can be done by drawing a simple model in the canvas and describing the idea using only key elements, i.e. the value proposition and main revenue streams (i.e. outline & pitch a rough idea). Then, a more elaborated canvas can be developed to explore all the elements needed to make the business model work. Next, the detailed canvas should be turned into a spreadsheet to estimate the business model's earning potential to examine the viability of the idea, and finally a field test may be performed to investigate customer acceptance and feasibility.

Additionally, [136] provides a number of useful hints for designing the business model:

- Customer insights. It consists on viewing the business model through customers' eyes. This means that customer perspective must be included when evaluating a business model, not just asking them what they want, but developing a deeper understanding of customers' wills. In particular, customers must be considered when choosing the value proposition(s), distribution channels, customer relationships and revenue streams.
- Ideation. This technique aims at using a creative process for generating a large number of business model ideas and successfully isolating the best ones. For that purpose, the authors propose to ignore the *statu quo* and challenge orthodoxies (the power of "what if" questions), as well as to forget about competitors and about the past, in order both to look into the future to envisage what is possible to happen and to identify needs which are unsatisfied or undiscovered. The innovation for an innovative business model may be resource-driven (use existing infrastructure or partnership to expand or transform the business model), offer-driven (creation of new value propositions), customer-driven (satisfaction of a new customer need, facilitation of access to customers or increase in convenience for customers), finance-driven (new revenue streams, pricing mechanisms or reduced cost structures), or even emerge from several epicentres. A SWOT analysis may also be helpful in this process.
- Visual thinking. The use of visual tools, such as pictures, sketches, diagrams and stickers is very helpful to understand what a business model is about. Since business models are systems where each component affects the rest of the elements in the canvas, these tools permit capturing the whole picture and facilitate a common understanding of the business model idea. Moreover, visual thinking allows uncovering many tacit assumptions, converting abstract concepts into concrete objects and adding, removing or moving components to the business model in a smoother way.
- Prototyping. Prototypes are tools aimed at discussing, inquiring or making the proof-of-concept of a business model. Therefore, they are powerful instruments to develop new, innovative business models, as they make abstract concepts tangible and facilitate the exploration of new ideas. Rather than considering a prototype as a rough picture of what the actual business model will look like, it is a thinking tool that helps the business developer explore different directions that the business model can take. This way, the planner can challenge the initial business model idea by considering new customer segments, channels or allies, of removing costly items or adopting innovative pricing strategies. The aim is to add, replace and/or remove elements to explore new and, perhaps (or not), absurd ideas. This prototyping process is iterative in nature, until the business developer analyses the pros and cons of each alternative and selects the best one for the company. A business model prototype can range between a rough sketch of an idea (e.g. in a napkin) and a detailed business model canvas representation or even a field-testable business model.
- Storytelling. Since new or innovative business models can be difficult to describe and/or understand, communicating them as a story can be very helpful to overcome the likely resistance to their novelty. In other words, storytelling helps the business developer communicate and explain the business idea, while the audience can more

easily dive into the business details. A good story is a compelling way to quickly outline a broad idea (how it will create value for customers and how it will make money doing so) before getting caught into the details, as well as to blur the lines between reality (present business model) and fiction (the future of your business model). The story can be told from the perspective of the employee (what he or she discovered to solve customer problems or to make a better use of resources, activities or partnerships) or from the perspective of customers (what he or she needs i.e. what he or she is willing to pay for, how the company can create value for him or her, and with which resources and activities). Adding emotion to the story (especially if the customer perspective is taken) is always a good point, but the general tone of the story must be authentic.

- Scenarios. The function of scenarios is to inform the business model development process by making the design context specific and detailed. There are two types of scenarios: the ones which describe customer settings (how products and services are used, which kinds of customers use them, or which the main customers' concerns, desires and objectives are) and the ones which describe future environments where the business model may compete. The use of this second type of scenario is called "scenario planning" in literature and it is very useful to anticipate potential future conditions for the business model and its environment. The idea of scenario planning is not to predict the future, but to prepare for the future, by envisaging potential changes and checking the robustness of the business model and its ability to adapt to those changes. Scenarios are very useful when designing the business model and they are usually more efficient than brainstorming when thinking about possible future business models, but developing several scenarios is usually costly, depending on their depth and realism. Therefore, it is recommended to develop a set of future scenarios (between two and four) based on two or three main criteria, then describe each scenario with a title and a story that outlines its main elements, next develop one or more appropriate business models for each scenario and, finally, identify common points in the business models developed for each scenario.

The business developer can also use some "business models patterns" or archetypes of business model as an inspiration to build up their own business model:

- Unbundling. There are basically three types of core business (customer relationship, product innovation and infrastructure), which have different necessities. Although all of them may coexist in a single company, the unbundled business model pattern refers to companies that focus on just one of them and outsource or create alliances for the other two, in order to avoid undesirable trade-offs created by the economic, competitive and cultural differences of the three types. An example of this pattern is the mobile telecom company, which focused on the customer relationship and outsourced product innovation to content providers (Netflix…) and infrastructure management to equipment manufacturers (Ericsson, Nokia-Siemens…).
- The Long Tail. It consists on offering a large number of niche products, each of which sells relatively infrequently. Usually, niche products can provide higher revenues per unit, but they are sold in low figures, so aggregating many niche products can be a very lucrative activity. In addition, inventory costs can be reduced, if strong channels are available to facilitate product visibility and to make the content readily available for customers. Examples of this business model include Netflix (large portfolio of

non-blockbuster films) or eBay (large amount of sellers and buyers of niche products).

- Multi-sided platforms. This business model pattern brings together two (or more) interdependent customer groups to a platform which creates value by facilitating the interactions between those groups (intermediation), so it is of interest for a group of customers only if the other group(s) of customers is also present. The value created for customers on one side grows with the number of users on the other sides. They often face the “chicken and egg” dilemma, i.e. how to create value to multiple sides if there is no customer in any of them. One alternative to overcome this problem is to subsidise one of the customer segments to attract customers on the other side(s). Visa or eBay are examples of this pattern of business model.
- FREE. In this pattern, at least one substantial customer segment is able to continuously benefit from a free-of-charge offer. For that purpose, another part of the business model must finance those non-paying customers. Main alternatives include multi-sided platforms (advertising or other types of platforms where only one of the sides pays), “freemium” (free basic services with optional premium services which must be paid for) and “bait & hook” (a free or inexpensive attractive initial offer which “captures” customers to make them repeat purchases: free phones in exchange for subscription to telecoms, razor and blades…).
- Open. It consists in creating and capturing value by systematically collaborating with outside partners. For that purpose, the company may take ideas from outside to exploit opportunities within the firm, or it can provide ideas to external parties which can exploit them. It can be seen as a way to outsource R&D or to provide R&D to other parties.

It is also important to consider the environment for the business model, which is composed of four main areas:

- Market forces. They include aspects such as market issues (Where is the market heading?), market segments (Which is the most important segment? Which has the biggest growth potential? Which are declining? Are there any other peripheral segments which deserve attention?), customers’ needs and demands (What do they need? Which are the biggest unsatisfied needs? Where is demand increasing / declining?), switching costs (What binds customers to a company? Is it easy for them to find and purchase similar offers? How important is brand?), and revenue attractiveness (What are customers really willing to pay for? Where can the largest margin be achieved? Can customers easily find cheaper competing products and services?).
- Industry forces. The environment is made of suppliers and other value chain actors (Who are they? To what extent does the business model depend on them? Are there new players emerging?), stakeholders (the actors who influence the business model, who are they? How they influence and how much?), competitors (incumbents, who are they? Which is their competitive advantage/disadvantage? How is their canvas model?), new entrants (insurgents, who are they? How are they different? Which is their competitive advantage/disadvantage? How is their canvas model? Which barriers must they overcome?), as well as substitute products and services (Which product/service can replace ours? How much do they cost? Is it easy for customers to switch?).

- Key trends. The business model developer must consider existing and/or future technology trends, regulatory trends, societal and cultural trends, and socioeconomic trends (demography, wealth distribution, spending patterns, urban vs. rural…).
- Macroeconomic forces. In this category, there are the global market conditions, the situation of capital markets, economic infrastructure (public services/infrastructures: transportation, school quality, health care, other public services; trade, access to suppliers and customers, taxation, quality of life…) and the trends of commodities and other resources.

The combination of this analysis of the environment and a detailed assessment of each of the nine building blocks in the canvas model, may also be used to perform a SWOT analysis, not only for the business model as a whole, but also for each of the building blocks, in order to identify potential risks or opportunities for the business model. Some hints to perform it are provided in [136].

3.4.3 e^{3}value

e^{3}value is a conceptual modelling[21] approach aimed at facilitating the statement, communication and understanding of the value proposition[22] of an innovative business idea. In addition, it is also designed to allow for a rigorous evaluation of its economic feasibility. As a third goal, it also intends to build the bridge between the expression of the business idea and the identification of the required supporting information systems, in order to avoid the usual thinking of information and communication technologies (ICTs) as an expense only, rather than as a tool to create value for customers and the company itself.

e^{3}value was created to provide answers to the main challenges of the e-commerce development in the times of the turn of the century and it was thereafter adapted to analyse services for the energy market [139]. Many e-commerce ideas have failed because they did not have a sound and clear value proposition. A value proposition must be sound (so that each entity involved can make profit or increase its economic utility) and it must be clear (because customers hesitate to adopt new products or services if their added value is not obvious or if they are considered to be too complex). In other words, all the stakeholders involved in the business idea must be able to make profit or to increase their economic utility, and all of them must have a common understanding of the value proposition.

e^{3}value uses a semi-formal, conceptual approach, which is founded in the conceptual modelling techniques borrowed from the requirements engineering arena, to analyse the economic value creation, distribution and consumption in a multi-actor network (including business ecosystems). This way, the requirements engineering perspective is extended to include the point of view of the value-based requirements engineering, which is "*an approach that takes into account the economic value perspective when developing ICT-*

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[21] "*A conceptual modelling approach comprises the activity of formally defining aspects of the physical and social world around us for the purpose of understanding and communication. Formal in this context means the abstraction, structure and representation of knowledge in a way that makes it possible to reason about this knowledge*" [138].

[22] A value proposition is "*something offered by a party for consideration or acceptance by another party*" [138].

intensive products through an iterative and co-operative process of analysing a business case, documenting the resulting observations in a variety of representation formats, and checking the accuracy of the understanding gained" [138]. The main characteristics of e^{3}value are described below:

- It is **lightweight**. Many times, innovative business models need to be created within short development times and with only limited manpower available. A lightweight methodology is required to avoid demanding non-available resources.
- It takes a **multi-viewpoint** perspective. Exploration of innovative business ideas is a very complex task. On the one hand, the idea must be articulated before its nature and consequences can be seen. Although this holds true for most businesses, when there is a strong technological component, it is even more difficult to clearly state the value proposition and not only vaguely articulate it. On the other hand, when several stakeholders are involved in the business development, each of them with their own skills, responsibilities, knowledge and expertise, the task is even harder. In order to ease the understanding, e^{3}value distinguishes three viewpoints, which stakeholders may have, and which should contribute to the assessment of the profitability of the business idea (regarding its content) and be based on a similar focus of a group of stakeholders, avoiding any overlapping between these three standpoints:
    - Value viewpoint. This top-level viewpoint focuses on the (usually new) way of economic value creation, distribution and consumption in a multi-actor network. It is represented through e^{3}value models and it contributes to stating the revenues and expenses of the business idea, caused by the exchange of valuable objects between actors. It represents the vision of Chief Executive Officers, Chief Financial Officers, etc.
    - Business process viewpoint. This middle-level viewpoint focuses on the business processes required to put the new value proposition in practice and on the ownership of these processes in order to determine the operational and capital expenditures of the performing actor. It is represented through Unified Modelling Language activity diagrams with swim-lanes to represent actors, interaction and sequence diagrams, or other methods. It represents the vision of operational managers.
    - Information system viewpoint. This bottom-level viewpoint focuses on the information systems and components that enable and support the business processes, so as to identify the components which require expensive capital or operational expenditures. It is depicted via Unified Modelling Language or ownership diagrams. It represents the vision of the ICT department.
- It is a **graphical, conceptual modelling** method. Conceptual modelling refers to formally defining aspects of the physical and social world for the purpose of understanding and communication. Although modelling is common for engineers and technicians in general, it is not so common for business-oriented stakeholders, which tend to use natural language. This use of natural language may result in irrelevant information, omission of important information, over-specification, contradictions, ambiguity, forward references and wishful thinking. Conceptual modelling may be useful to avoid these drawbacks, but a way must be found to communicate it to business-oriented stakeholders and, thus, enhance the common understanding of the business idea among stakeholders, while allowing for an evaluation of its economic feasibility. Also, the language constructs must be made so that they closely

resemble to the perspective of stakeholders over the business idea, mainly regarding the value viewpoint. Thus, e^3value takes a semi-formal, conceptual style, rather than a strictly logical one, and it uses a graphical syntax, which facilitates communication.

- It is **scenario-based**. There are two main types of scenarios: operational scenarios and evolutionary scenarios:
    - Operational scenarios explain and capture a business idea to create a common understanding of it. They also allow for evaluating the value proposition. For this purpose, Use Case Maps (UCM) are used, which show how a particular scenario works out.
    - Evolutionary scenarios represent likely changes in the future, in order to perform a sensitivity analysis for the business idea.
- It is **aware of economic-value**. The primary goal of the approach is to ensure that all actors participating in the business idea can make profit or obtain products or services which are of economic value for them. This approach is well-suited for business ecosystems, as described in section 2.2.1.

As discussed above, two of the main characteristics of the e^3value methodology are that it has a graphical style and that it focuses on the economic value. Therefore, the representation of the business idea takes the shape of a value model. This value model represents a number of actors who exchange objects of economic value with each other, i.e. it represents what objects of economic value are exchanged by whom, as opposite to process models, which represent how those exchanges are operationally performed. Hence, it focuses on the value viewpoint described above, rather than on the business process viewpoint. In fact, it represents what is offered to whom and what is requested for it in return (in the economic sense).

The model takes an ontological approach to describe the generic concepts, relationships and rules. A detailed description of e^3value can be found in [137], but its main concepts are described below:

- Actor. It is perceived by its environment as an independent economic (and often also legal) entity. An actor makes a profit or increases its utility. Economically independent means that it is profitable after a reasonable period of time (when referring to companies) or that it increases its economic utility (when referring to end customers). In a sound and sustainable business model each actor should be capable of making profit.
- Value Activity. Actors perform value activities in order to increase their profit or economic utility. Therefore, the execution of a value activity must yield profit for, at least, one actor. In addition, each value activity must be able to be completely assigned to an actor.
- Value Object. Actors exchange value objects, which are services, products, money, or even consumer experiences. The important point here is that a value object is of value for one or more actors.
- Value Port. An actor uses a value port to show to its environment that it wants to provide or request value objects. The concept of ports enables us to abstract away from the internal business processes, and to focus only on how external actors and other components of the business model can be ‘plugged in’.
- Value Offering. It models what an actor offers or requests from its environment. It is made of a set of equally directed value ports (either requesting or offering, but not

both) exchanging value objects. It is to model e.g. bundling (the situation that some objects are of value for an actor only if all of them are combined).

- Value Interface. It models an offering to the actor's environment and the reciprocal incoming offering, i.e. what the actor needs and what he/she is willing to offer for it. Actors have one or more value interfaces, grouping individual value offerings. A value interface shows the value object that an actor is willing to exchange in return for another value object, via its ports. The exchange of value objects cannot be divided at the level of the value interface.
- Value Exchange. It is used to connect two value ports. It represents one or more potential trades of value objects between value ports.
- Market Segment. It shows a set of actors that, for all of their value interfaces, give the same economic value to objects.

The concepts above can be used to model value exchanges between actors or market segments, but do not give the idea of which value activities or value exchanges must take place, so that some other value activities or value exchanges can also take place. In other words, they do not represent the order in which value exchanges must take place. To that end, some other concepts from UCM are used and presented below:

- Scenario path. It consists of one or more segments, which are related by connection elements, and both start and stop stimuli. A path indicates via which value interfaces objects of value must be exchanged, as a result of a start stimulus, or as a result of exchanges via other value interfaces.
- Stimulus. A scenario path starts with a start stimulus, which represents a consumer's need. The last segment(s) of a scenario path is connected to a stop stimulus. A stop stimulus indicates that the scenario path ends.
- Segment. A scenario path has one or more segments. Segments are used to relate value interfaces with each other (e.g. via connection elements) to show that an exchange on one value interface causes an exchange on another value interface.
- Connection. They are used to relate individual segments. Each fork splits a scenario path into two or more sub-paths, while each join collapses sub-paths into a single path. In AND forks/joins, all incoming and outgoing paths have the same number of occurrences, while in OR forks (joins) the number of occurrences of the incoming (outgoing) path equals the addition of the number of occurrences of the outgoing (incoming) sub-paths. An implosion shows a change in the number of occurrences within a sub-path.

The goal of the e^{3}value is to evaluate a business idea, and discover a business scenario, which consists of the value model and the scenario path, feasible for every stakeholder. Therefore, e^{3}value assumes that business developers already have a business idea in mind and, thus, it aims at clarifying and evaluating such idea more thoroughly. As a result, e^{3}value is not intended to find business ideas themselves.

In order to create the business scenario, a number of sequentially executed steps are needed. The result of each step is an input for the following step, and the outcome of the whole process is a business model including a graphical representation and corresponding financial profitability sheets, which facilitate sensitivity analysis of the business case. The graphical description of the process to build a business model is depicted in Figure 17 [140].

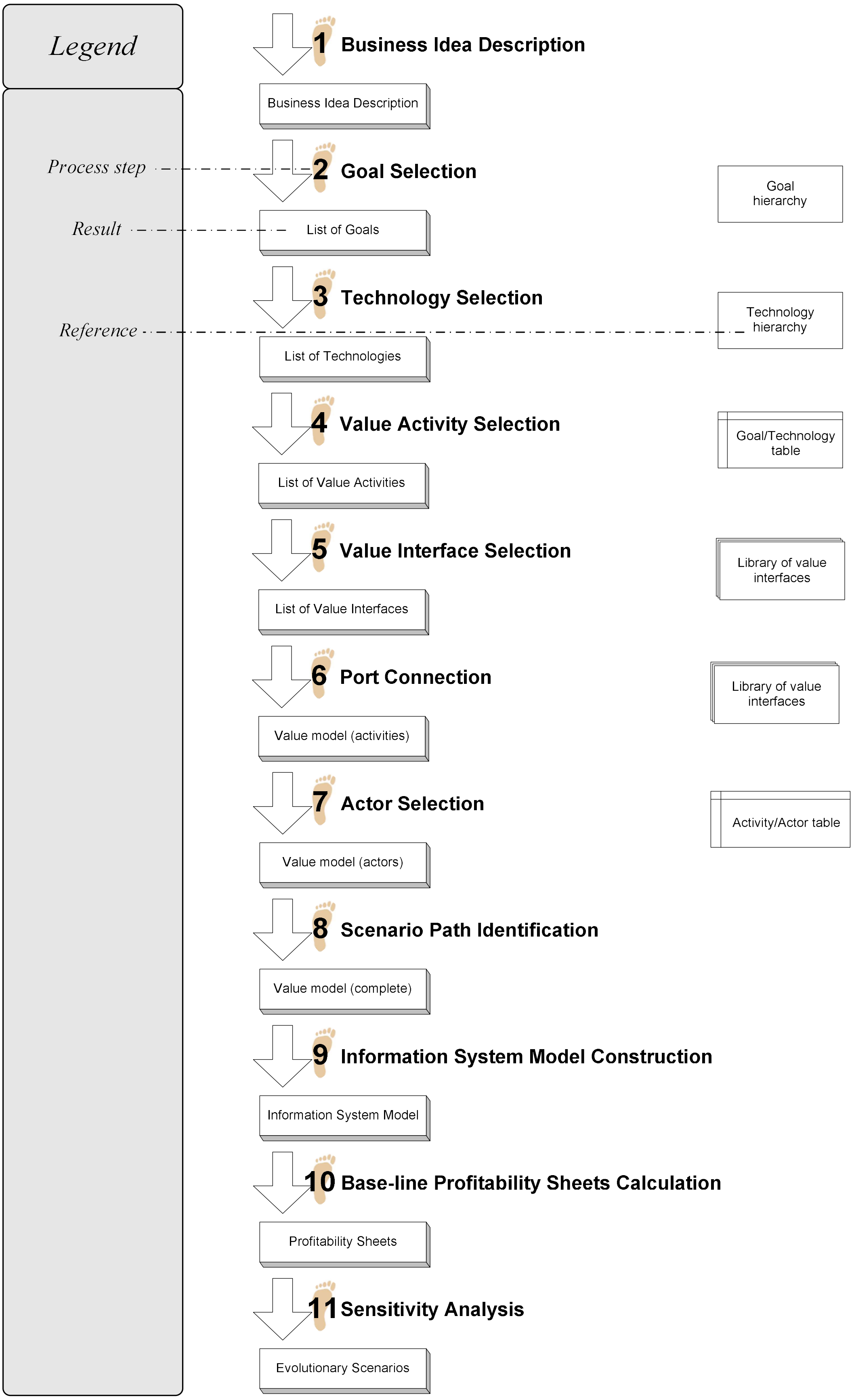

Figure 17: Diagram of the e^3value process steps

1. Step 1 – Business idea description: Write down a short business case description to express the business idea. The value model is a representation of the real world and, hence, such a representation cannot include all the objects of the real world. Before the modelling process starts, it is important to consider what needs to be modelled and what not. In addition, a novel business idea can only succeed if all involved actors regard it as a profitable idea, so all involved actors should have benefits from the business idea, and the only way to calculate the profitability is to include these actors in the value model. Consequently, the basic rule is to include all involved actors and activities in the value model process.
2. Step 2 – Goal selection: The first task to be performed when creating the value model for the business is specifying all the goals that stakeholders want to satisfy with such business. Some stakeholders' goals may be in conflict with some others' goals, since every actor wants to maximise its profit; but some other stakeholders' goals can also be mutually beneficial. Stakeholders' goals can be strategic (long-term) or operational (short-term).
3. Step 3 – Technology selection: Once the goals are identified, the next step is to select an appropriate technology which will deliver the best output of the scenario and achieve both operational and strategic goals.
4. Step 4 – Value activity selection: In this step, value activities to be included in the model are selected. As a guidance, [140] presents a hierarchy for operational goals, which is built in a way that every goal has an activity associated with that goal.
5. Step 5 – Value interface selection: In this step all value interfaces necessary to model the business case are selected from a library of interfaces (see [140]), where general and optional interfaces are provided for each activity. For each value activity selected in the previous step, at least the general interfaces must be modelled. Depending on the scope and the goals to accomplish, the optional interfaces can also be added to the model.
6. Step 6 – Ports connection: The value interfaces must be connected to obtain a connected value model.
7. Step 7 – Actor selection: Each activity should be performed by an actor, but this is not a strict one to one relation: some actors perform more than one activity, and in some cases an activity should be divided over two actors.
8. Step 8 – Scenario path identification: A scenario path is used to explain cause-effect relationships by travelling over paths through a system. By travelling over the scenario path, it can be seen which actor starts the value exchange and what exchanges are done as a result of this start. Scenario paths allow to count the number of value exchanges in a given time period, which is very important to perform the profitability analysis.
9. Step 9 – Information system model construction: Once a correct value model has been constructed, the information system needed to support such a model must be addressed (here, the information system viewpoint is considered). This step is performed only when the expenses to maintain such an information system are substantial; otherwise they will be included as O&M costs.
10. Step 10 – Base-line profitability sheets calculation: The evaluation of a business model focuses on the question whether it is feasible from an economic point of view, and whether a scenario is profitable for each actor involved in the value model. The impact of the business model in the different actors is assessed by creating

profitability sheets for each actor involved, where economic value is assigned to objects delivered and received.

11. Step 11 – Sensitivity analysis: During the execution of a business model, the profitability of each actor estimated by using profitability sheets, valuation functions, and scenario occurrences and path probabilities, may change substantially. Since it is not possible to predict the future, especially in the case of innovative business ideas where the business developer cannot rely on historical data, the important result of the analysis is not the numbers on profitability themselves, but the reasons behind them (why the business case proved to be profitable/unprofitable) and to do a sensitivity analysis to check the robustness of the results obtained when different assumptions are taken. For that purpose, evolutionary scenarios, i.e. scenarios which describe events that can possibly take place in future, are used. The analysis of the effects of evolutionary scenarios on profitability discovers the structural uncertainties and risks, and may lead to 1) a change in value models, 2) an increase in confidence and 3) a better understanding of the business idea by stakeholders. It is recommended to develop scenarios which capture a change in valuation functions, scenarios which represent a change in the expected number of scenario path occurrences and scenarios which suppose a change in the structure of the value model itself (e.g. actors entering or leaving the model).
12. Step 12 – Investment analysis: After a scenario is chosen, a detailed analysis of financial aspects must be made. There are several standard criteria for investment analysis, like the ones explained in section 3.2.

3.5 CONCLUSIONS

Economic analyses are performed with the aim of obtaining the required information to make a judgement or a decision and are often used in strategic planning and policy making. In general, they assess the interest of making an investment. An investment is a means to allocate different resources (money, time, efforts…) to obtain incomes in the future, i.e. the investor makes the investment in order to create enough incomes to obtain a benefit. Therefore, the investor must assess the expected costs and benefits and must take into account the time value of money. Moreover, uncertainty must also be dealt with, for which either a sensitivity or a scenario analysis can be a very useful tool.

There are many methods to appraise investments, as described in this chapter. However, it is not always easy to determine which costs and benefits are relevant for the investment project under analysis, and the assessment of projects in business ecosystems is not easy to perform. In order to provide some guidance, a number of cost- benefit analysis methods are available. Yet, none of them seems to be perfectly fit for assessing innovative business models.

There is no unique definition of what a business model is. Different authors define business model in a different way but, in general, the different business models definitions include three main aspects: how value is created, how value is delivered and how value is captured.

There are many methods for assessing the interest of an investment and also of a company. Some of them are well-known and considered as standards the facto for certain types of analysis, especially for those about investment in electricity transmission & distribution infrastructure. However, there is not such a standard for other types of energy-related businesses, including for assessing EV-related investment projects.

Canvas is a well-known methodology for exploring innovative business ideas and to represent them graphically. e^{3}value can be very useful when going a step forward, i.e. when the business idea has been identified and a thorough analysis of its profitability is required. But the usability of these approaches for analysing EV-related business models is not clear, as demonstrated in the next chapter.

CHAPTER 4

APPLICATION OF BUSINESS MODELS ANALYSIS TO EVS

4 APPLICATION OF BUSINESS MODELS ANALYSIS TO EVS

4.1 INTRODUCTION

In previous chapters of this thesis, EV technology and electro-mobility ecosystem have been presented, as well as the fundamentals for economic assessment and business models analysis. This chapter presents a literature review to identify the different approaches to link both fields, i.e. which type of economic assessments have been performed for electro-mobility. Therefore, after chapter 2 described the field of application (publicly accessible EV charging infrastructure, but focusing on the whole complexity of the electro-mobility ecosystem) and chapter 3 presented the most widely used methodologies for business models analysis (also introducing the fundamentals for the economic analysis), this chapter compiles the experiences in analysing innovative business models for publicly accessible EV charging infrastructure.

By looking at the bibliography used so far, some authors focused on different aspects of EV technology and electro-mobility:

- Technology reviews, either for electro-mobility as a whole [2], [27], [28] or for elements such as the electric vehicles themselves [3], [30], batteries [57] and different charging alternatives [29], [37]. Some of them only present technological aspects, while some others also present cost or other economic components, but not a detailed analysis of the business model for deploying publicly accessible infrastructure for EV charging. Advantages and disadvantages of EVs have also been detailed [20], [21].
- EV market statistics, including travel behaviour [61], environmental impact [62], [100], new vehicle registrations [77], [72], [73], [91], [102], [110], [113], [117], [120] and the energy dependence per country [141]. General statistics [1], [5], [6], [11], [67], [88], [101] have been analysed too.
- Overarching policy, legal and regulatory framework. In addition to energy and EV outlooks [22], [130], different legal [7], [8], [9], [12], [47], [68], [69], [71], [85], [86], [89], [90], [126], [129] and standardisation [13] [26], [34], [35], [36], [38], [39], [40], [41] requirements have been compiled, as well as the best practices of public support to electro-mobility [55], [56], [64], [77], [74], [81], [93]. Market models [45], regulatory options [46] and role models [48] have also been discussed. In addition, specific regulatory measures for EVs in certain countries have been presented [75], [76], [78], [79], [80], [83], [84], [92], [94], [95], [96], [97], [98], [99], [103], [104], [105], [106], [107], [108], [109], [111], [112], [114], [115], [116], [118], [119].
- Customer behaviour and preferences [53], [54].

Additional bibliography has been used to describe the fundamentals for economic assessments [121], [122] and business models [42], [43], [131], [132], together with some generic methodologies for visualisation of ideas [49]. References to websites for specific EV models [59], [60], [63], institutions [124], [125], news about EV stakeholders [31], [32] or projects [139] have also been made.

Moreover, there is extensive literature focusing on an optimal operation of EV charging infrastructure, including V2G capabilities, to improve the operation of the electricity distribution grid [18], [142], [143], either to avoid creating constraints in the grid, or to better integrate RES [144] or microgrids [145]. Additional studies about how to minimise the charging duration, either from a power engineering perspective (by improving the efficiency of power electronics or by attaching storage systems to the charging station) or by using statistical metrics (aimed at reducing the EV waiting time and at increasing the percentage of EV users served through queuing theory) are referenced in [142].

However, few studies have focused on the economic performance of the deployment of EV charging stations.

This chapter presents a compilation of the different attempts to make an economic evaluation of innovative business ideas related to developing publicly accessible charging infrastructure for electric vehicles, which uncovers the need for a holistic methodology as the one presented in this thesis.

For that purpose, the applicability of the main methods and approaches described in sections 3.3 and 3.4 to the analysis of business models for deploying publicly accessible charging infrastructure is briefly assessed first (section 4.2) and, then, a literature review is made to identify the existing gaps in the existing experiences for assessing the economic performance of such EV charging infrastructure (section 4.3). The analysis of e^{3}value is presented in a separate section 4.4, since it is the starting point for the methodology described in this thesis.

4.2 ANALYSIS OF MAIN CBA AND BUSINESS MODELS ANALYSIS METHODS

An evaluation of the different methodologies presented so far is discussed below.

4.2.1 CBA methodology by the JRC

The methodology [123] has a number of positive points, such as considering the whole value chain, including guidelines and taking into account both environmental and social impact in addition to the economic impact. Furthermore, the overall step sequence is logic: define boundaries, state objectives, consider benefits, compute costs, compare them and make a sensitivity analysis.

However, it has two major limitations for assessing the economic performance of EV charging infrastructure. On the one hand, it is very oriented to analysing projects to be implemented by DSOs, i.e. smart grid projects from the perspective of the grid operator. Therefore, it is not easy to use from the perspective of actors in competitive environments, such as CSOs or EMSPs, or from the perspective of EV customers.

On the other hand, the combination of the quantitative and the qualitative analysis is difficult to justify and, moreover, the use of weights in the qualitative assessment introduces arbitrary judgement. Although equally arbitrary, the use of a common unit for all the impacts, i.e. money, would facilitate the comparison of different alternatives. In fact, as discussed in section 3.3.1, such conversion into money is the main difference between CBA and pure multi-criteria analysis methods.

4.2.2 CBA methodology by ENTSO-E

Although the CBA methodology by ENTSO-E [127] has also some good points, it is even more focused on grid development projects than the CBA methodology by the JRC. In this case, it is almost impossible to use it for any purpose, other than for the analysis of transmission network development projects (especially on those that affect transfer capabilities between individual TSOs or price zones).

Moreover, in this methodology, costs are not even compared with the monetised benefits, on the grounds that not all benefits can be monetised: "*a fully monetized approach would entail one single monetary value, but because all results of the CBA are very dependent on the scenarios and horizons, this would lead to a perceived exactness that does not exist*" [127]. This approach helps obtain some results, but it does not guide on how to interpret them to choose one or another project, leaving the decision to the project planner, who does not receive additional common criteria.

Nevertheless, it provides useful guidelines when selecting the number of scenarios to be analysed: a compromise must be met between robustness (the number of scenarios should be large enough to get a complete picture of the effects that a project may have under different possible future conditions) and workload (the calculations under each scenario must be sufficiently detailed and accurate). In addition, it provides a full list of potential benefits and the methodology to calculate and to monetise them.

Some of these drawbacks may be corrected in the second version of the methodology [128], but it has not been published yet in August 2017.

4.2.3 SWOT analysis

The SWOT analysis is a straightforward method to obtain a good view of the company's advantages and disadvantages, so it is very useful to define a strategy for a company or to identify potential business ideas, either to offer new products/services to the market or to improve internal processes.

However, it only provides a qualitative assessment, not a quantitative one, so it does not allow for a detailed assessment of the potential profitability of a business idea.

4.2.4 Canvas model

As in the case of the SWOT analysis, the Canvas model [134], [135], [136] is a good method to identify potential business ideas in the very early stage of exploration of business opportunities, as well as to represent them once identified. In addition, its simplicity, flexibility and the ability to communicate a direct message, facilitates the selection of ideas and the adaptation of some elements in order to get the most of them.

However, it is not designed to be used for a more detailed profitability analysis of the ideas: "*turning a prototype business model into a spreadsheet is time-consuming, and each change to the prototype usually requires a manual modification of the spreadsheet*" [136]. Moreover, it also requires a deep knowledge of company's insights in order to select the most appropriate distribution channels or to identify key partners [23].

4.3 STATE OF THE ART FOR ECONOMIC APPRAISAL OF EV CHARGING INFRASTRUCTURE

This section summarises the main characteristics of the most relevant literature for the aim of this thesis. Therefore, it focuses on studies that assess the economic feasibility of operating publicly accessible CS and it analyses their strengths and weaknesses from a methodological point of view.

4.3.1 Policy options for electric vehicle charging infrastructure in C40 cities

This report [4] presents a policy analysis with the aim of assessing the feasibility of CS operation by public bodies. The authors create easy-to-use models for calculating CS demand, build up a well-developed cost structure model and complete the assessment with a sensitivity analysis. The study concludes that convenience charging[23] infrastructure is expensive and that it must be used regularly to be profitable. Still, there are some scenarios where potential EV users only want to see the infrastructure to overcome range anxiety although they will not use it because they will regularly rely on private charging. In this case, they propose to use subscription models, rather than pay-per-use schemes.

However, the report is too focused on the public sector and, thus, it somehow overlooks the business perspective of the CSO. Moreover, it only analyses the impact for the CSO, leaving aside the rest of the value chain. Additionally, the authors analyse the delimited geographical scope (city, region) as if there were only one CSO, which, again, does not facilitate the assessment of a real company being the CSO. Likewise, the revenue model is not as clearly defined as the cost model and the synergies of operating a broad CS network are not clearly identified. As a final drawback, the report only considers different public charging technologies in separate analyses, without analysing whether any semi-fast and/or fast public CS combination can adequately complement private charging.

4.3.2 Electric vehicle charging infrastructure deployment: Policy analysis using a dynamic behavioral spatial model

This master thesis [10] performs a regulatory analysis to draw conclusions on how public bodies can contribute to achieving the triple goal of:

1) having an economically profitable CS network for the CSO,
2) avoiding range anxiety from EV customers, and
3) avoiding that EV customers have to queue at CSs.

It identifies the need for publicly accessible charging infrastructure, but more from a psychological perspective than from a technical one, and it recommends investing in infrastructure rather than in increasing battery size.

The analysis provides a detailed CS cost structure, divided into hardware, installation and other costs and, assuming a subscription price of about USD 100, it calculates the required

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[23] *"All non-home and non-office charging, including on public streets, public garages, supermarket garages, etc."* [4]

price per kWh for the CSO to make a profit. In order to obtain a price per charging which can be acceptable by EV customers, it proposes both to charge EV customers for parking time (instead of per kWh) and to increase the incomes for the CSO either through advertising or through convenience stores (especially in fast charging stations, which can be bundled in groups of about 8 CSs). It considers EVs as the sole competitors to ICE vehicles and it performs a sensitivity analysis, where it also includes PHEV.

Although it states the importance of considering the whole value chain, it just focuses on the CSO and, somehow, on EV customers. Even if it does well by comparing the cost per kWh to the mileage cost of ICE vehicles, it does not take it as the benchmark to calculate the required usage. Quite contrarily, it estimates a CS usage and, then, it calculates the charging price, which is then compared to the mileage cost. In spite of identifying the importance of TOU tariffs for promoting EV deployment (especially for the private home charging case), it does not consider how different charging alternatives and their combinations can improve the business model for the CSO. More surprisingly, private home charging is left out of scope of the quantitative analysis, even if it is mentioned along the document.

4.3.3 Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships

This article [14] describes different charging alternatives and the agents involved in each of them, in order to pave the way for the definition of some components of EV business models, such as new agents, options for charging infrastructure ownership and development, or commercial relationships between involved agents. Since EVs have a number of advantages, the authors highlight that technological development, policy measures (incentives or tax exemptions) and regulatory issues are required for EV deployment. The financing of CS infrastructure may be public (taxpayers), private (investors and EV users) or mixed, which also leads to the need for defining whether CSOs should be a monopoly or under competition. Another important issue is whether the electricity for EVs should have different taxes to account for e.g. road use or, on the contrary, must have incentives for their contribution to reducing CO_2 emissions.

Agents are assumed to be profit-oriented and to react to economic signals. This assumption facilitates the analysis by putting the focus on economic incentives when making decisions. Different charging alternatives are considered and, for each of them, the whole value chain is taken into account. Among them, private home charging is expected to be the first alternative, as it is the cheapest alternative, but it can be combined with public charging. In private home charging, the EMSP is expected to be the electricity retailer for the regular home electricity consumption and the use of TOU tariffs can provide important savings for EV customers.

Only the physical connections, ownerships, contractual relationships and communication exchanges are presented, without any further economic analysis. Moreover, even if different charging alternatives are considered for public charging, they are not combined.

Although not directly linked to the methodological approach, authors state that "w*hen involving the use of a public good such as the public location, the business should be regulated and charging stations developed by the corresponding DSO in the area. In this case, the infrastructure would be considered as other grid expenditures and the access to the charging points should be made universal to EV owners contracted with different EV* *suppliers. This way, it is avoided that private companies monopolize this limited resource. In the case of CPM*[24] *acting on privately owned property, however, infrastructure could be installed and investment risk assumed by private agents while the activity would be open to competition depending on the development rights of the location*" [14]. In this context, it seems difficult to justify why the DSO should compete with private CSOs for EV users. If the idea is to use the scarce private space in a "fair" way, it is better to open tenders among the private CSOs, but not to include the DSO here. An alternative would be to have the DSO being the only CSO.

4.3.4 New business models for electric cars – A holistic approach

This article [15] presents a methodological approach for considering different alternatives when designing business models for EVs. EV business models are described to be somewhere between extreme cases of product-oriented (e.g. buying the EV) and service-oriented, either as use-oriented (e.g. mobility guarantee, car sharing, fleets) or result-oriented (e.g. paying for a taxi). Due to the complexity of the electro-mobility ecosystem and the number of potential alternatives, a morphological approach is provided.

The methodology proposed considers the whole value chain, with a commercial approach. It focuses on how to increase the value that EVs can create, by considering options such as car sharing, charging via TOU tariffs, providing services for grid operation, using the old batteries for second-life applications or having occasional access to ICE vehicles when needed.

The morphological approach is very useful to guide the business model definition process, but it is not used to perform the detailed quantitative economic assessment of the business model. In that sense, it can be included in the same methodological category as the SWOT analysis or the Canvas model [136].

4.3.5 Business models for sustainable technologies: Exploring business model evolution in the case of electric vehicles

This article [16] reviews the EV business models in the period 2006-2010, by focusing on the value proposition (product vs. service oriented, target market segment), the value network (in-house vs. outsourced, purpose-built vs. refitted, etc.) and the revenue/cost model (government support, selling vs. leasing vs. use per km) to identify business models archetypes.

The analysis focuses on the EV with added service components, while CS and energy system are seen as external. Therefore, they do not consider the whole value chain. Moreover, the analysis only provides qualitative insights and leaves aside any quantitative result.

4.3.6 Analysis of two typical EV business models based on EV taxi demonstrations in China

This article [17] presents the economic impact of using fast charging vs. battery swapping for EV taxis in China. Although it considers the whole value chain, it assumes that EV users and

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[24] This term refers to EV charging point managers, which, in this thesis, are called CSOs.

car manufacturers make a profit and assigns all costs and benefits to the CSO. It makes a quantitative assessment, but both the revenue and the cost models are not clearly stated, so it is difficult to assess the advantages/disadvantages of the approach and even the accuracy of the analysis is not clear.

4.3.7 An evidence-based approach for investment in rapid-charging infrastructure

The article [19] presents an economic analysis of the potential to deploy fast charging infrastructure in the UK. The authors take ICE vehicles as a benchmark and, as they state, they make a good contribution to the State of the Art by providing real figures regarding CS usage and investment costs. They consider several years to account for the likely increase in EV share. The authors also stress the need to have publicly accessible charging infrastructure to avoid range anxiety, although EV customers may not use it. The consideration of the whole electro-mobility ecosystem (including the description of the different stakeholders and the likely conflicts in their needs and interests) and the possibility to have additional sources of income for the CSO are also positive points of the analysis. In addition, they highlight the fact that pricing for EV charging is very sensitive to demand for charging. Finally, they aim at providing break-even values for profitability by combining annual electricity demands in the CS and the electricity mark-up price (ratio between the prices for the electricity sold and the electricity bought by the CSO).

However, there are also some points not covered by this analysis. The main one is that only fast charging is considered in the analysis, leaving aside home charging, despite it accounts for about 70 % of the energy demand by EVs. Furthermore, there is no assessment of the impact of the considered pricing strategy (it is assumed that electricity for EV charging can be sold up to 3.3 times the regular electricity price) on the rest of the stakeholders in the value chain (EV customers' willingness to pay is assessed through interviews, where they seem not to accept such high mark-ups). Besides, it is unclear whether the CS network is expanded ("*the charger is installed in 2015 (year 0) and will be generating revenue from 2016 to 2025*" [19]) and there is no discussion about the impact that the compound energy growth (which reaches up to 33 % in some cases) may have in CS occupation, although some queueing issues are mentioned ("*A maximum of two EVSE were located at any one site, and some sites subsequently experienced queues of EV waiting to recharge at busy times of the day*" [19]), even at the adoption rate considered in the base year.

4.3.8 The business case of electric vehicle quick charging — No more chicken or egg problem

This article [23] aims at demonstrating the economic feasibility of publicly accessible, fast charging CS. For that purpose, the authors use a morphological approach to describe the different alternatives, create a detailed cost model and convert all fixed costs into annualised values. For the revenue model, the authors set the right constraints in the sense that they aim at having "*a working business model, which provides profit for charging station owners and is at the same time attractive to customers thus making the business viable in the long term*" [23]. Therefore, the CSO must establish a pricing strategy which covers all the costs (unless some additional sources of revenue can be found) and which do not imply higher mileage costs for EV customers than with ICE vehicles. Moreover, it states that it is more important trying to offer a good service (location, charging time, etc.) rather than trying to minimise costs and that the most efficient method of testing customer value is to see whether they are willing to pay for the product or service. Another good point of the study is that it assumes that EV number will increase, hence, making the CSO business more profitable as time passes. In opposition to many of the articles discussed so far, it performs a quantitative analysis and obtains some numerical results, which are then used to derive conclusions.

However, the study also presents a number of unsolved issues. On the one hand, although different agents in the value chain are identified, the whole value chain is not presented. What is more, only a fast charging price of EUR 8 is discussed, but the impact of the business model on EV customers is not presented, even if the ICE mileage cost is taken as a benchmark. In this sense, it must be noted that it only considers fast charging and, despite mentioning private home charging, it does not make a combined analysis for both. On the other hand, the study is made for only one CS, and not for a CS network. This way, the analysis does not account for the synergies and benefits of having a large CS network for the CSO, and neither does it detect the potential impact of having a large queue of EVs waiting for the CS to be free. This effect is especially important, taking into account that the break-even CS usage number is 2 500 full charges per year (which means about 3 hours of full operation of the CS per day) and that it considers up to 6 000 full charges per year (7 hours of full operation of the CS per day). It is not likely that the fast charging station will be usually in operation during the night time (it may have one overnight charging every now and then, but not every day), so, for a 7 a.m. to 10 p.m. working time, this would mean having the CS running almost 50 % of the time. Therefore, some queues can be expected in rush hours.

4.3.9 The economics of fast charging infrastructure for electric vehicles

This article [24] aims at analysing the economic performance of a fast charging CS. The study itemises the different components of the CS costs for different private and public CS charging capacities and annualises them. In order to calculate the revenues, it provides some CS usage patterns to calculate the CS demand and it considers the mileage cost of an equivalent ICE vehicle as the mark-up when defining the charging price to be requested to EV customers. The study also assumes that involved actors are perfectly competitive, so changes in overall profits are negligible when different regulatory options are considered and, thus, the analysis of the most generic one should be enough to extract conclusions for any other arrangement. The results of the analysis are provided in a quantitative manner and a sensitivity analysis is performed to see the impact of different variables. For example, the use of TOU tariffs instead of flat tariffs for electricity is evaluated.

However, the study does not combine different charging alternatives, even if it recognises that fast charging CSs must compete with home charging, battery swapping and other public charging stations, and despite having discussed the cost components for different types of CSs. Moreover, the study focuses on the CSO and overlooks the rest of the value chain, including EV customers for whom the ICE vehicle mileage cost is used as a benchmark, but without a detailed TCO analysis.

4.3.10 Sustainable business models for public charging points

This article [25] aims at identifying the optimal scenario for placing and operating public CSs by performing an economic assessment for the CSO. It uses a morphological analysis to identify alternatives and investigates measures to reduce the cost (both practical and legal), increase income (mostly subsidies or soft loans for CSOs) and to improve organisational aspects. Then, it uses scenario planning to identify the viable framework and likely situations (it creates scenarios by mixing different variables and considers the interrelation between them in order to select the possible and likely scenarios). Finally, it provides some recommendations.

It considers different annual mileages, subsidies and funds, adding also an analysis to check the impact of setting a starting rate (according to which customers should pay EUR 1 every time they charge, on top of the per-kWh payment). In order to ensure the validity of data and the initial scenarios considered in the analysis, the authors interviewed a number (14) of stakeholders (after having made the assumptions).

The main conclusions of the study are that “*The scenario planning, financial analysis and sensitivity analysis showed that all measures are profoundly interlinked and must be seen as part of a whole (…) small differences in parameters significantly influence the budget of the business case. However, predictions on these parameters are uncertain, due to the fast developments in the field of electric mobility. As a result, business cases implemented during this period of development and innovation are linked with high risks*” [25].

It analyses the number of slow and semi-fast chargers which provide the best option for the CSO (in terms of cumulative cash-flow from 2013 until 2020), so it combines different charging alternatives. However, fast charging is left out of scope and it is unclear whether private charging is combined with public charging.

Moreover, there are few data about costs (quantities) and it is unclear how the calculations were made. In addition, there is no analysis over the whole value chain, focusing only on the CSO and, besides, only the specific situation in the Netherlands is considered. Another important point to be made is that the study is aimed at guiding municipalities in establishing the framework for CSOs, so the business perspective may be slightly lost, even if it also guides municipalities in case they want to become CSOs.

As a final comment, the study concludes that it is better to install only two-outlet, 3.7 kW stations, rather than installing 11 kW CS, but it is not assessed whether such slow charging points can satisfy the charging requirements of EV customers, especially for convenience charging, or whether they would lead to queueing issues.

4.3.11 Infrastructure planning for fast charging stations in a competitive market

This article [44] proposes an interesting approach for fast CS network deployment, by considering a completely selfish behaviour of stakeholders (what they call “business-driven competitive market”). However, they consider that none of them has enough power to set the price, so that they develop an equilibrium model to assess how locational prices are affected as a result of traffic network congestion, accessibility and charging services.

As in many other cases, they only focus on fast CSs, leaving aside the rest of charging alternatives, even if they recognised their importance. Furthermore, although the article provides numerical results, it is unclear which investment costs have been considered to obtain them and whether the CSs installed are profitable or not.

4.3.12 A comparison of European charging infrastructures for electric vehicles based on the project Transport Innovation Development in Europe (TIDE)

This article [50] uses a morphological approach to perform a qualitative comparison of two business models for publicly accessible charging infrastructure. Therefore, it focuses on the CSO (leaving aside the rest of the value chain) and does not provide any numerical result.

4.3.13 A techno-economic analysis of BEVs with fast charging infrastructure

This article [65] performs a quantitative analysis to compare the TCO for EV customers in three different alternatives: ICE vehicle, EV and EV without battery ownership and a subscription plan with an integrated CSO-EMSP, which also provides access to publicly accessible fast CS.

The authors perform a detailed analysis of the cost components in the three alternatives, including the CSO-EMSP costs in the subscription model (which are then used to estimate the charging cost that the EV customer will need to pay). They also use an extensive driving pattern portfolio (398 patterns) to determine the probability of occurrence for the different conclusions obtained. A thorough sensitivity analysis is also performed, which permits identifying the cost of batteries, the cost of financing and the fast CS utilization rate as the parameters that most impact CSO-EMSP's business and, hence, the TCO for EV customers in the third alternative.

Although the authors combine private home charging and publicly accessible fast charging, they do not consider semi-fast charging, which may be an interesting option for cheaper convenience charging. Moreover, the proposed analysis only considers the combined CSO-EMSP option, which may create synergies but also cross-subsidies, and does not analyse the feasibility of each business on its own. Likewise, the rest of the value chain is not considered.

4.3.14 Development and evaluation of a range anxiety-reducing business model for connected full electric vehicles

This master thesis [66] aims at developing a business model for EVs which integrates all major stakeholders, because the whole ecosystem is needed to boost electro-mobility. For that purpose, the author develops the Canvas model for different agents in the value chain (a CSO which is also the EMSP, two car manufacturers, a technology provider for car manufacturers and an electric utility) and merges all of them, together with the view of the government and the ICT enabler, into a single model for the whole value chain. The resulting business model consists in the EMSP selling the EV without battery and signing a medium-term contract with EV customers, so that they buy kilometres to use it, i.e. the value proposition is driving kilometres, not owning the vehicle. This business model is based on the existing one for phone companies which offer phones if customers sign multi-year contracts with them to use the phones.

Based on [146], the author states that quantitative approaches are highly selective and aim to explain relationships of a small number of variables in a very precise way ("*better knowing* *few things exactly, than knowing many things vaguely*”) and, thus, are usually better accepted by academic community; while qualitative approaches follow a holistic approach to generate understanding of a phenomenon in its entirety (“*better knowing the important things vaguely, than knowing small things in absurdly precise ways*”) and, hence, have a high degree of applicability to social reality because their holistic view is better suited to explain multifaceted sociological phenomena. Therefore, the author proposes a combined (not merged) quantitative and qualitative method, with a slight dominance of quantitative approach.

The resulting overall canvas model is then used to compare the proposed business model to the traditional ICE vehicle ownership from behavioural, technical and economic perspectives. Behavioural and technical approaches follow a qualitative comparison, by listing the strengths and weaknesses of the business model with respect to ICE vehicle ownership.

On the contrary, the economic analysis is made in a quantitative manner. Surprisingly, the author assumes that “*demand-side changes for BEVs*[25] *will entail the necessary, economically sensible supply-side changes allowing for a profitable serving of the market*” [66] and, thus, focuses on a TCO analysis for the EV customer, leaving aside the rest of the value chain.

Moreover, the author mentions conductive charging (for private home charging), but it is unclear how it is considered in the analysis, as most discussions only refer to battery swapping. In addition, EMSP roaming is not allowed, which creates a major barrier for electro-mobility deployment.

4.3.15 Competing and co-existing business models for EV: Lessons learnt from international case studies

The article [133] analyses four existing business models around EVs. Some of them leverage partnership strategies along the value chain, while some others coexist as competitors.

The analysis considers the whole value chain and identifies 11 criteria to compare business models, 6 of them related to the supply side (reduces the battery ownership costs, reduces vehicle ownership costs, reduces customer exposure to electricity prices, spreads risks across ecosystem, increases driving range and encourages change in consumer behaviour) and the other 5 to consumer perspective (enables technological innovation, clarifies formulation of business model strategy, enables business model experimentation, uses intelligent charging infrastructure and service-oriented business model). Based on this comparison, the authors conclude that business models should leverage ecosystem resources (build strong partnerships and alliances with both complementing and competing firms), should be designed to be flexible (to be prepared for ecosystem reconfiguration) and should capitalise on the developer’s competencies (case studies show that strengthening one’s position in a few specific areas can be enough to have a viable business model) to expand the value proposition in a subsequent step.

Although the proposed methodology seems to be very useful to compare business models from a qualitative point of view, it does not enter into details on how to quantitatively assess

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[25] The original text refers to FEV, Full Electric Vehicles.

the economic feasibility of the alternatives under study. Therefore, this methodology can complement a SWOT analysis, the Canvas model [136] or the methodology proposed in [15].

4.4 E^{3}VALUE

As described in section 3.4.3, e^{3}value is a conceptual modelling approach aimed at facilitating the statement, communication and understanding of the value proposition of an innovative business idea, designed to allow for a rigorous evaluation of its economic feasibility. It also intends to build the bridge between business-thinking people and ICT people in a company. It is a lightweight, multi-viewpoint, graphical, scenario-based and economic-value-aware approach. The goal of the e^{3}value is to evaluate a business idea, and discover a business scenario, which is feasible for every stakeholder, i.e. all the stakeholders involved in the business idea must be able to make profit (or to increase their economic utility) and all of them must have a common understanding of the value proposition. The representation of the business idea takes the shape of a value model, which represents a number of actors who exchange objects of economic value with each other, i.e. it represents what objects of economic value are exchanged by whom in economic terms (and not how those exchanges are operationally performed).

The aim of e^{3}value is to evaluate a business idea and discover a business scenario which is feasible for every stakeholder. Therefore, e^{3}value aims at clarifying and evaluating a business idea already in mind of business developers, rather than at finding business ideas themselves. For business ideas investigations, methods such as the Canvas model seem to be more appropriate. An interesting comparison between both approaches can be found at [135].

e^{3}value was developed to provide answers to the main challenges of the e-commerce development [137], [138] at the turn of the century, so it is tailored to analysing e-commerce innovative business ideas. The methodology was adapted to the particularities of distributed generation and other DER in the BUSMOD project (EU-EESD-11622, [139]) and the methodology proposed in this thesis is another adaptation to be able to deal with complex, interrelated business ecosystems, like electro-mobility is.

Despite its strong capabilities to analyse complex business models by presenting the whole interrelations of stakeholders for a given business case, e^{3}value was not designed to analyse the interrelations between stakeholders across complementary business cases, so it does not provide the tools to interrelate different business cases for the deployment of publicly accessible charging infrastructure. This holds true for electro-mobility, where different charging alternatives co-exist, but also in electricity markets, where actors have a limited resource (e.g. demand flexibility) to arbitrage between different co-exclusive markets (day-ahead, intraday, secondary regulation, tertiary regulation, self-balancing…), or when different energy vectors (electricity, heat, gas, etc.) must be taken into account in the analysis.

4.5 CONCLUSIONS

The literature review performed in this chapter shows that some authors perform quantitative analyses, while some others only focus on qualitative approaches. Likewise, some of them consider the whole value chain, but only few perform the analysis for the complete chain and the rest just focus on one or two actors (mainly the CSO). In some cases, a public sector view is considered instead of a fully commercial perspective as required by the publicly accessible charging infrastructure. In general, each charging technology is analysed as a stand-alone option and, only in few cases, private home charging is included in an analysis for publicly accessible CSs. However, none of them performs a complete quantitative analysis, which considers and analyses the whole value chain with a business perspective, and which merges all different charging alternatives into the same analysis, as shown in Table 2.

Nº	Looks at the whole value chain	Business-oriented	Quantitative analysis	Compares versus ICE	Charging options
[4]	CSO	No	Yes	Yes	All, but separately
[10]	CSO, EV customers	Yes	Yes	Yes	Publicly accessible
[14]	Yes	Yes	No	Yes	All, but separately
[15]	Yes	Yes	No	Yes	All, but separately
[16]	EV customers	Yes	No	No	None
[17]	CSO	Yes	Yes	No	Fast, battery swap
[19]	Yes	Yes	Yes	Yes	Fast
[23]	CSO, EV customers	Yes	Yes	Yes	Fast
[24]	CSO	Yes	Yes	Yes	Fast
[25]	CSO	No	Mixed	No	Public slow, semi-fast
[44]	CSO, EV customer	Yes	Yes	No	Fast
[50]	CSO	Yes	Mixed	No	Semi-fast
[65]	EV customers, CSO+EMSP	Yes	Yes	Yes	Home, fast
[66]	Yes (but CSO+EMSP)	Yes	Mixed and only for EV customers	Yes	Battery swapping
[133]	Yes	Yes	No	No	Fast, battery swapping

Table 2: Summary of economic analysis methods used in electro-mobility

This thesis aims at filling the identified gap, by defining a new methodology to help business developers find potentially interesting business cases for the development of publicly accessible CSs.

The new methodology, which is described in chapter 5, looks at the whole value chain, is business-oriented, performs a quantitative analysis, takes ICE as the benchmark and takes into account the relationships between the different charging alternatives into a single assessment.

CHAPTER 5

THE NEW PROPOSED METHODOLOGY

5 THE NEW PROPOSED METHODOLOGY

5.1 INTRODUCTION

Electro-mobility presents a number of advantages over a fossil-fuel-based transportation system, as already discussed in previous chapters, but there are also several barriers which hinder its deployment. One of the most important hurdles is the need to have publicly accessible charging infrastructure to avoid range anxiety, but it is difficult to build a sustainable business model around it, due to its high costs and (likely) low usage. Traditional business model analysis methods have not been able to demonstrate a feasible solution yet, as discussed in chapter 4. This thesis aims at filling this gap, by defining a new methodology to enlarge the scope of the analysis to help business developers to find potentially interesting business cases for the development of publicly accessible charging infrastructure for EVs.

The ecosystem nature of electro-mobility (as discussed in section 2.2) requires that the new methodology looks at the whole value chain to ensure that all the stakeholders needed to make the business case profitable can obtain a benefit from the EV-related business to be developed.

Another important feature of the new methodology is that it should be business-oriented. Although some authors consider the option of publicly-owned publicly accessible charging infrastructure deployment [4], [25], such deployment is expected to be quite capital intensive. Taking into account the growing concern about public debt rise (Figure 7), it seems more sensible to involve private investors in this process. However, public bodies can also play an important role when defining the regulatory environment and the incentives for promoting electro-mobility. Consequently, the consideration of the whole value chain and the analysis of the impact in all the stakeholders are identified again as key features of the new methodology.

In addition, the methodology should also focus in the economic components of the business case and perform a quantitative analysis. As a result, private investors will be able to perform a more straightforward comparison between different alternatives for deploying publicly accessible charging infrastructure for EVs, but also public bodies will be able to identify the alternatives which may yield higher profits for society as a whole. However, as stated by [66], qualitative approaches are better suited to represent and explain multifaceted, sociological phenomena. Therefore, the new methodology should perform a quantitative analysis, but without overlooking the advantages that qualitative approaches can bring.

The methodology must also be able to deal with an additional characteristic of electro-mobility: its novelty. The adaptation of the methodology described in this thesis started in early 2011, when there were only 3 BEV models available and "*several hundred registrations in 2010*" [77]. By 2016, more than 63 thousands BEV registrations took place [73], but the main barriers highlighted in this thesis still remain.

As discussed in Chapter 1, this novelty affects the analysis capabilities in three main dimensions:

- There is no previous experience, so regulators can only use the experience of regulating similar sectors and monitor closely their performance in this new environment. This characteristic uncovers again the need for an overall and economic approach, as discussed above.
- The lack of previous experience also makes it very difficult to obtain data which can be useful for performing the economic assessment (which is also recognised e.g. in [24]). Previous experiences in using e^3value have demonstrated the high relevance of building up an expert group, whose members must understand the aim, scope and needs of the analysis, in order to select the most appropriate data and assumptions for the quantitative assessment. As discussed in chapter 3, a sensitivity analysis is also a very useful risk-hedging tool for investors, so the methodology should also consider such type of analysis.
- Electro-mobility is expected to evolve in the next years to a consolidated, mass-market [22]. Therefore, the regulatory requirements, technological characteristics, adoption rate and costs will also evolve. As a result, the methodology must take into account inter-temporal effects, including these aspects and the variation of value of money with time.

Since electro-mobility aims at replacing traditional, fossil-fuel-based transportation system, the new methodology must compare both alternatives because, although electro-mobility deployment may prove to be feasible under certain conditions, no paradigm change will happen if it is not better than traditional mobility. Moreover, there are other potential alternatives (hydrogen, biomass-based fuels…) which may prove to be better than electro-mobility, so the new methodology should allow business developers to compare the different transportation alternatives.

However, electro-mobility has a big advantage over other transportation alternatives, which is the possibility to use private home charging. Such type of charging is, by far, the most convenient way for car users to recharge their vehicle, because they can do it by their own and, moreover, at home. As previously discussed, most of the analysis methods used so far overlook either the necessity to have a publicly accessible charging infrastructure for convenience charging or the possibility to use private home charging as the main source for providing driving range (kilometres) to the vehicle. Even the few authors who did consider both options overlook some of the potential alternatives for convenience EV charging.

As a result, a need for an integrated methodology to analyse the economic performance of electro-mobility-related business ideas has been identified, whose main characteristics can be summarised as:

a) It looks at the whole value chain.
b) It is business-oriented.
c) It focuses on economic components of the business case.
d) It aims to perform a quantitative analysis.
e) It takes into account inter-temporal effects.
f) It compares EVs against ICE vehicles and/or other potential alternatives.
g) It considers all the alternatives for EV charging together.
h) It guarantees the accuracy of data and assumptions by actively involving relevant stakeholders in all the steps where decisions must be made.

5.2 THE NEW PROPOSED SOLUTION FOR ANALYSING PUBLICLY ACCESSIBLE CHARGING INFRASTRUCTURE FOR EVS

The conceptual modelling approach taken in e^3value is deemed to be the best solution for assessing the economic feasibility of publicly accessible charging infrastructure. It also includes some of the characteristics listed in the section above (at least, a), b), c), d) are included and both e), and f) can also be taken into account in the methodology). However, the main limitation identified in section 4.4 demonstrates that a different approach is needed for this purpose. Hence, the following steps are proposed:

1. **Preliminary description of the business idea.** Similar to e^3value, this step consists in writing down a short business case description to express the business idea. In this step, it is important to bear in mind that a novel business idea can only succeed if all involved actors[26] regard it as a profitable idea (all the actors in the electro-mobility ecosystem which play a role in the development of publicly accessible charging infrastructure should have benefits from the business idea). As a result, all these actors must be included in the value model and, thus, it must be decided what must be modelled and what not. In order to facilitate understanding of the business idea, it should be presented in the form of a table, as shown in Table 3.

Business case description	Highlighted issue
	Business idea
	Scope
	Business process
	Ownership, Actors
	Technology
	Regulatory incentives

Table 3: Business idea description in a tabular form

2. **Establishment of an expert group to guide the whole analysis process.** The different actors identified in step 1 must be represented in the group to be able to consider the points of view of all the relevant stakeholders. If possible, more than one company per type of actor should be represented, to avoid having only one company's perspective. In the case of electro-mobility, these should include car manufacturers, electric utilities (if possible, both DSOs and electricity suppliers), software developers, CS and/or other electric equipment manufacturers, communication providers, CSOs, EMSPs, public bodies, regulatory authorities and EV customer representatives.
3. **Strong implication of the expert group in the assessment**. This is probably one of the most important and difficult steps in the new methodology. The objective is to

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[26] It is important to stress that actors should be assigned to archetypical roles, to avoid confusion between existing roles in different countries.

ensure that the expert group is able to understand all the details of the methodology and of the analysis. It is not about just explaining the methodology: the experts must really get embedded in the process and they should be able to assimilate the essence of this methodology. As a result, they can be fully aware of the implications of the different assumptions and of any change in the data (they can “feel” them). The establishment and implication of this expert group provides a much better insight into the details of the analysis than traditional methods for gathering information, such as questionnaires, interviews, etc. However, this strong involvement is not just a tool to provide confidence in the accuracy of the analysis which cannot be otherwise obtained (due to the lack of real life experience in the field), but it has also proven to be crucial to set up the necessary commitment by the participants to ensure the achievement of a reliable outcome. Therefore, this methodology follows a mixed-methods approach as suggested by [66], but giving a higher dominance to the quantitative approach, while including the qualitative approach by considering the expertise, commitment and expectations of the electro-mobility experts in the group.

4. **Agreement on the main boundaries for the analysis**. Once they are able to understand all the details of the analysis, the expert group will be able to define the framework for the analysis[27]. For that purpose, they must:
    a. Refine the business idea description (if needed): As discussed in 3.4.3, e^{3}value is not intended to find business ideas themselves, but to evaluate a business idea and discover a business scenario which is feasible for all stakeholders. Therefore, the expert group can also be very useful to discover potential additional business ideas to facilitate EV adoption or to fine-tune more vague ideas identified in step 1.
    b. Make decisions in a number of aspects:
        i. To make an incremental or a full analysis (e.g. assess only the provision of a defined service by the CSO, assuming that the charging infrastructure is already in place or analyse the whole business case of a CSO, including CS investment).
        ii. To consider typical days (winter/summer, weekday/weekend, only one type…) or hourly profiles.
        iii. To assess only one year (with annualised values) or a multi-year analysis to reflect the growing need for investment and EV customer base.
        iv. To focus on short-term, medium-term or long-term analysis.
        v. To consider only one alternative competitor (e.g. ICE vehicle) or all the potential alternative solutions for transportation.
        vi. To include the system level impact in the analysis or not. If so, define the metrics or KPIs to be included in the analysis.
    c. In case there is a group of actors (usually two, such as an aggregator and DER owners) who will always collaborate to increase the benefits for the group as a whole, it must be decided whether to model the group as a whole or each

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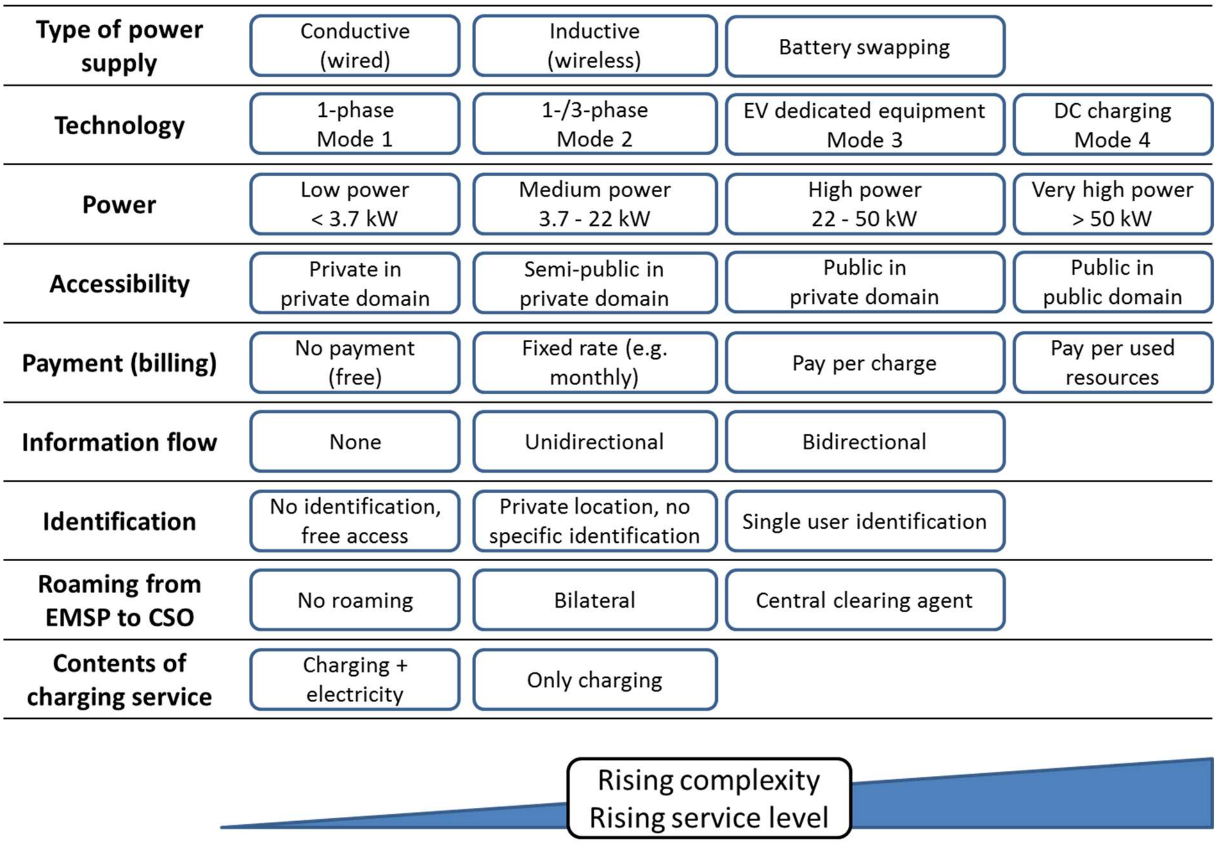
[27] In this sense, the proposed approach turns the process around, in comparison to e.g. [25] where different EV charging scenarios were created first and then validated through interviews.

of them separately. They can be included in the value model as separate entities to identify the money exchanges between them, but should anyway be included as a single entity in cash-flow calculations to facilitate the analysis.

d. Establish the services to be provided, which also affect the types of electricity markets to be considered in the analysis (day-ahead market, intra-day market, balancing market, capacity markets, etc.).
e. Agree on the regulatory option. Unless there is a solid need for one specific option (e.g. private home charging is expected to bundle the roles of either the CSO and the EV customer or the CSO and the EMSP), the most unbundled one should be selected. The reason is that it is easier to make the analysis for the completely unbundled market model and, then, assess any other market model by adding the results of the required roles (also taking into account the cost synergies) than analysing any other market model and trying to estimate the results components for the different roles performed by a single actor.
f. Select the charging alternatives to be included in the study (Figure 18).



Type of power supply	Conductive (wired)	Inductive (wireless)	Battery swapping	
Technology	1-phase Mode 1	1-/3-phase Mode 2	EV dedicated equipment Mode 3	DC charging Mode 4
Power	Low power < 3.7 kW	Medium power 3.7 - 22 kW	High power 22 - 50 kW	Very high power > 50 kW
Accessibility	Private in private domain	Semi-public in private domain	Public in private domain	Public in public domain
Payment (billing)	No payment (free)	Fixed rate (e.g. monthly)	Pay per charge	Pay per used resources
Information flow	None	Unidirectional	Bidirectional	
Identification	No identification, free access	Private location, no specific identification	Single user identification	
Roaming from EMSP to CSO	No roaming	Bilateral	Central clearing agent	
Contents of charging service	Charging + electricity	Only charging		

Figure 18: Morphological box for the different charging alternatives for EVs

g. Check whether other energy vectors/commodities (gas, heating/cooling energy, hydrogen, etc.) are relevant for the analysis.
h. Define the data and assumptions to be considered for the analysis, at least for the base case:

        i. As discussed above, industrial partners are usually reluctant to provide data. In general, each stakeholder has a range of values in mind for each type of data to be used, but it is quite common that they do not want to be the first ones to set the values when there are potential competitors around the same table. However, they tend to strongly disagree with proposals of values that fall outside their expected range (having people with different backgrounds in the group permits discriminating between wrong data and data that simply are against the interests of a certain expert). Therefore, the use of reference values (CS costs, EV prices, EV adoption rates…) is very useful to start the discussions [147], [148]. If a consensus is reached for a type of data, it means that the agreed value falls within the expected range for all the stakeholders involved, which provides strong grounds for the acceptance of the data, given the very diverse nature and the experience of participants.
        ii. In addition, industrial partners can provide very useful guidance to select the most relevant (publicly available) sources of information.
        iii. If the analysis can have access to data from pilot demonstration projects, it must be decided which information from those projects can be really useful for the analysis (and which data and results should be discarded). As discussed in [25]: "*small differences in parameters significantly influence the budget of the business case. However, predictions on these parameters are uncertain, due to the fast developments in the field of electric mobility. As a result, business cases implemented during this period of development and innovation are linked with high risks*".
        iv. If the analysis looks into the future, the methodology for price and cost extrapolation can also be defined.
    i. Investigate the possibility of having additional sources of revenue or potential synergies with other businesses which may improve the economics of the business case. Examples include using the CS for advertisement purposes, installing the CS as an additional service of a restaurant/hotel, etc.

5. **Creation of the value model(s)**. The same process as proposed in [140] can be used, but the designer of the value model must take into account that tables and catalogues are outdated. However, a good knowledge of the field of study, such as the one provided by the electro-mobility expert group, can provide the required guidance to complement the preliminary model built up based on the outcome of BUSMOD project [139]. In any case, it is advisable not to include the expert group in the whole modelling process, but to follow the sub-steps below:
    a. Create the value model as proposed in [140] but, in general, step 9 (information system model construction) can be skipped, because it is seldom a trivial task for people not used to working with ICT and, unless ICT were at the very heart of the business idea, it could be replaced by a good estimate of overall investment and O&M costs for ICT. All the assumptions agreed in step 4.h must be taken into account when creating the model.

   b. Remove all the activities and leave only the actors and the exchanges between them, because those exchanges will be the only ones to be considered in the economic assessment.
   c. Explain the scenario path. The use of colour codes for different parts of the path is very helpful for explaining the process in the value model.
   d. Decide whether the additional sources of revenue identified in 4.i will be included in the value model or just in the cash-flow analysis (to simplify the model in case it became too complex).
   e. Repeat steps 5.a to 5.d to create the value models for:
      i. Each of the charging alternatives considered in step 4.f.
      ii. Each of the services (markets) selected in step 4.d.
      iii. Each of the energy vectors/commodities included as a result of step 4.g.
   f. Ask the expert group to check whether any further actor or value exchange is missing in the model(s).
   g. Identify the relationships between the value models resulting from step 5.e.
6. **Calculation of the cash-flows for all the actors.** Based on the value exchanges in the value model and by using the data agreed in step 4.h, calculate the cash-flows for all the actors represented in the value model. Unless there is a good reason for selecting another period, these cash-flows should be calculated in annual values.
7. **Investment analysis for the main actors.** The innovative business idea is always created around one or several actors, which will make the investments needed to launch the business case. In the case of publicly accessible charging infrastructure, the CSO is always one of them, but the analysis may also look at the investments by the EMSP, EV customers and/or the DSO.
8. **Sensitivity analysis.** The parameters to be included in the sensitivity analysis should also be agreed within the expert group. A scenario analysis can also be considered.
9. **Presentation of results.** This is another important step, because it will provide the conclusions of the analysis. Since electro-mobility aims at replacing a fossil-fuel-based transportation system, the results must always be compared against the results for an equivalent analysis for ICE vehicles, either in absolute terms or by showing the difference between both. In the new methodology proposed, results are presented in a way that they show the break-even values for the most important parameters, rather than making some blind assumptions and obtaining results. This way, on the one hand, the most important part of the sensitivity analysis is already performed while, on the other, stakeholders can quickly grasp the critical values for the business model to succeed. Other important aspects to be taken into account when presenting the results are:
   a. As described above, negative results can raise criticism over the whole analysis process. However, the strong implication of the expert group in the analysis from the very beginning can be very helpful to avoid such criticism. The important point is not that stakeholders complain about results (they will, if results are not positive for their business), but that they deem them to be realistic or not.
   b. Results should also be presented in a comparable way, so that it must be decided whether to present them in absolute figures (EUR or EUR/year) or in figures related to another magnitude (EUR/EV customer, EUR/CS, EUR/times

certain service is provided, EUR/kW…), especially if different geographical/scale levels are being compared.

10. **Conclusions**. As any other analysis, meaningful conclusions must be obtained from the assessment.

Although the development and proof of the new methodology described in this thesis has focused on electro-mobility, this new methodology can be used in any other field where the general conditions (multi-actor, multi-level and complex business ecosystem for a brand new application/market with lack of data and/or lack of defined market rules…) are similar.

5.3 CONTRIBUTIONS

The first and main contribution of this thesis is the extension of the scope for analysing complex business cases to consider the different dimensions of the business case at the same time. In e^3value, the relationships within the business ecosystem are represented by means of value models. Such value models are bi-dimensional representations of the value exchanges between the different actors. However, when the business ecosystem is so complex that different value propositions co-exist and interrelate with each other, as in the case of electro-mobility and the different charging alternatives (no single EV customer will always use private home charging and no single EV customer will only use fast charging), the bi-dimensional approach of e^3value must be converted into a three-dimensional approach, as the one proposed in this thesis. On the one hand, the relationships between the different actors for each single charging alternative must be assessed, but, on the other, the relationships between different charging alternatives for each single actor must also be considered. This twofold approach requires a deep knowledge of the whole electro-mobility ecosystem and it is the first contribution (Contribution #1) of this work. This concept is described in Figure 19.

Blue planes in Figure 19 represent the bi-dimensional value models created with e^3value for each of the value propositions included in the business idea. Green lines represent the relationships of one actor in one value model with another actor in another value model. These relationships do not imply value exchanges, but other types of links, such as synergies, constraints or limitations. Orange lines reflect that the overall assessment must consider the resulting cash-flow for each actor by considering the cash-flows resulting in the different value models. Therefore, the resulting assessment provides higher yields than the ones obtained for that actor in each individual value model, but it will be different from the addition of the yields in each value model when the relationships between value models are not taken into account.

For example, if one single investment can allow an actor to provide three services, if each service is considered on its own, it may not be feasible, but providing the three of them at the same time with one single investment may be. Likewise, it must be taken into account that the three services cannot be provided at the same time, so the real assessment should not add the incomes from each service (without considering the constraints resulting from being providing another service) and compare it to a single investment afterwards.

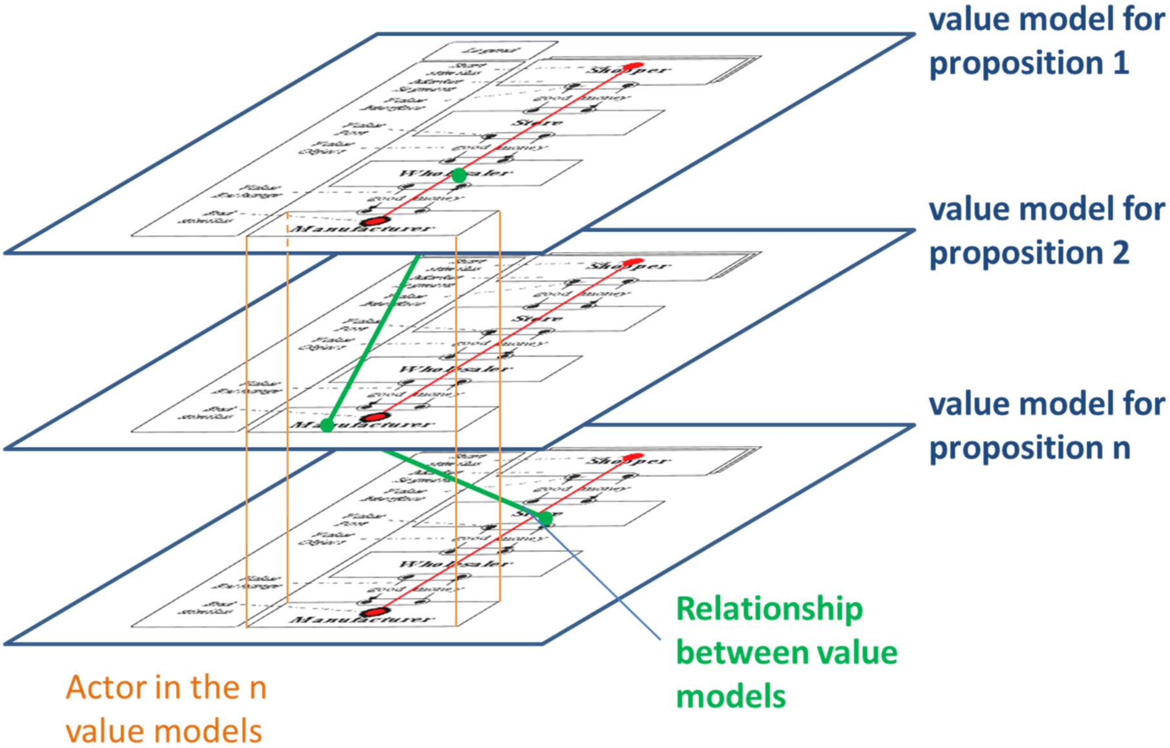


Figure 19: Graphical representation of Contribution #1

The second main contribution of this new methodology is the awareness of the crucial need to involve appropriate representatives of the relevant stakeholders (decision-makers) in the analysis from the very beginning of the process. This is a main fundamental process that must be included in the whole scheme and which has proven to be of paramount importance, despite its apparent obviousness. Hence, the guidelines to create and conveniently manage an expert group have been also proposed. In fact, being able to make the participants fully understand the essence of the new methodology described as Contribution #1 and the added-value of such understanding is an original added-value of the new methodology described in this thesis. It is an innovative way to gather data (e.g. for future prospects) from a market where existing data are few and not relevant for the mass market, due to the expected evolution. Therefore, it is the second contribution (Contribution #2) of this work.

The third main contribution of this thesis is an oriented, tailored approach from the early stages of the analysis to obtain significant results which increase the reliability of the outcomes and guide the decision-making process. The traditional method to approach an economic assessment is to make some assumptions, consider different data values, perform the calculations to obtain the results and carry out a sensitivity analysis to check the break-even values for the most relevant parameters. The new methodology presented in this thesis goes a step beyond this approach by performing the most important part of the sensitivity analysis within the calculations themselves. For that purpose, the analysis must identify (with the help of the expert group detailed in Contribution #2) the most critical parameters (or the parameters with a significant impact and the highest uncertainty) for the different stakeholders. This way, the analysis is oriented, from the very beginning, to validate or refute a hypothesis which may have been considered otherwise in the phase of assumptions. In the case of electro-mobility, the most critical parameter for CSOs is the usage rate of their CSs, since the pricing strategy is limited by the competitor of electro-mobility (i.e. ICE vehicles). As demonstrated in chapter 6, this way of presenting results is very useful and straightforward to identify the break-even point for profitability. Again, a deep knowledge of the electro-mobility ecosystem is required to identify such critical parameters. The orientation of the analysis to identify the critical parameters and the presentation of results by means of break-even values is the third contribution (Contribution #3) of this work.

5.4 CONCLUSIONS

The state of the art analysis presented in chapter 4 showed the need for a new methodology to assess the economic feasibility of the deployment of publicly accessible charging infrastructure for EVs. This thesis presents such new methodology, whose main contributions are:

1. The new methodology extends the scope for analysing complex business cases to consider the different dimensions of the business case at the same time.
2. This new methodology highlights the crucial need to involve appropriate representatives of the relevant stakeholders (decision-makers) in the analysis from the very beginning of the process.
3. The new methodology has an oriented, tailored approach from the early stages of the analysis to obtain significant results which increase the reliability of the outcomes and guide the decision-making process.

CHAPTER 6

DEVELOPMENT AND VALIDATION OF THE NEW METHODOLOGY

6 DEVELOPMENT AND VALIDATION OF THE NEW METHODOLOGY

6.1 INTRODUCTION

The proposal for the new methodology described in this thesis (chapter 5) is the result of fifteen years of application of e^{3}value to the analysis of different innovative business models in the field of smart grids, five of which were fully devoted to electro-mobility.

This chapter presents the application of the new methodology to the analysis of the deployment of publicly accessible charging infrastructure for electric vehicles. The study takes data from [82], [149], [150] and [151], where some of the characteristics of the new methodology can be found. Furthermore, the lessons learnt for the creation and for ensuring the strong involvement of the expert group are based on the experience of the Green eMotion project (FP7-TRANSPORT-265499, [152]), where such process was tested for the first time.

Those early uses of the methodology in real-life applications were essential for the identification of the existing gap in the current methodologies for analysing EV-related business models, especially when dealing with the complexity of the ecosystem and with the consideration of the different dimensions of the business case at the same time. Despite those early partial usages of the methodology, this thesis presents the first complete application of the new methodology.

Based on the description of the new methodology in section 5.2, the analysis can be divided into four main tasks:

1. Definition of boundaries
2. Value model creation
3. Calculations and results
4. Evaluation of results

6.2 DEFINITION OF BOUNDARIES

The main boundaries of the analysis are established by performing steps 1 to 4 in the methodology.

6.2.1 Step 1: Preliminary description of the business idea

The business idea must be profitable for all the involved actors, so step 1 facilitates the common understanding of the idea by writing down a short business case description, as shown in Table 4.

Business case description	Highlighted issue
Installation and operation of private and publicly accessible CSs, where EV customers from different EMSPs can charge their EVs through roaming agreements between their EMSPs and the respective CSO on the one hand and a marketplace operator on the other. New actors (CSO, EMSP, marketplace operator) must be able to make a profit, while offering EV customers a charging price which is competitive against using ICE vehicles.	Business idea
Four different alternatives are considered for EV charging, all of them through conductive charging, paying per used resources and including charging and electricity in the charging service: 1. Charging at a point of interest (POI): Mode 3, medium-power (22 kW), public charging in private or public domain, with bi-directional communication. Single user identification is needed, but not roaming, since the user will pay directly to the CSO (who also performs the EMSP role in this case). 2. Highway charging: Mode 4, high-power (50 kW), public charging in private domain, with bi-directional communication. Single user identification and a central clearing agent are needed. 3. Home charging: Mode 2, low-power (3.7 kW), private charging in private domain. The payment is included in the regular home bill and no communication or specific identification is required (private location). Roaming is neither required. 4. Charging while parked on curbside: Mode 3, medium-power (22 kW), public charging in public domain, with bi-directional communication. Single user identification and a central clearing agent are needed.	Scope
EV customers pay a fixed subscription fee to EMSPs and a variable price for the energy they charge in each charging session in cases 2 and 4 (which is billed on a monthly basis), while the electricity for charging is included in the regular electricity bill in case 3 and there is a direct payment system in case 1. EMSPs and CSOs in cases 2 and 4 have a roaming agreement with a third party (the marketplace operator, i.e. the central clearing agent), which guarantees economic performance of the other party and requests a membership fee. CSOs buy the electricity required to charge EVs from regular electricity retailers.	Business process
Main actors are EV customers, CSO(s), EMSP(s) and the marketplace operator. Other regulated (DSO, TSO) actors or actors under competition (retailers, producers) are also taken into account, but to a lower extent. An independent CSO (not the DSO, the retailer or the EMSP, except in case 1) owns and operates CSs. EV customers own EVs (and CSs in case 3).	Ownership, Actors
EVs are considered to be BEV (no hybrids).	Technology
Government subsidies for EV purchase are taken into account. TOU tariffs are considered for home charging (case 3).	Regulatory incentives

Table 4: Business idea description for the deployment of charging infrastructure

6.2.2 Step 2: Establishment of an expert group

An expert group has to be created to agree on the data, assumptions and boundaries for the analysis. As discussed in section 5.2, the expert group should be created as soon as possible and include a set of stakeholders as broad as possible, with a real commitment towards the success of the analysis to be performed and towards the reliability of its final results.

In this use case, the expert group has included representatives from car manufacturers (BMW, Nissan and Daimler), electric utilities (RWE, Enel, Iberdrola, ESB and Endesa, with participants both from the DSO and the retail businesses), software developers (IBM and Siemens), CS manufacturers (Siemens and Bosch), providers of communication systems (IBM and Siemens), CSOs (RWE, Enel, Bosch, Iberdrola, ESB and Endesa) and EMSPs (RWE, Enel, BMW, Iberdrola, ESB and Endesa). Therefore, all the relevant business stakeholders in the electro-mobility ecosystem have participated in the expert group. Regulatory authorities and EV customer representatives have not been included in the expert group, but they have been replaced by research institutions (in particular by DTU and ECN, who led the sociological study and the regulatory recommendations respectively), while public bodies have been represented in the consortium by the municipalities of Rome, Copenhagen, Berlin, Dublin, Cork, Malmö, Barcelona and Málaga. Although these public bodies have not contributed to the discussions in the expert group, they have been regularly informed about the progress of the activities.

It is important to stress that, at the time of establishing the expert group, electro-mobility was at a very early stage of development (for example, Eurelectric had published its first concept paper on market models for electro-mobility [153], but not the one to organise the market [46], and the German Platform for electro-mobility had only very recently issued its second report [154]).

6.2.3 Step 3: Strong implication of the expert group

In the practical application of the methodology, the whole process to ensure the deep involvement of the experts into the details of the methodology took about three years and a half, which provides an idea of the difficulty behind it. For the first two years, a traditional approach was followed, according to which the expert group reacted to the different proposals arising from the technical developments within the task.

However, the progress in the analysis was not satisfactory and, hence, a new approach was needed.

Thus, a task force was created to improve the involvement of experts and to be able to finally agree on the boundaries. The task force included experts involved in the process since the very beginning (RWE, Enel, BMW, IBM), together with the project coordinator (Siemens) and the partner leading the task about regulatory recommendations (ECN). The latter two had been involved in the expert group at an earlier stage, but not from the very beginning, so bilateral meetings were organised with each of them (about 3 within a month) to let them know about all the process followed from the beginning. Then, monthly physical meetings and phone conferences were established to monitor the progress of the activity.

In the first of these meetings, data and assumptions were proposed to the expert group, who provided feedback. Based on such feedback, some results could be obtained and presented to the expert group at the next meeting. Then, the experts reacted to those results by fine-tuning the data or assumptions. Finally, the experts were able to understand the implications of those changes and final data and assumptions were agreed in autumn 2014.

6.2.4 Step 4: Agreement on the boundaries

In the practical application described here, the scope of the analysis is broader than usual, in order to take the perspectives of different actors into account and to consider a combined effect of different charging alternatives. Moreover, the impact of the conditions in different countries is assessed through the sensitivity analysis.

As described in step 1, the business case to be evaluated is the installation and operation of both private and publicly accessible charging points, where EV customers from different EMSPs can charge their vehicles through roaming agreements between, on the one hand, their EMSPs and the respective CSO and, on the other, a marketplace operator. New actors (CSO, EMSP, marketplace operator) must be able to make a profit, while offering a charging price to EV customers which is competitive against using ICE vehicles. This way, four alternatives for EV charging are considered:

1. Charging at a POI: Charging at a publicly accessible CS on private domain. The charging speed is assumed to be semi-fast (22 kW). EV customers pay for EV charging and for parking their EV, so it is assumed that they pay directly to the operator of the POI who, hence, acts as EMSP and CSO at the same time (no roaming required and, thus, no marketplace, because it is assumed that a direct payment system already exists in the POI[28]).
2. Highway charging: Charging at a publicly accessible CS on private or public domain. The charging speed is assumed to be fast (50 kW, DC). EV customers pay for EV charging, so it is assumed that they use the roaming agreement of their EMSP with the CSO to be able to charge their EVs.
3. Home charging: Charging at a private CS. The charging speed is assumed to be slow (3.7 kW). EV customers themselves buy the CS required for charging their EVs (so they act as CSO) and buy electricity directly from the electricity retailer (which performs the EMSP role in this case), so there is no need for a roaming agreement.
4. Charging while parked on curbside: Charging is made at a publicly accessible CS on public domain. The charging speed is assumed to be semi-fast (22 kW). Roaming of EV customers is made through a roaming agreement, where both the EMSP and the CSO are subscribed.

In all the cases, conductive charging is considered, as it is the one expected to meet most of the charging events, at least in the short- to medium-term. In addition, only Mode 3 is considered for AC charging (cases 1, 3 and 4), while Mode 4 corresponds to DC charging (case 2).

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[28] It is expected that the POI has a high demand for car parking, so parking will not be for free and, thus, a direct payment system should already exist.

In order to cover a scope as broad as possible, the unbundled regulatory option, i.e. the case where the CS is operated by an independent entity (see section 2.2.3) is selected as the first option. Under this regulatory option, the DSO, the electricity retailer, the EMSP and the CSO are different legal entities. In case 1, the EMSP is assumed to be the CSO, because, as described above, it is considered that EV customers pay (for EV charging and for parking their EV) directly to the operator of the POI.

Under this regulatory option, roaming is required, so that the different actors have contracts in place that finally allow the EMSP to offer charging services to the EV customer (EV driver) using the CSs of the CSO. As a result, the CSO has the possibility to bill the EMSP for the charging event, which implies that the most natural approach is to consider that electricity is included in the charging ("roaming of charging service" in [46]).

It is assumed that each charging service corresponds to one individual CSO[29]. In this way, the main actors for the analysis are EV customers (who are the CSOs in case 3), the EMSP (who offers electric mobility services to EV customers in all charging alternatives, as well as roaming services in cases 2 and 4), the POI operator (who is the EMSP and the CSO in case 1), the highway charging CSO and the public charging spot operator. On the contrary, established roles (electricity retailers, electricity producers, BRPs…) are expected to be profitable, while the ones which may be required to make investments (DSOs, TSOs, electricity market operator) are regulated, so they will be able to get any extra cost refunded by the regulatory authorities. The analysis considers that the CSO would focus on owning the equipment, so that O&M and other issues related to CS operation (such as identification and evaluation of charge data for information or customer service and technical support, as e.g. RWE offers together with the energy supply and measurement [155]) are outsourced to third parties. Moreover, it is supposed that CSOs are not start-ups, but existing companies, so that their (incremental) staff and overhead costs can be assumed to be negligible. On the contrary, staff costs for EMSPs are deemed to be relevant, because, even if the EMSP can be an existing company, the provision of electro-mobility services is a new activity, which requires additional staff.

Regarding the marketplace operator, it is a new role, which is needed for the business cases to succeed (at least in cases 2 and 4) but which is not central to them. The business model for this actor is difficult to define, because their market is quite limited, there is little data available and the same hardware and software can be shared around the world, so it is very sensible to economies of scale. Therefore, the analysis takes into account the data in [82] in the expectation that current prices will either be the same or more beneficial for the business case. The definition of the business model for the marketplace is based on interviews with representatives of existing marketplaces in Europe [156], [157]. The costs of accessing them include a one-time subscription fee and an annual fee for both CSOs and EMSPs. On top of that, EMSPs must pay another annual amount per customer.

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[29] Although more than one charging service could be offered by a single CSO, the only cost which does not depend on the number of CS (and, hence, can be reduced if more than one type of charging service is provided) is the cost of accessing the marketplace. This cost can be relevant in the highway charging service and in the public charging spot for street side parking, so it has been included in the sensitivity analysis.

Regarding data, it is difficult to obtain reliable data for the analysis, which is a common problem when analysing innovative value propositions (“*The number of scenario occurrences and path likelihoods are hardly known in advance. Because we explore innovative value propositions, we cannot rely on historical data. In practice, such numbers can only be found by doing market research, and even then it is difficult because it is not very well possible yet to predict whether or how quickly an innovative idea will be adopted*” [138]). Additionally, “*Important components of any business case evaluation comprise data on cost and demand which can hardly be found in peer-reviewed literature but are exposed in project reports*” [24].

This application case study takes the data in [82] as the main starting point. Due to the limited market of electro-mobility at the time of performing the initial analysis (2013-2014), some data were updated in [149], [150] and [151], but some further updates are required here.

It is worth mentioning that Green eMotion included a number of demonstration pilot projects, whose data were available for [82]. Still, the experience in previous research activities and the limited scope of many of demonstration activities in those pilot projects discouraged the use of those data as being really representative of a situation with widespread adoption of electro-mobility. Therefore, only EV charging data is taken from pilot projects, while most cost data is obtained from literature, in particular from the reports prepared by the German National Platform for Electric Mobility [154], [158], [159].

Consequently, the analysis is made for only one year and it focuses in the medium term, in the hope of having a big enough EV customer base (about 50 000 EV customers and 10 000 CSs) so that there could be a profitable business case. Moreover, due to the limited availability of data, it is decided to consider hourly profiles for a typical day.

6.3 VALUE MODEL CREATION

The value model must be created by following the process in [140], but taking into account that tables and catalogues can be outdated. Moreover, previous experiences recommend, among others, removing the value activities to leave only the actors and the exchanges between them (see step 5 in section 5.2 for all the recommendations). Additionally, scenario paths are explained by using colour codes for different parts of the path.

6.3.1 Step 5: Creation of the value model

When creating value models for any type of business case, the regulation under which the business is developed must be taken into account. In particular, the regulation that applies to the electricity system is of paramount importance for representing the whole value chain for the provision of EV charging services. Since both the methodology presented in this thesis and the practical application described in this chapter are not aimed at describing the particular situation in one particular country, the specific conditions for the electricity supply have been removed from the value models and replaced by a black box named “Rest of the electricity system”. In addition, the presentation of the traditional electricity supply increases the complexity of the models, but has no impact on assessing the profitability of

EV services (including charging) for the main actors (EV customers, EMSP, CSO, DSO). As an example of what such black box would represent, Figure 20 presents the value model for “the rest of” the Spanish electricity system.

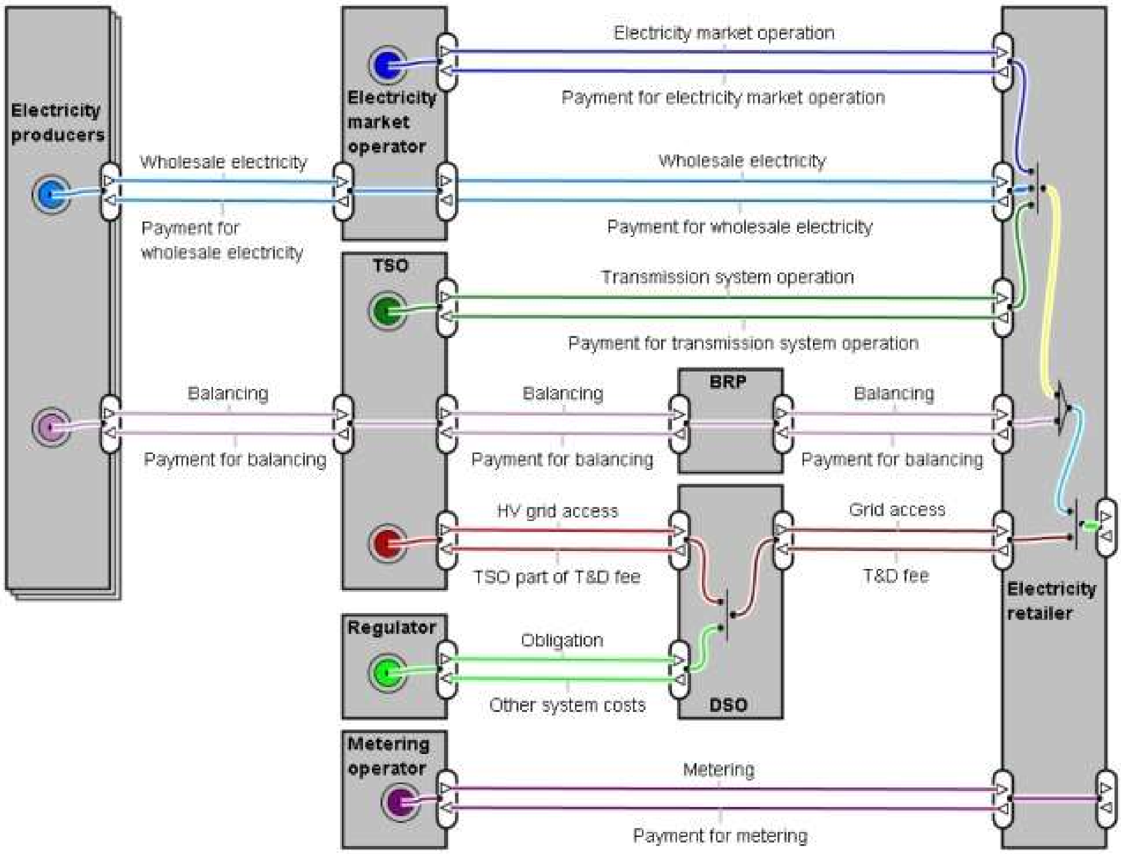

Figure 20: Value model for the traditional electricity supply in Spain

The “Rest of the electricity system” path in Spain would consist in the electricity retailer paying for electricity market operation, i.e. for accessing to the wholesale market (dark blue lines) and for wholesale electricity (light blue lines) to the electricity market operator, who would pay for electricity to electricity producers. In addition, the electricity retailer would pay for (transmission) system operation to the TSO (green lines), for balancing (in case he creates any imbalance in the system) to the BRP (pink lines), for grid access to the DSO (brown lines) and for metering to the metering operator (purple lines). The payment to the BRP will depend on the amount charged by the TSO for that balancing, which also depends on the amount that the TSO pays to electricity producers for balancing the system (again, pink lines). The DSO will transfer part of the T&D fee to the TSO for accessing the high voltage network (red lines) and the rest of the system costs to the regulator (light green lines).

The value model for the POI charging (case 1) is presented in Figure 21.

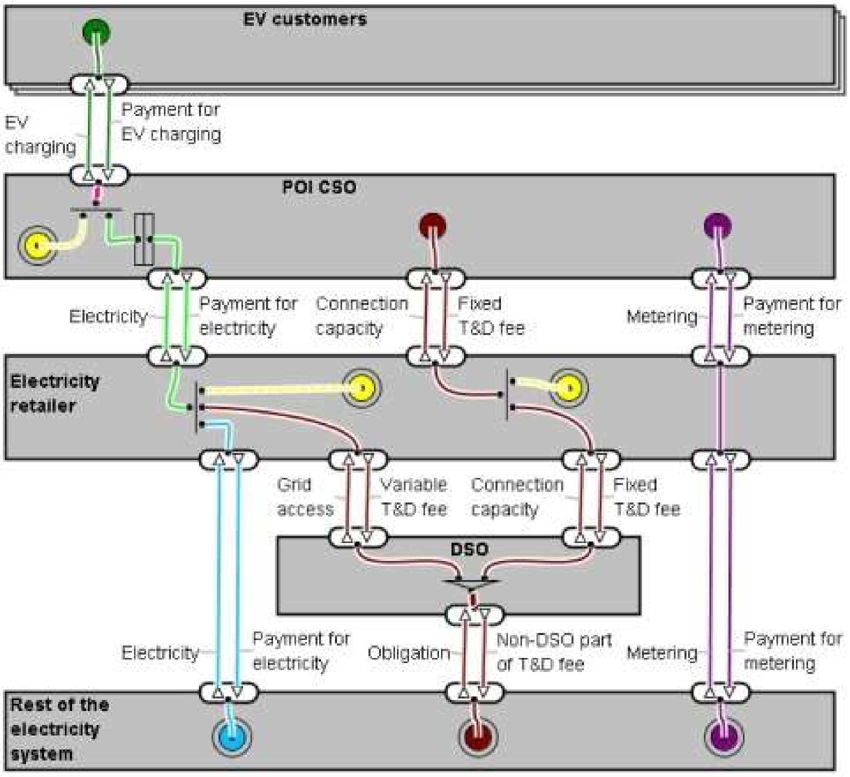

Figure 21: Value model for the POI charging case

EV customers want to charge their EVs (green start stimulus), so they will pay for it to the POI CSO (who performs the EMSP and CSO roles). In order to satisfy such need, the POI CSO needs to buy electricity from the electricity retailer (light green line) and keeps part of the remuneration (yellow end stimulus). In order to show that the charging may be billed per kWh, per time or any other magnitude, there is an implosion in the light green line which represents a change in magnitude (because the POI will always pay per kWh to the electricity retailer). On the other hand, it must also pay the fixed part of T&D fees or any other fixed cost which does not depend on the consumed amount of electricity (brown start stimulus) and pay for metering (purple start stimulus) to the electricity retailer, either if it consumes electricity or not (so a different scenario path is created for each of them). The electricity retailer must pay the two components of grid access to the DSO (brown lines), and pay for electricity itself (blue lines) and for metering (purple lines), while it can obtain its profit from the variable part of the billed electricity, from the fixed part or from both (yellow end stimuli). The money exchanges required for this to happen depend on the market arrangements of each individual country as discussed above, so they are included as “Rest of the electricity system”.

The value model for the highway charging (case 2) is presented in Figure 22. This model is the same as for charging while parked on curbside (case 4).

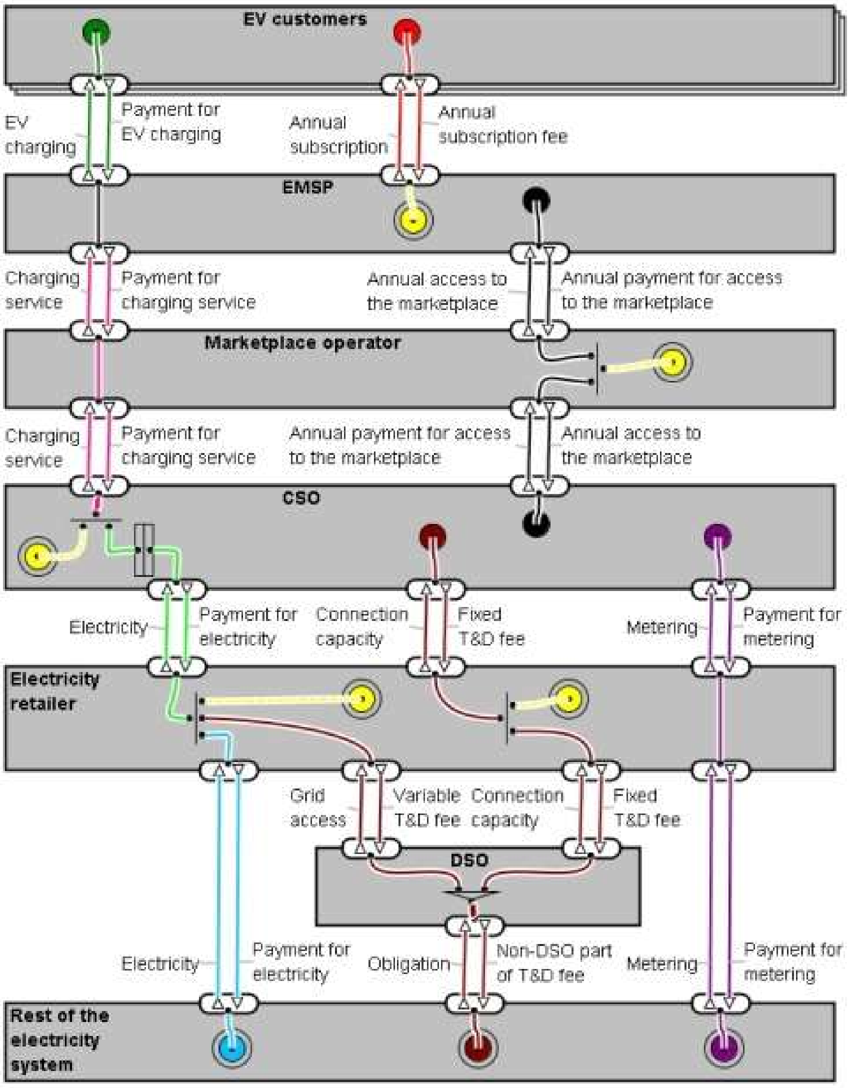

Figure 22: Value model for the highway charging case and for the case of charging while parked on curbside

EV customers want to contract an EMSP (red start stimulus) and to charge their EVs (green start stimulus), so they will pay for that to the EMSP. In order to satisfy the charging need, the EMSP needs to make a profit (yellow end stimulus) and buy the charging service (pink lines) from the marketplace operator. However, in order to be able to access the marketplace, the EMSP must pay an annual fee (black start stimulus and lines). Likewise, the CSO must pay an annual fee to be connected to the marketplace (black lines), but it receives the payment every time there is an EV charging event (pink line). The CSO must, on the one hand, buy electricity from the electricity retailer (light green line) and keeps part of the remuneration (yellow end stimulus). As in the case of the POI charging, there is an implosion in the light green line to represent the change in magnitude (because the POI will always pay per kWh to the electricity retailer, but it can charge the EMSP per kWh, per time or per any other magnitude). The CSO must also pay to the fixed part of T&D fees or any other fixed cost which does not depend on the consumed amount of electricity (brown start stimulus) and pay for metering (purple start stimulus) to the electricity retailer, regardless of whether electricity is consumed or not (so a different scenario path is created for each of them). The electricity retailer must pay the two components of grid access to the DSO (brown lines) and pay for electricity itself (blue lines) and for metering (purple lines), whereas it can obtain its profit from the variable part of the billed electricity, from the fixed part or from both (yellow end stimuli). Again, the money exchanges related to the market arrangements of each individual country are included as “Rest of the electricity system”.

The value model for the private home charging (case 3) is presented in Figure 23.

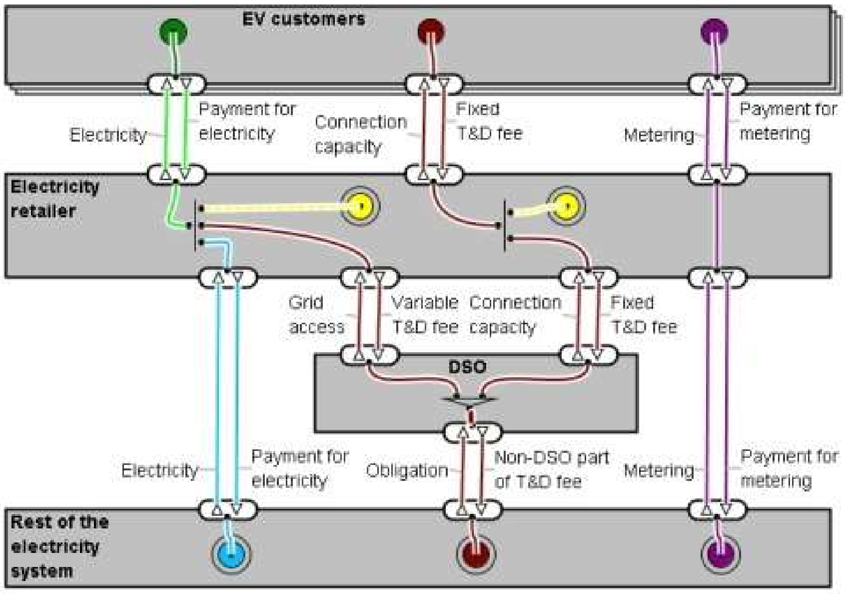

Figure 23: Value model for the private home charging case

In this case, EV customers are their own CSO and the electricity they consumer for EV charging is included in their home electricity bill. Therefore, when they have the EV charging need (green start stimulus), they will pay for electricity to their electricity retailer, to whom they must also pay the connection fee (brown start stimulus) and the metering fee (purple start stimulus). The retailer, as in the cases above, must pay the two components of grid access to the DSO (brown lines) and pay for electricity itself (blue lines) and for metering (purple lines), whereas it can obtain its profit from the variable part of the billed electricity, from the fixed part or from both (yellow end stimuli). The money exchanges required for this to happen depend on the market arrangements of each individual country as discussed above, so they are included as “Rest of the electricity system”.

Then, the relationships between the different value models must be identified. In this case, EV customers appear in all the models. The resulting EV charging prices for EV customers in the different cases will affect their TCO, so the number of kilometres driven as a result of the energy charged in each case must be taken into account.

In addition, both the EMSP and the marketplace operator are present in cases 2 and 4, but their main cost and income components do not depend on the number of charging events or on the energy charged, so the only impact of considering different alternatives is that they can increase the EV customer base using their services.

6.4 CALCULATIONS AND RESULTS

Steps 6 to 9 in the new methodology perform the calculations and obtain the results.

6.4.1 Step 6: Cash-flow calculation

Based on the value exchanges in the value model and by using the data agreed in step 4, the annual cash-flows for all the actors represented in the value model can be calculated.

In order to assess whether there is room for developing a positive business model for all the actors involved in the ecosystem, the analysis assumes that the different commercial actors (CSO, EMSP and the marketplace operator) use a pricing strategy which allows them to recover their costs. Then, the effect on EV customers is compared with a similar situation for an ICE vehicle driver. The detailed analysis for the different actors is presented in the paragraphs below. The costs and incomes for the CSO are different in the four charging alternatives presented, so the different CSOs will be analysed in individual paragraphs.

The base case presented in this section corresponds to Spain, while other countries (Germany and the Netherlands) are included in the sensitivity analysis.

6.4.1.1 Marketplace operator

Although this actor only appears in cases 2 and 4, it affects the cash-flows of the EMSP and CSO, so it is worthwhile to present it first.

By looking at Figure 22, it can be seen that the marketplace operator transfers the payment for charging service from the EMSP to the CSO (pink lines), without any profit on that, because the profit is made through the collection of the annual payments for accessing the marketplace, both from the EMSP and the CSO (black lines).

Based on [149], it is assumed that, for 50 000 EVs and 10 000 CSs to be included in the marketplace, marketplace staff costs and Earnings Before Interest and Taxes (EBIT) account for EUR 40 000 per month, while another EUR 25 000 are required for the clearing house service. Therefore, the operational costs of the marketplace operator (including the clearing house service) account for EUR 65 000 per month, or EUR 780 000 per year.

According to interviews with representatives of existing marketplaces in Europe, the one-time subscription fee for CSOs and EMSPs is EUR 5 000 and the annual fee EUR 1 600. On top of that, EMSPs pay EUR 25 per customer and per year, up to maximum EUR 25 000 per year. The number of participants in the marketplace is likely to increase and, hence, lower prices can be expected in the future. However, to be on the safe side, the 2013 prices were considered in the analysis.

One of the marketplaces in commercial operation stated that it had more than 120 partners in 2014, but it has more than doubled since then so that it has more than 270 partners in May 2017 [156]. Since both EMSPs and CSOs pay the same annual subscription fee and the only difference between them (regarding the payments to the marketplace operator) is the additional payment per EV that EMSPs are requested to pay, the minimum number of EMSPs for the marketplace operator business to become profitable can be calculated.

Hence, the number of EMSPs (N_{EMSP}) and of CSOs (N_{CSO}) sum 270, as shown in equation (18).

$$N_{EMSP} + N_{CSO} = 270 \tag{18}$$

Also, the incomes of the marketplace operator will equal its costs if equation (19) is met.

$$MPO_{cost} = MPO_{income} = EMSP_{variable} + EMSP_{fixed} + CSO_{fixed} \tag{19}$$

Therefore, equation (20) can be obtained.

$$\begin{aligned} 780\,000 &= \sum_{n=1}^{N_{EMSP}} Max[(25 * EV_n), 25\,000] + (N_{EMSP} * 1\,600) + (N_{CSO} * 1\,600) \\ &= \sum_{n=1}^{N_{EMSP}} Max[(25 * EV_n), 25\,000] + (N_{EMSP} + N_{CSO}) * 1\,600 \\ &= \sum_{n=1}^{N_{EMSP}} Max[(25 * EV_n), 25\,000] + (270 * 1\,600) \\ &\Rightarrow \sum_{n=1}^{N_{EMSP}} Max[(25 * EV_n), 25\,000] = 348\,000 \end{aligned} \tag{20}$$

If all the EMSPs pay the maximum amount (EUR 25 000 per year), the minimum number of EMSP needed to make the marketplace operator business profitable can be calculated according to equation (21).

$$N_{EMSP} * 25\,000 = 348\,000 \Leftrightarrow 13.92 \approx 14 \tag{21}$$

As a result, from the total 50 000 EV customers, each EMSP will manage about 3 600 EV customers on average, so they will really pay the maximum EUR 25 000 per year.

The summary of the data used and the results obtained (in bold) for the marketplace operator can be found in Table 5.

Parameter	Value
Number of EVs using the marketplace	50 000
Number of CSs using the marketplace	10 000
Marketplace staff cost and EBIT (EUR/month)	40 000
Clearing house staff cost and EBIT (EUR/month)	25 000
One-time subscription fee for the marketplace operator (EUR)	5 000
Annual subscription fee for the marketplace operator (EUR/year)	1 600
Additional annual subscription fee requested by the marketplace operator to EMSPs (EUR/year.EV customer)	25 (up to 25 000)
Number of companies in the marketplace	270
Minimum number of EMSPs in the marketplace	**14**
Average number of EV customers per EMSP in the marketplace	**3 600**

Table 5: Data and results of the marketplace operator profitability analysis

6.4.1.2 EMSP

Like for the marketplace operator, the EMSP only appears in cases 2 and 4, but it is a fundamental actor for allowing EV customers to perform convenience charging.

According to Figure 22, the EMSP has two main paths for money flows. On the one hand, there is the flow for each EV charging session (green and pink lines) and, on the other, the annual subscription fees, both the one paid by the EMSP to the marketplace operator (black lines) and the one paid by EV customers to the EMSP (red lines).

It is assumed that the EMSP passes through the EV charging costs directly to EV customers, without any profit or loss per charge. Yet, EV customers, being final customers, will have to pay the VAT, which will be transferred to the government by the EMSP (not represented in the value models for the sake of simplicity). Therefore, the EV charging price they pay (green lines) is slightly higher than the charging service price requested by the CSO (pink lines).

Again, EV customers' annual subscription fees must be able to pay for all the costs incurred by the EMSP. The main costs for the EMSP are listed below:

- Costs for accessing the marketplace: As described in paragraph 6.4.1.1, they include a one-time subscription fee of EUR 5 000 and an annual fee of EUR 1 600. If the one-time subscription fee is assumed to be amortised in the long-term (e.g. 20 years) and with a 5 % discount rate, the annual marketplace access costs can be assumed to be EUR 2 000 per year. As shown in equation (22), they are the sum of the annual payment (EUR 1 600) and the annualised value of the one-time investment, which is calculated by using equation (11).

$$Annual\ MP\ access\ cost = 1\,600 + \frac{5\,\% * (1+5\,\%)^{20}}{(1+5\,\%)^{20}-1} * 5\,000 \approx \text{EUR } 2\,000 \tag{22}$$

- On top of that, the EMSP must pay EUR 25 per customer and per year (up to a maximum annual payment of EUR 25 000). As estimated in paragraph 6.4.1.1, each EMSP is assumed to have 3 600 EV customers, so they would pay the maximum EUR 25 000 per year.
- Communications costs: internet costs for small and medium enterprises can be as low as EUR 12 per month ([160], in May 2017), which, for 3 600 EV customers, would mean EUR 0.04 per year and per EV customer.
- Amortisation of radio-frequency identification (RFID) card: RFID card costs are assumed to be EUR 1 [161]. Although card lifetime might be about 20 years, a shorter replacement period is envisaged (about 5 years). Considering a 5 % discount rate, the annual amortisation costs are calculated in equation (23).

$$Annual\ RFID\ card\ amortisation = \frac{5\,\% * (1+5\,\%)^{5}}{(1+5\,\%)^{5}-1} * 1 \approx \text{EUR } 0.23 \tag{23}$$

- Staff and overhead costs: They include staff costs, facility related costs (including non-product related media/energy supply), R&D expenses not directly related to the product and marketing and communication. It was decided to use a bottom-up approach, because EMSPs are more likely to resemble start-up companies and small or medium-sized enterprises. According to this approach, the needed resources were estimated in [82]. For that purpose, 6 staff categories have been identified, with their corresponding average cost per person, as well as the number of people required for different EV penetration scenarios (as shown in Table 6), because these costs strongly depend on the number of EV customers managed. Overheads including cost for buildings/facilities and office equipment (including standard office ICT) are expected to be around 50 % of staff costs. For the case of 3 600 EV customers, total costs are about EUR 427 500 per year.

Personnel category	Number of clients							Average cost (EUR/year)
	≤10	≤50	≤1 000	≤5 000	≤10 000	≤50 000	>50 000	
CEO	0	0	0	0	0	0	1	100 000
Director	1	1	1	1	1	1	1	60 000
Salesperson	1	1	2	2	2	2	2	30 000
Operator	5	5	5	5	5	5	5	25 000
Administrative	1	1	1	2	5	5	10	20 000

Table 6: Estimates of new staff requirements and its costs for the EMSP

Hence, equation (24) calculates the annual costs for an EMSP with 3 600 customers.

$$
\begin{aligned}
Cost_{EMSP}^{year} &= 2\,000 + 25\,000 + (12 * 12) + 0.23 * 3\,600 + 427\,500 \\
&= \text{EUR } 455\,472
\end{aligned}
\tag{24}
$$

This amount results in EUR 126.52 per EV customer, which is the minimum, before-taxes annual subscription price to be requested by the EMSP. Table 7 summarises the data used and the results obtained (in bold) for the EMSP.

Parameter	Value
Number of EV customers in the portfolio	3 600
One-time subscription fee for the marketplace operator (EUR)	5 000
Annual subscription fee for the marketplace operator (EUR/year)	1 600
Additional annual subscription fee requested by the marketplace operator to EMSPs (EUR/year.EV customer)	25 000
Marketplace access one-time subscription fee amortisation period (year)	20
Communication costs (EUR/month)	12
RFID card cost (EUR)	1
RFID card amortisation period (years)	5
Discount rates	5 %
Staff costs (EUR/year, calculated from Table 6)	427 500
Overheads	50 %
Minimum, before-taxes subscription price to be paid to the EMSP (EUR/year)	**126.52**

Table 7: Data and results of the EMSP profitability analysis

6.4.1.3 POI CSO

According to Figure 21, the POI CSO must pay for electricity (light green lines), for being connected to the grid (brown lines) and for metering (purple lines), while it receives the payment by EV customers for EV charging (green lines). All these variable costs per charge can be assumed to be included in a monthly electricity bill to be issued by the electricity retailer.

In addition, it must also pay for CS O&M and for its amortisation, which can be obtained by using the data in [159] for the 11/22 kW charging point. Based on them, investment cost is EUR 10 500, O&M cost (metering and communications included) is EUR 1 725 and lifetime of the CS is 7.5 years. Using again equation (11), with a 7 % discount rate, CS amortisation can be calculated as shown in equation (25).

$$Annual\ CS\ amortisation\ cost = \frac{7\,\% * (1+7\,\%)^{7.5}}{(1+7\,\%)^{7.5}-1} * 10\,500 \approx \text{EUR } 1\,846.90 \qquad (25)$$

The electricity bill calculation depends on the country, but as discussed above, the conditions in Spain have been considered. Although the structure of the electricity bill in Spain is almost the same for all types of consumers, there is a classification in the T&D fees to be paid by consumers, depending on their contracted power (connection size) and the voltage level at which they connect [162].

In the case of a POI, the considered CS has a charging capacity of 22 kW, with two outlets, so the tariff to be considered is 3.0.A, which applies to connections at low voltage (less than 1 kV) with a contracted power of more than 15 kW. This tariff is divided into three periods per day [163]: p1 (from 18.00 to 22.00 in winter and from 11.00 to 15.00 in summer), p2 (the times not included in the other two categories) and p3 (from 0.00 to 8.00, both in winter and in summer). The way to calculate the electricity bill is defined by [90], [159], [162] and [164].

Based on the data collected in the demo regions, 25 % of charges are assumed to happen in p1, 60 % in p2 and 15 % in p3 [51]. Only one CS is considered in the analysis, so the contracted power in the three periods is the same.

Taking into account that POI charging will be for convenience charging, but not requiring the full-charge of the battery, it is assumed that the average amount of energy demanded per charge is 10 kWh. Consequently, the charging process takes about 1 hour (10 kWh at 11 kW), which is a quite acceptable assumption for the minimum parking time at a POI.

The electricity prices in Table 8 are considered (present prices can be found at [165]).

KPI description	P1	P2	P3
Tp (EUR/kW.month)	6.832399	6.832399	6.832399
Te (EUR/kWh)	0.122383	0.096216	0.065923

Table 8: Prices for a three-period, low-voltage, corporate customer in Spain

Therefore, for *C* charges per day, the total costs for the CSO can be calculated as presented in equation (26).

$$\begin{aligned} CSO_{cost} &= Electricity\ bill\ cost + CS\ amortisation\ cost + O\&M\ cost = \\ &= \{[22 * (6.832399 + 6.832399 + 6.832399) * 12] \\ &+ [(0.122383 * 25\ \% + 0.096216 * 60\ \% + 0.065923 * 15\ \%) * 10 \\ &* C * 365]\} * 1.051127 + 1\ 846.90 + 1\ 725 \end{aligned} \tag{26}$$

This cost must be compared against the incomes that the CSO can obtain. The incomes depend on the number of charges per day (*C*) and the charging price requested by the CSO (*CP*), as shown in equation (27).

$$CSO_{income} = C * Cp * 365 \tag{27}$$

Since EV customers use the POI for convenience charging, they will accept paying higher prices than they do at home, but not more than the price for an equivalent trip with an ICE vehicle. Therefore, equation (28) must be met.

$$(OM_{EV} * d) + CP * (1 + VAT) \leq (FC_T * FP_T * d) + (OM_T * d) \tag{28}$$

Where:

- OM_{EV} is the O&M cost of EVs, including VAT. It is set at EUR 0.012/km.
- *CP* is the charging price requested by the CSO.
- *VAT* must be paid by EV customers.
- FC_T is the fuel consumption of ICE vehicles (for type T).
- FP_T is the fuel price of ICE vehicles (for type T), including VAT.
- OM_T is the O&M cost of ICE vehicles, including VAT (for type T).
- *d* is the distance that can be travelled within the trip, which depends on the energy charged (*Ei*) and on the efficiency of the trip (*EFi*), as shown in equation (29).

$$d_i = \frac{Ei}{EFi} \tag{29}$$

Since the ICE vehicle can be fuelled by petrol or by diesel, the comparison must be made for both types (*T*) of vehicles. Table 9 presents the data used for this calculation.

Parameter	Petrol	Diesel
Fuel consumption (l/100 km)	5.6	4.9
Fuel price (EUR/l)	1.383	1.303
O&M (EUR/km)	0.034	0.037

Table 9: Operational data of ICE vehicles per type

As EVs charge 10 kWh per event and by assuming that EV efficiency (*EFi*) is 0.150 kWh/km, equation (28) becomes equations (30) and (31) for petrol and diesel, respectively.

$$\left(0.012 * \frac{10}{0.150}\right) + CP * (1 + 21\ \%) \leq \left(\frac{5.6}{100} * 1.383 * \frac{10}{0.150}\right) + \left(0.034 * \frac{10}{0.150}\right) \tag{30}$$

$$\left(0.012 * \frac{10}{0.150}\right) + CP * (1 + 21\ \%) \leq \left(\frac{4.9}{100} * 1.303 * \frac{10}{0.150}\right) + \left(0.037 * \frac{10}{0.150}\right) \tag{31}$$

Based on equations (30) and (31), the maximum charging price (*CP*) to be requested by the CSO could be EUR 5.47 per session, to be competitive with petrol ICE vehicles, and EUR 4.90 per session, to be competitive with diesel ICE vehicles. As a result, the most restrictive alternative in this case is diesel, so it is taken as the benchmark.

Starting from equations (26) and (27), the incomes by the CSO will exceed its costs if the average charges per day are higher than the ones calculated in equation (32).

$$CSO_{cost} = CSO_{income} \Leftrightarrow 3\,571.90 + \{[22 * (6.832399 + 6.832399 + 6.832399) * 12] + (0.122383 * 25\,\% + 0.096216 * 60\,\% + 0.065923 * 15\,\%) * 10 * C * 365\} * 1.051127 = C * 4.90 * 365 \qquad (32)$$

Table 10 summarises the data used and the results obtained (in bold) for the POI CSO.

Parameter	Value
Number of CSs	1
CS capacity (kW)	2*11
CS investment cost (EUR)	10 500
CS O&M cost (EUR)	1 725
CS lifetime	7.5
Discount rate	7 %
Electricity tax	5.1127 %
Share of charging events in peak period (p1)	25 %
Share of charging events in off-peak period (p2)	60 %
Share of charging events in super off-peak period (p3)	15 %
Average charged energy per charging event (kWh)	10
Price for contracted capacity (EUR/kW.month)	6.832399
Energy price in p1 (EUR/kWh)	0.122383
Energy price in p2 (EUR/kWh)	0.096216
Energy price in p3 (EUR/kWh)	0.065923
O&M costs for EVs (EUR/km)	0.012
O&M costs for petrol ICE vehicles (EUR/km)	0.034
O&M costs for diesel ICE vehicles (EUR/km)	0.037
EV efficiency (kWh/km)	0.150
Fuel consumption for petrol ICE vehicles (l/100 km)	5.6
Fuel consumption for diesel ICE vehicles (l/100 km)	4.9
Petrol price (EUR/l)	1.383
Diesel price (EUR/l)	1.303
Minimum required CS usage (charging events/day)	**6.57**

Table 10: Data and results of the POI CSO profitability analysis

From equation (32), the minimum number of charges per day that make POI CS operation feasible is 6.57. This means that, if each CS installed for POI charging is used to charge 7 times per day on average, i.e. 3.5 charging sessions per outlet and per day, there is room for a pricing strategy that allows the CSO to recover its costs and still offer a competitive mileage cost for EV customers in comparison with ICE vehicles.

In a future scenario with enough EVs on the road, this target usage does not seem to be very difficult to reach in a point of interest, as it is expected to be a location with heavy traffic. The CS has high fixed costs but low variable costs, so the CSO wants to operate it for as long as possible. Consequently, the CSO may establish a time-dependent, variable pricing strategy, e.g. while the EV is charging, the price may be set to make the charging price competitive with ICE vehicle mileage cost (EUR 0.60 per kWh or EUR 0.22 per minute, including VAT) but an additional price may be requested after the charging process finishes (e.g. EUR 0.03 per minute) to compensate the CSO for not having the CS available for other EV customers.

6.4.1.4 Highway CSO

According to Figure 22, the highway CSO must pay for electricity (light green lines), for being connected to the grid (brown lines) and for metering (purple lines), as well as for accessing the marketplace (black lines), while it receives the payment from EV customers for EV charging (green lines). As a result, the money flows are the same as in the case of the POI CSO, but adding the marketplace access cost, which, based on equation (22), is EUR 2 000 per year.

As in the case of the POI, the highway CSO must also pay for CS amortisation and O&M, which can be obtained from [159] for the 50 kW CS considered in this case. Thus, lifetime is 7.5 years, investment cost is EUR 27 150 and O&M cost (communications and metering included) is EUR 3 075.

If a 7 % discount rate is considered, equation (11) becomes equation (33).

$$Annual\ CS\ amortisation\ cost = \frac{7\ \% * (1 + 7\ \%)^{7.5}}{(1 + 7\ \%)^{7.5} - 1} * 27\ 150 \approx \text{EUR}\ 4\ 775.54 \qquad (33)$$

By adding this amount to the O&M costs and the marketplace access costs, the non-electricity bill costs for the CSO become EUR 9 850.54.

Again, the case with only one CS is analysed and, thus, despite having higher capacity than in the POI case, it has the same electricity bill structure. Therefore, equation (26) can be used, except for the average energy charged per charging event.

Although highway charging is also convenience charging, it is expected that EV customers will use it to drive longer distances and, hence, a full-charge of the battery (20 kWh) per charge is considered.

This means that the charging will take about 30 minutes (20 kWh at 50 kW), which will most likely require that there is a bar/shop/restaurant close, so that EV customers can rest during the trip and wait until the charge is completed.

The costs for the CSO can be calculated with equation (34).

$$CSO_{cost} = 9\,850.54 + \{[50 * (6.832399 + 6.832399 + 6.832399) * 12] + (0.122383 * 25\,\% + 0.096216 * 60\,\% + 0.065923 * 15\,\%) * 20 * C * 365\} * 1.051127 \tag{34}$$

Regarding the incomes, equation (27) can still be used. However, when comparing with ICE vehicles, it must be taken into account that vehicle efficiencies decrease at higher speeds. For the highway case, efficiency is assumed to be 33 % lower than in the POI case for all types of vehicle (33 % higher fuel consumption for ICE vehicles).

Thus, equation (28) becomes equations (35) and (36), for petrol and diesel, respectively.

$$\left(0.012 * \frac{20}{0.200}\right) + CP * (1 + 21\,\%) \leq \left(\frac{7.4}{100} * 1.383 * \frac{20}{0.200}\right) + \left(0.034 * \frac{20}{0.200}\right) \tag{35}$$

$$\left(0.012 * \frac{20}{0.200}\right) + CP * (1 + 21\,\%) \leq \left(\frac{6.5}{100} * 1.303 * \frac{20}{0.200}\right) + \left(0.037 * \frac{20}{0.200}\right) \tag{36}$$

Based on equations (35) and (36), the maximum charging price (*CP*) to be requested by the CSO could be EUR 10.33 per session, to be competitive with petrol ICE vehicles, and EUR 9.08 per session, to be competitive with diesel ICE vehicles. Again, the most restrictive alternative is diesel, so it is the benchmark in this case too.

The incomes by the CSO will exceed its costs if the average charges per day are higher than the ones calculated in equation (37), based on equations (34) and (27).

$$CSO_{cost} = CSO_{income} \Leftrightarrow 9\,850.54 + \{[50 * (6.832399 + 6.832399 + 6.832399) * 12] + (0.122383 * 25\,\% + 0.096216 * 60\,\% + 0.065923 * 15\,\%) * 20 * C * 365\} * 1.051127 = C * 9.08 * 365 \tag{37}$$

From equation (37), the minimum number of charges per day that make highway CS operation feasible is 8.89. This means that, if each CS installed for highway charging is used to charge 9 times per day on average, the CSO can recover its costs and still offer a competitive mileage cost for EV customers in comparison with ICE vehicles.

With enough EVs on the road, this target usage can be reached in heavy-traffic points, such as a highway, but queueing issues must be solved (see section 2.2.6). The CS has high fixed costs but low variable costs, so the CSO wants to operate it for as long as possible. As a consequence, the CSO may establish a time-dependent, variable pricing strategy, so that the charging price may be set to be competitive with ICE while the EV is charging (EUR 0.60 per kWh or EUR 0.50 per minute, including VAT) but an additional price may be requested once the charging is finished (e.g. EUR 0.05 per minute) to compensate the CSO for not having the CS available for other EV customers.

Table 11 summarises the data and the results obtained (in bold) for this CSO.

Parameter	Value
Number of CSs	1
CS capacity (kW)	50
Annual marketplace access cost (EUR/year)	2 000
CS investment cost (EUR)	27 150
CS O&M cost (EUR)	3 075
CS lifetime	7.5
Discount rate	7 %
Electricity tax	5.1127 %
Share of charging events in peak period (p1)	25 %
Share of charging events in off-peak period (p2)	60 %
Share of charging events in super off-peak period (p3)	15 %
Average charged energy per charging event (kWh)	20
Price for contracted capacity (EUR/kW.month)	6.832399
Energy price in p1 (EUR/kWh)	0.122383
Energy price in p2 (EUR/kWh)	0.096216
Energy price in p3 (EUR/kWh)	0.065923
O&M costs for EVs (EUR/km)	0.012
O&M costs for petrol ICE vehicles (EUR/km)	0.034
O&M costs for diesel ICE vehicles (EUR/km)	0.037
EV efficiency (kWh/km)	0.200
Fuel consumption for petrol ICE vehicles (l/100 km)	7.4
Fuel consumption for diesel ICE vehicles (l/100 km)	6.5
Petrol price (EUR/l)	1.383
Diesel price (EUR/l)	1.303
Minimum required CS usage (charging events/day)	**8.89**

Table 11: Data and results of the highway CSO profitability analysis

6.4.1.5 EV customers

EV customers are the only new stakeholders in the electro-mobility ecosystem who appear in all the charging alternatives considered in this analysis, so the analysis for them must include all the charging cases. Although vehicle purchase is mostly driven by emotions, economy also has a big importance in choosing the driving alternative [64]. A TCO analysis of the three types of vehicles (EV, petrol ICE vehicle and diesel ICE vehicle) allows determining whether buying an EV is economically interesting. The TCO analysis includes:

1. For ICE vehicles: vehicle amortisation cost, vehicle O&M cost and vehicle fuel costs.
2. For EVs: By looking at Figure 21, Figure 22 and Figure 23, EV customers pay for EV charging, for being subscribed to an EMSP and for the electricity bill in their homes. They must also pay for O&M and amortisation of both the home CS and the EV itself.

In order to make a comparable analysis, similar assumptions must be made for EVs and for ICE vehicles. As discussed in [151], it is expected that 85 % of the required charging infrastructure will be for private charging (either at home or at work), 10 % will be publicly accessible CS in private property (9 % AC, 1 % DC) and the remaining 5 % will be publicly accessible CS in public property. Therefore, home charging is assumed to account for 85 % of the mileage, POI charging for 9 %, highway charging for 1 % and curbside parking for 5 %[30]. It is expected that POI charging, home charging and charging while parked on curbside are used for similar driving conditions, so driving efficiency in the three cases is assumed to be the same. Considering the low impact of highway charging (1 %), the average efficiency is considered to be the same as in the other three cases.

Convenience charging prices have already been calculated for POI and highway charging. The before-taxes prices obtained were EUR 4.90 in POI and 9.08 in highway. Since EV customers are final customers, they must pay the VAT, so after-taxes EV charging prices are EUR 5.93 (EUR 0.60 per kWh or EUR 0.22 per minute) and EUR 11.00 (EUR 0.60 per kWh or EUR 0.55 per minute), respectively. The prices for curbside parking are assumed to be similar to the ones for POI, (since the same type of CS is used and the same driving efficiency is assumed).

As calculated in section 6.4.1.2, the minimum, before-taxes annual subscription price is EUR 126.52 per EV customer. Adding 21 % VAT, the tax-inclusive minimum subscription price becomes EUR 153.01. For simplicity, it is assumed to be EUR 156 (EUR 13 per month).

For home charging, a low-capacity (3.7 kW) CS has been considered. The reports used for cost figures [154], [158], [159] do not include cost estimates for home charging CS. The closest one is the public street light wall box charger, whose investment cost is EUR 2 500 EUR and whose O&M cost is EUR 1 175. Based on [151], investment cost is assumed to be EUR 1 500 and O&M costs EUR 50 per year (without communications and metering, because the CS is for private use). Using again equation (11), with a 7 % discount rate and a lifetime of 7.5 years, CS amortisation can be calculated according to equation (38).

$$Annual\ CS\ amortisation\ cost = \frac{7\ \% * (1 + 7\ \%)^{7.5}}{(1 + 7\ \%)^{7.5} - 1} * 1\ 500 \approx \text{EUR}\ 263.84 \tag{38}$$

As discussed above, T&D fees are classified depending on the contracted power (connection size) and the voltage level at which they connect. Household consumers are expected to have connection capacities below 15 kW, so the electricity bill for private consumers is slightly different. The Spanish regulation recommends having a separate connection for EV charging [166] and not including it in the regular home connection (to supply the rest of the electric appliances) for security reasons. Thus, the electricity bill for EV charging would be tailored for the 3.7 kW supply. In small connections, power control switches are used, which have regulated sizes. The minimum connection size to supply 3.7 kW is 4.6 kW, which corresponds to the tariff for consumers with contracted power below 10 kW (2.0). There is a three-period tariff (2.0.DHS), which has been specifically created for EV charging, so it has been considered in this analysis. The periods for this tariff are p1 (13.00-23.00), p3 (1.00-7.00) and p2 (the rest) [86]. In this case, the meter renting cost is EUR 0.81 per month [167] and the prices in Table 12 are used (present prices can be found at [165]).

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[30] The study in [19] presents a slightly different distribution of charges, but home charging is still the preferred option (with 71 % of energy being charged at home).

KPI description	P1	P2	P3
Tp (EUR/kW.month)		3.50362	
Te (EUR/kWh)	0.15081	0.07188	0.04415

Table 12: Prices for a three-period, low-voltage, residential customer in Spain

The energy demand can be calculated as a function of the annual mileage (k) and the driving efficiency (*EFi* = 150 Wh/km, as discussed above), in line with equation (39).

$$E_{p3} = k * EFi * \%_{Home} = k * 0.150 * 85\ \% = 0.1275 * k \tag{39}$$

Assuming that EV is charged only in p3, the electricity bill in this case is calculated by means of equation (40).

$$\begin{aligned} Electric.bill = \{&[(4.6 * 3.50362 * 12) + (0.1275 * k * 0.04415)] * 1.051127 \\ &+ (0.81 * 12)\} * 1.21 = 257.74 + 0.00716 * k \end{aligned} \tag{40}$$

Assuming a lifetime of 12 years and a discount rate of 7 %, the annual vehicle amortisation cost can be calculated with equation (11) as shown in equation (41).

$$Annual\ vehicle\ amortisation\ cost = \frac{7\ \% * (1 + 7\ \%)^{12}}{(1 + 7\ \%)^{12} - 1} * Vehicle\ price \tag{41}$$

The vehicle prices considered are EUR 12 000, EUR 13 800 and EUR 16 500, for petrol, diesel and EVs (considering the subsidy by the Spanish government for EV acquisition) respectively. Thus, amortisation costs are EUR 1 510.82, EUR 1 737.45 and EUR 2 077.38. Regarding fuel and O&M costs for ICE vehicles, the right side of equation (28) can be taken, as well as the values in Table 9, to calculate their TCO. Equations (42) and (43) are used for such purpose.

$$\begin{aligned} Petrol\ vehicle\ TCO &= 1\ 510.82 + \left(\frac{5.6}{100} * 1.383 * k\right) + (0.034 * k) \\ &= 1\ 510.82 + 0.111448 * k \end{aligned} \tag{42}$$

$$\begin{aligned} Diesel\ vehicle\ TCO &= 1\ 737.45 + \left(\frac{4.9}{100} * 1.303 * k\right) + (0.037 * k) \\ &= 1\ 737.45 + 0.100847 * k \end{aligned} \tag{43}$$

The TCO for EVs is calculated with equation (44).

$$\begin{aligned} EV\ TCO = Cost\{&POI\ charging + Curbside\ charging + Highway\ charging \\ &+ Subscription + Electricity\ bill + CS\ O\&M + CS\ amortisation \\ &+ EV\ O\&M + EV\ amortisation\} \\ &= \left[(9\ \% + 5\ \%) * k * 0.150 * \frac{5.93}{10}\right] + \left[1\ \% * k * 0.200 * \frac{11.00}{20}\right] \\ &+ 156 + [257.74 + 0.00716 * k] + 50 + 263.84 + (0.012 * k) \\ &+ 2\ 077.38 = 2\ 804.96 + 0.032712 * k \end{aligned} \tag{44}$$

The minimum annual mileage to make EVs competitive with ICE vehicles can be obtained by comparing equations (42) and (43) with (44). It is 16 437 km/year (45 km/day) for petrol and 15 668 km/year (43 km/day) for diesel, which are very close to the average driven distance per vehicle in Europe (14 200 km/year [151]).

Table 13 summarises the data and the results obtained (in bold) for EV customers.

Parameter	Value
Number of CSs	1
CS capacity (kW)	3.7
CS investment cost (EUR)	1 500
CS O&M cost (EUR)	50
CS lifetime	7.5
Discount rate	7 %
Share of charges in home charging	85 %
Share of charges in POI charging / charging while parked on curbside	14 %
Share of charges in highway charging	1 %
EV charging price in POI / curbside (EUR/charging, including VAT)	5.93
EV charging price in highway (EUR/charging, including VAT)	11.00
EMSP subscription price (EUR/year, including VAT)	156
Price for contracted capacity (EUR/kW.month)	3.50362
Energy price in p1 (EUR/kWh)	0.15081
Energy price in p2 (EUR/kWh)	0.07188
Energy price in p3 (EUR/kWh)	0.04415
Electricity tax	5.1127 %
Meter renting (EUR/month)	0.81
VAT	21 %
Share of charging events in peak period (p1)	0 %
Share of charging events in off-peak period (p2)	0 %
Share of charging events in super off-peak period (p3)	100 %
EV efficiency (kWh/km)	0.150
Vehicle purchase price for EV (EUR)	16 500
Vehicle purchase price for petrol ICE vehicle (EUR)	12 000
Vehicle purchase price for diesel ICE vehicle (EUR)	13 800
O&M costs for EVs (EUR/km)	0.012
O&M costs for petrol ICE vehicles (EUR/km)	0.034
O&M costs for diesel ICE vehicles (EUR/km)	0.037
Fuel consumption for petrol ICE vehicles (l/100 km)	7.4
Fuel consumption for diesel ICE vehicles (l/100 km)	6.5
Petrol price (EUR/l)	1.383
Diesel price (EUR/l)	1.303
Minimum mileage for EVs to be competitive with petrol vehicles (km/year)	**16 437**
Minimum mileage for EVs to be competitive with diesel vehicles (km/year)	**15 668**

Table 13: Data and results of the profitability analysis for EV customers

By introducing this data (k = 16 000 km/year) in equation (39), the total demand of electricity in this type of charging can be obtained, as shown in equation (45).

$$E_{p3} = k * EFi * \%_{Home} = 16\,000 * 0.150 * 85\,\% = 2\,040\ kWh/year \tag{45}$$

6.4.1.6 Public CSO

The public CSO only appears in the case for charging while parked on curbside. The value model for this charging case is the same as for highway charging, but the CS is the same as for POI, while some EV customers may use this charging option as their main source of charging (like the home charging case) when they do not own their own parking space. Therefore, two different pricing strategies are expected to be needed.

According to Figure 22, the public CSO must pay for electricity (light green lines), for being connected to the grid (brown lines) and for metering (purple lines), as well as for accessing the marketplace (black lines), while it receives the payment from EV customers for EV charging (green lines). As the other CSOs, it must also pay for CS O&M and amortisation.

From the calculations for the EMSP (equation (22)), the marketplace access cost is EUR 2 000 per year. Since the CS used in this case is the same as for the POI case (11/22 kW charging point), investment costs are EUR 10 500, O&M costs are EUR 1 725 and lifetime is 7.5 years. From equation (25), the annual amortisation of the CS is EUR 1 846.90.

The electricity bill can be calculated as in the case of the POI CS. Therefore, the tariff considered is 3.0.A, with the same periods and prices. However, the energy demanded per tariff period must be calculated.

As discussed above, this charging case has the particularity that it serves two main types of EV customers. On the one hand, it can be used for convenience charging during daytime (e.g. for EV customers driving into the city, but not parking at a POI), while it can be used as home charging by EV customers who do not own their own parking space.

For night-time charging, the CS is expected to serve 2 charging events per night, since it has 2 outlets and it is quite unlikely that EV customers will leave the CS in the middle of the night allowing for another charging event. Due to the similarities with home charging, two main assumptions are made:

- Since overnight charging can be done at lower power (3.7 kW * 2 outlets ≈ 7.36 kW [166]), the contracted power for overnight charging is assumed to be lower than for daytime charging. In this case, tariff 3.0.A is considered, so the size of the power to contract is not constrained by the sizes of the fuses (as it was in private home charging, where tariff 2.0 was used).
- Regarding the energy to be charged, it is assumed that EV customers not owning a parking space will use this type of charging as much as parking space owners do. Therefore, each EV customer will charge 2 040 kWh/year overnight. Since 2 EVs can be served at once, it is expected that each CS will provide 4 080 kWh/year at night.

For daytime charging, contracted power is the maximum power (22 kW), because convenience charging must be done as quickly as possible, while the energy to be demanded is unknown. Assuming the same energy demand per charging event (10 kWh) and daytime charging distribution (30 % in p1 and 70 % in p2)[31] as in the POI case, the average CS usage per day (C) becomes the unknown to be calculated.

By using the data in Table 8, the electricity bill is calculated in equation (46).

$$\begin{aligned} CSO's\ electricity\ bill &= \{[(2 * 22 * 6.832399 * 12) + (7.36 * 6.832399 * 12)] \\ &+ [(10 * C * 30\ \% * 0.122383) + (10 * C * 70\ \% * 0.096216) \\ &+ (4\,080 * 0.065923)]\} * 1.051127 = 4\,708.95 + 1.0938 * C \end{aligned} \tag{46}$$

The price for overnight charging should be similar to that faced by EV customers who use home charging. The cost per kWh for EV customers who charge at home can be obtained from equation (40) and the annual amount they charge (2 040 kWh/year), as presented in equation (47).

$$\frac{EV\ customers'bill}{Annual\ electricity\ demand} = \frac{257.74 + 0.00716 * 16\,000}{2040\ kWh} = EUR\ 0.1825/kWh \tag{47}$$

This price includes taxes, so, considering that the CS serves 2 EV customers, the incomes from overnight charging for the CSO are obtained in equation (48).

$$CSO\ incomes\ from\ overnight\ charging = \frac{0.1825}{1 + 21\ \%} * 2 * 2\,040 = EUR\ 615.36 \tag{48}$$

If the same price per EV charging as in the POI case (EUR 4.90 per session, before taxes) is considered, the minimum usage rate can be calculated according to equation (49).

$$\begin{aligned} CSO_{cost} = CSO_{income} \Leftrightarrow 2\,000 + 4\,708.95 + 1.0938 * \mathrm{C} + 1\,725 + 1\,846.90 = \\ 615.36 + \mathrm{C} * 4.90 * 365 \Leftrightarrow \mathrm{C} = 5.412\ charges\ per\ day \end{aligned} \tag{49}$$

Consequently, the minimum number of daytime charges per day that make curbside CS operation feasible is 5.42. This means that, if each CS installed for charging while parked on curbside is used to charge 5.5 times per day on average, i.e. 2.75 charging sessions per outlet and per day, there is room for a pricing strategy that allows the CSO to recover its costs and still offer a competitive mileage cost for EV customers in comparison with ICE vehicles for daytime charging and a comparable cost per kWh to home charging for overnight charging.

As in the case of the POI, this is a reachable usage if there are enough EVs on the road, especially in city centres. Again, the CS has significant fixed costs but low variable costs, so the CSO wants to have it in operation for as long as possible. Therefore, a time-dependent, variable pricing strategy can be envisaged, e.g. during the EV charging process, the price may be set to make the charging price competitive with ICE vehicle mileage cost (EUR 0.60 per kWh or EUR 0.22 per minute, including taxes) but an additional price may be requested after the charging process finishes (e.g. EUR 0.03 per minute) to compensate the CSO for not having the CS available for other EV customers.

The summary of the data used in this paragraph and the results obtained (in bold) can be found in Table 14.

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[31] 25 % of total charges were made in p1 and 60 % in p2. If we convert those values to sum up 100 %, we obtain about 30 % for p1 and 70 % for p2.

Parameter	Value
Number of CSs	1
CS capacity (kW)	2*11
Contracted capacity in super off-peak period (kW)	7.36
Annual marketplace access cost (EUR/year)	2 000
CS investment cost (EUR)	10 500
CS O&M cost (EUR)	1 725
CS lifetime	7.5
Discount rate	7 %
Electricity tax	5.1127 %
Share of daytime charging events in peak period (p1)	30 %
Share of daytime charging events in off-peak period (p2)	70 %
Energy demanded in super off-peak period (kWh)	2*2 040
Average charged energy per daytime charging event (kWh)	10
Price for contracted capacity (EUR/kW.month)	6.832399
Energy price in p1 (EUR/kWh)	0.122383
Energy price in p2 (EUR/kWh)	0.096216
Energy price in p3 (EUR/kWh)	0.065923
O&M costs for EVs (EUR/km)	0.012
O&M costs for petrol ICE vehicles (EUR/km)	0.034
O&M costs for diesel ICE vehicles (EUR/km)	0.037
EV efficiency (kWh/km)	0.150
Fuel consumption for petrol ICE vehicles (l/100 km)	5.6
Fuel consumption for diesel ICE vehicles (l/100 km)	4.9
Petrol price (EUR/l)	1.383
Diesel price (EUR/l)	1.303
Overnight usage (charging events/day)	2*1
Minimum required CS usage (charging events/day)	**5.42**

Table 14: Data and results of the public CSO profitability analysis

6.4.2 Step 7: Investment analysis

The innovative business idea is always created around one or several actors, which will make the investments needed for the business case to be possible.

In the case under study, several actors needed to make investment for the different charging alternatives to become possible. Due to the nature of the analysis, which has considered just one year in the future, the investments made by the marketplace operator, the EMSP, the different CSOs and EV customers have been included as annualised values in their cash-flow analysis, so there is no independent investment analysis to be presented here.

6.4.3 Step 8: Sensitivity analysis

In addition to the data to be considered for the general appraisal, the parameters to be included in the sensitivity analysis must also be agreed within the expert group. As an alternative, a scenario approach can also be considered.

As discussed in section 3.1, the aim of this sensitivity analysis is to allow investors to have a hedging tool to minimise the risk resulting from uncertain variables which may have an important effect on the results of the assessment.

During this analysis, a number of parameters have been considered for the sensitivity analysis:

- Country. The conditions in Germany and in the Netherlands have been assessed. The differences concentrate in the electricity bill structure and prices, fuel costs for ICE vehicles, vehicle (EV and ICE) purchase cost and VAT. In general, the conditions in Germany are the best ones and the situation in the Netherlands is also better than in Spain, but the subsidies for EV purchase in Spain and the electricity bill characteristics in the Netherlands reverse the order when analysing the annual mileages for TCO break-even between EVs and ICE vehicles.
- CS amortisation. Aspects such as higher CS investment cost (due to e.g. higher grid reinforcement needs), longer CS lifetimes (in spite of potential vandalism) and lower CS costs in the future have been taken into account. Lower investment costs and longer lifetimes result in more beneficial conditions for the CSO.
- Increased battery size. At the moment of starting the analysis, 24-kWh batteries were state-of-the-art. However, bigger batteries were already envisaged (40 kWh for 2016 [59] and 80 kWh for longer term), so they have been included in this analysis. Bigger batteries allow reaching CSO profitability at lower usage rates, but they will also allow EV customers charge less frequently and, hence, use convenience charging more seldom. Moreover, charging speed should also be increased to avoid extending too long the charging process[32]. However, increased battery size is expected to have a positive effect, since it will allow both overcoming range anxiety and making longer distance trips (which is very important in the highway charging case), resulting in an increased EV market.
- EV efficiency. The effect of having lower EV driving efficiencies has been analysed. The lower the efficiency (higher consumption per km), the worse the business case for all actors is, as EVs lose competitiveness versus ICE vehicles. Likewise, increased petrol and diesel prices, or lower ICE vehicle efficiencies improve the conditions for electro-mobility.
- Additional costs for the CSO operator. The effect of additional costs for the CSO has been analysed, including the need to install the direct payment system (about EUR 400) or the cost of accessing the marketplace for the POI case. Such low costs do not make a big difference in the business case for the CSO.

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[32] Although existing standards (Combo [39] and CHAdeMO [40]) were designed to work at up to 400 V, there is an ongoing effort to increase charging voltage to 800 V [168]. This way charging speeds of up to 350 kW could be possible, to compete with Tesla's superchargers, which charge at 120 kW [169].

- Additional incomes for the CSO operator. The CS is a good candidate for being used as advertising media, especially in high visibility cases, such as POI or curbside parking. In the case of highway charging, the linkage of the CS to an existing shop of restaurant has been assessed, so that the CS serves as a “hook” to attract new customers to the main business (based on [151], [19] confirmed that EV customers spend about EUR 10 per charge in nearby shops and cafes while waiting for EVs to charge). In this case, the customer base increase may pay off the CS investment in case the EV charging business does not prove to be successful. Both types of additional incomes are very beneficial for the success of CSO business case: advertising may reduce by more than half the required daily charges per CS (even in the most conservative approach) in the POI and curbside charging cases, while restaurant/shop may also reduce the required usage in the highway charging case.
- Number of CS. In the case of highway charging, there may be some synergies if more than one CS is installed in the same place, as some fixed (not dependent on the number of CS) exist, such as the cost of accessing the marketplace. Moreover, the increase in CS number may avoid the (annoying) need for EV customers to queue for EV charging (see section 2.2.6). In the case of highway charging too, the possibility to install dual-charging CSs (CSs which allow fast DC charging and semi-fast AC charging as the one described in [19]) has been assessed, in order to allow for higher daily charges by slightly increasing CS investment costs. If the regulation allowed to use the “Large-scale consumer” approach described in Table 1 (as suggested in [25]), there would be higher synergies when operating a wide CS network.
- EV purchase cost. Different purchase cost spreads between EVs and ICE vehicles have been considered, as well as the effect of subsidies for EV purchase. The lower the spread and the higher the subsidy are, the more favourable the conditions for electro-mobility are.
- EV charging included in the regular home electricity bill. Although the Spanish regulation recommends having a separate installation, meter and supply point for EVs, the possibility to include EV charging demand into the regular electricity bill has also been considered. As some costs can be shared between both electricity supply types, EV customers’ TCO is reduced. This option is quite beneficial in the Netherlands, where the connection size is big enough to accommodate both regular home consumption and overnight EV charging, without increasing the contracted power.

Another parameter not included in the sensitivity analysis in [82] (nor in the one in [151]), but which is worthwhile to assess, is the distribution of charges per CS type. As stated in footnote 30, the energy supplied per CS type may be different to the one presented here, even if home charging would remain the main source for charging.

However, the parameters with higher uncertainty and which have the most relevant impact on results are exactly those used as target variables for calculations. In the case of the marketplace operator, the relative share of EMSPs and CSOs (once the number of participants in the marketplace and the pricing strategy are fixed) is unknown and important. Likewise, for the EMSP, the subscription price to be requested to EV customers is an important and unknown parameter (although the calculations could have been made to obtain the minimum EV customers that allow requesting a certain subscription price, the non-linearity of staff and overhead costs would have complicated too much the calculations). In the case of CSOs, the most important parameter is CS usage. Last, for EV customers, the minimum annual mileage for making electro-mobility competitive is of key importance.

6.4.4 Step 9: Presentation of results

As discussed above, the way in which results are presented is very important, because they will feed the conclusions of the analysis.

In the application example presented in this chapter, as it should be the case for any business model related to electro-mobility, the traditional, fossil-fuelled transportation system must be taken as the benchmark for comparison purposes. When convenience charging has been analysed, the cost per kilometre of an equivalent trip with an ICE vehicle has been considered. Likewise, when a TCO analysis has been required, the benchmark has been the ICE vehicle too. In all comparisons, both petrol and diesel vehicles have been considered and the most demanding one has been chosen to obtain the target values for electro-mobility.

For an easier understanding of the meaning of the obtained results, minimum charging prices to be demanded by CSOs have been presented in EUR/charging, EUR/kWh and in EUR/min, so that any business developer reading this thesis can choose the most appropriate one for his/her own business. Similarly, the subscription price to be requested by the EMSP has been presented in EUR/year and EUR/month. Additionally, the minimum annual mileage of EV customers for a profitable electro-mobility has been presented in km/year and km/day.

Another important feature of this analysis is that results themselves are presented in a way that facilitates the sensitivity analysis and the understanding of break-even values for profitability of different stakeholders. Moreover, the use of graphical representations also helps the reader to understand the implications of the different parameters checked in the sensitivity analysis.

6.5 EVALUATION OF RESULTS

6.5.1 Step 10: Conclusions

In this case and due to the nature of the analysis, the conclusions focus on estimating whether the obtained results are likely to be reached in the medium term or not.

As repeatedly stated in this thesis, electro-mobility is a complex ecosystem, where different actors create a network of interactions and demand a positive business case. The complexity is further demonstrated in the example application case described in this chapter, where four EV charging alternatives have been presented. In each of them, the required CS usage has been calculated, so that the CSO covers its costs while, at the same time, the price for EV charging still allows EV users to have a cost comparable to ICE vehicles. The analysis has also assessed the required usage and pricing strategies that the marketplace operator and the EMSP should establish.

According to this analysis, it can be stated that users who have access to private home charging are expected to be the early adopters of EVs, as their TCO can be lower than the cost of ICE vehicles, as long as they drive high annual mileages (not that high if subsidies for EV purchase are in place) and charge their EVs at lower prices overnight.

Nonetheless, the rest of the charging alternatives analysed are also required for the widespread adoption of electro-mobility but, due to their likely low rate of use, their number must be kept to a minimum to ensure that they will help EV customers overcome range anxiety, while still provide a profitable business case for their CSOs.

In the case of the POI charging, the minimum CS usage so that the CSO can offer competitive prices for EV users (in order to have a cost per kilometre which is comparable to the cost of ICE vehicles) and still make a profit is about 6.57 (2 398 charging events per year). On average, each EV customer will drive 16 000 km/year, and 9 % of them will be based on charging at a POI, with an average driving efficiency of 150 Wh/km and an average charge of 10 kWh. This way, the minimum number of EV customers served by each POI CS can be calculated according to equation (50).

$$Minimum\ EV\ customers\ per\ POI\ CS = \frac{2\,398}{\frac{16\,000 * 9\,\% * 0.15}{10}} \approx 111 \tag{50}$$

In the case of highway charging, minimum CS usage is 8.89 charges/day (3 245 charges/year), but they will account for only 1 % of the charges, driving efficiency is 200 Wh/km and the average charged energy is 20 kWh/charge. In this case, the minimum number of EV customers served by each highway CS is obtained from equation (51).

$$Minimum\ EV\ customers\ per\ highway\ CS = \frac{3\,245}{\frac{16\,000 * 1\,\% * 0.2}{20}} \approx 2\,029 \tag{51}$$

Regarding the case of charging while parked on curbside, minimum daytime CS usage is 5.42 charges/day (1 978 charges/year), they will account for 5 % of the charges, driving efficiency is 150 Wh/km and the average charged energy is 10 kWh/charge. As a result, the minimum number of EV customers served during daytime by each curbside CS is shown in equation (52).

$$Minimum\ EV\ customers\ per\ curbside\ CS = \frac{1\,978}{\frac{16\,000 * 5\,\% * 0.15}{10}} \approx 165 \tag{52}$$

Once there are some tens of EVs in an area, there might be enough demand for charging in publicly accessible CS, so that POI or curbside charging can become profitable. In order for highway charging to become profitable, the number of potential users of each CS should rise to some hundreds or even thousands, so it is not likely to be profitable in the short-term and doubtful in the medium-term.

Based on the initial scenario of having 50 000 EV customers, and by dividing the minimum number of EV customers served per each type of CS, the maximum number of profitable CSs per type can be calculated:

- 447 POI CSs (3 600 / 111)
- 25 highway CS (3 600 / 2 029)
- 304 curbside CSs (3 600 / 165)

Since curbside CSs would provide charging services to 2 EVs at once, a minimum of 608 EVs can be served by curbside CS for overnight charging, so there would be about 49 400 home CSs.

As presented in section 6.4.1.1, the marketplace considered in this case has 270 companies, out of which 14 are EMSPs, so there are 256 CSOs. As the total number of publicly accessible CSs is 776, each CSO could operate 3 CSs on average and there would still be room for a profitable business case for all the stakeholders in the value chain.

6.6 CONCLUSIONS

This chapter presents the first complete application of the new methodology described in this thesis. The application shows that the methodology can be used, that it leads to meaningful results and that the results can be interpreted in order to identify the required conditions for the deployment of publicly accessible charging infrastructure for EVs to become economically feasible.

CHAPTER 7

CONCLUSIONS OF THE THESIS AND FUTURE WORK

7 CONCLUSIONS OF THE THESIS AND FUTURE WORK

7.1 CONCLUSIONS OF THE THESIS

Electro-mobility presents a number of advantages with respect to traditional, fossil-fuelled transport systems, both in environmental (air quality, GHG emissions…) and economic (energy independence…) terms. However, it also has a number of barriers (high EV purchase cost, short driving range, lack of publicly accessible charging infrastructure and slow charging rate) which are preventing the required shift of paradigm to happen faster. Technological development is improving the conditions to remove some barriers, but the lack of publicly accessible charging infrastructure requires further actions.

In fact, the commercial viability of deploying publicly accessible CS for EV charging is uncertain, as demonstrated by the literature approaching this issue. On the one hand, the deployment of charging infrastructure is very expensive, because EV customers want to see a dense enough network of publicly accessible CSs (to avoid range anxiety) and they want to charge their EVs within relatively short times. On the other hand, the publicly accessible CS network will be used quite seldom by EV customers who can use their own private charging system. Indeed, this customer segment is expected to include the early adopters of electro-mobility, as home charging is the most economically efficient option of EV charging.

Moreover, the complexity of the electro-mobility ecosystem, with many stakeholders interrelating with each other, with several alternatives for EV charging and with the lack of completely defined framework conditions so far, presents a challenge when analysing EV-related business models.

The literature review revealed a gap in existing approaches for assessing the economic performance of publicly accessible CS, since no method performs a complete quantitative analysis, focusing on the economic components of the business case, which considers and analyses the whole value chain with a business perspective, and which merges all different charging alternatives into the same analysis.

The new methodology described in this thesis guides the approach to improving the economics of publicly accessible CS, while taking into account the complexity of the electro-mobility ecosystem. The three main novelties of the methodology consist in:

1. This new methodology considers the different dimensions of the business case at the same time, by performing a twofold analysis. The relationships between the different actors for each single charging alternative are defined (traditional approach), but also the relationships for each single actor between different charging alternatives (novelty) are taken into account.
2. The new methodology highlights the need to create an expert group to agree on the boundaries, data and assumptions for the analysis (traditional approach), but it requires the expert group to fully understand the essence of the analysis, so that they are fully aware of the implications of the assumptions considered and data prospects for the mass market can be obtained from an incipient market where existing data are few and not relevant for the mass market (novelty).

3. The new methodology orients the analysis to obtain significant results for the decision-making process by identifying profitability break-even values for the most critical parameters of the analysis.

The new methodology optimises the decision-making process for the deployment of a publicly accessible EV charging infrastructure, while taking into account the complexity of the electro-mobility ecosystem, and help business developers find potentially interesting business cases.

Although the new methodology is developed to provide answers to the challenges arising from electro-mobility, it can be used in any other field where the general conditions (multi-actor, multi-level and complex business ecosystem for a brand new application/market with lack of data and/or lack of defined market rules…) are similar.

7.2 FUTURE WORK

In this thesis, the integration of EV charging in distribution grids has not been analysed and its impact in the operation of the electric infrastructure has not been considered. Existing distribution grids were designed to meet consumers' demand for electricity, but now they must also cope with increasing shares of distributed generation, storage, active demand and demand derived from EV charging. This effect will be even more important in the future if CS charging capacities are increased (either because battery sizes are increased or just to reduce charging time), so it would be interesting to include such analysis into the business model analysis. Despite some experience in this regard [87], this aspect was not the core of this thesis. However, as EV penetration grows, this topic may deserve further attention and, even, a dedicated step within the methodology.

Linked to the previous research line, the consideration of grid impact may also lead to uncovering new services to be provided either by or to EVs. In this thesis, both the CSO and the EMSP have been assumed to provide only EV charging services, but the management of EV charging can provide additional sources of revenue for both parties:

- The CSO may offer services for grid support to the DSO, either by controlling the EV charging process (active demand management) or by feeding back to the grid part of the energy stored in the EVs (V2G) when required by the DSO. If the DSO can save money by using these services (compared to reinforcing the grid), the CSO will receive some remuneration for it [87]. This approach is fully aligned with the European Commission's mid-term policy [170].
- The EMSP may also benefit from the provision of grid-support services by the CSO, because each CSO may offer different charging prices, depending, not only on their cost structure, but also on the incomes they may get from the DSO. As a result, EV charging pricing may become dynamic, so that EMSPs can offer services to their EV customers, such as CS location and routing, CS charging conditions comparer (e.g. price and speed), etc. All these services have not been considered in this thesis, so it may be worthwhile to further investigate their impact in the profitability for the whole electro-mobility ecosystem. Moreover, these services can be provided by using dedicated mobile phone apps, which introduces new actors in the ecosystem, including telecom companies, app developers and so on.

Another potential theme to investigate is the consideration of different energy vectors for vehicles. In this thesis, only EVs were considered and, in particular, the development and validation of the methodology have been based on battery electric vehicles. An interesting research exercise would be to apply the new methodology to PHEV and to compare its results to the ones in chapter 6. Likewise, other types of alternative fuels, such as hydrogen, biofuels, liquefied petroleum gas or natural gas [12] have been left out of the scope of the thesis, but the application of the methodology to studying their profitability could also be of interest.

In addition to the research topics discussed above, the new methodology described in this thesis should be disseminated, in order to allow the research community to propose new subjects. In fact, the methodology is the result of the evolution imposed by its application to different areas of research, so it is likely that it will continue evolving. In this sense, it is important that regulators are aware of this methodology and that they can be involved in the process of investigating new regulatory provisions from the very beginning, so that they can also be aware of the implications of assumptions, including regulatory conditions, and can make better decisions to ensure fair and efficient public regulation.

CHAPTER 8

BIBLIOGRAPHY

8 BIBLIOGRAPHY

[1]‘Key World Energy Statistics 2017’. International Energy Agency, Sep-2017.

[2]G. Meyer, J. Dokic, H. Jürgens, and S. Stagl, Eds., ‘Hybrid and Electric Vehicles. The Electric Drive Delivers’. Implementing Agreement for Co-operation on Hybrid and Electric Vehicle Technologies and Programmes. International Energy Agency, 2015.

[3]C. C. Chan, ‘The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles’, *Proc. IEEE*, vol. 95, no. 4, pp. 704–718, Apr. 2007.

[4]A. Wiederer and R. Philip, ‘Policy options for electric vehicle charging infrastructure in C40 cities’. Harvard University, 2010.

[5]‘CO2 Emissions from Fuel Combustion: Overview (2017 edition)’. International Energy Agency, 2017.

[6]Statista, ‘Number of passenger cars and commercial vehicles in use worldwide from 2006 to 2015’, 2017. [Online]. Available: https://www.statista.com/statistics/281134/number-of-vehicles-in-use-worldwide/. [Accessed: 16-Nov-2017].

[7]UNFCCC Secretariat, ‘Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. Addendum. Part two: Action taken by the Conference of the Parties at its twenty-first session.’ United Nations Office, Jan-2016.

[8]Directorate-General for Mobility and Transport. European Commission, ‘Alternative fuels for sustainable mobility in Europe’, *Mobility and Transport*. [Online]. Available: https://ec.europa.eu/transport/themes/urban/cpt. [Accessed: 16-Nov-2017].

[9]European Commission, ‘COM(2013) 17 final. Communication from The Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions. Clean Power for Transport: A European alternative fuels strategy’. 24-Jan-2013.

[10]M. J. Kearney, ‘Electric Vehicle Charging Infrastructure Deployment: Policy Analysis Using Dynamic Behavioral Spatial Model’, Master thesis, Massachusetts Institute of Technology, Engineering Systems Division, Technology and Policy Program, 2011.

[11]U.S. Census Bureau. Department of Commerce. U.S. Government, ‘Foreign Trade - U.S. Imports of Petroleum’, 03-Nov-2017. [Online]. Available: https://www.census.gov/foreign-trade/statistics/graphs/PetroleumImports.html. [Accessed: 16-Nov-2017].

[12]The European Parliament and The Council of the European Union, ‘Directive 2014/94/EU of The European Parliament and of The Council of 22 October 2014 on the deployment of alternative fuels infrastructure’, *Official Journal of the European Union L 307*, pp. 1–20, 28-Oct-2014.

[13]‘ISO 15118-1:2013(en). Road vehicles — Vehicle to grid communication interface — Part 1: General information and use-case definition’. International Organization for Standardization, Sep-2013.

[14]T. Gómez San Román, I. Momber, M. R. Abbad, and Á. Sánchez Miralles, ‘Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships’, *Energy Policy*, vol. 39, no. 10, pp. 6360–6375, Oct. 2011.

[15]F. Kley, C. Lerch, and D. Dallinger, ‘New business models for electric cars—A holistic approach’, *Energy Policy*, vol. 39, no. 6, pp. 3392–3403, Jun. 2011.

[16]R. Bohnsack, J. Pinkse, and A. Kolk, ‘Business models for sustainable technologies: Exploring business model evolution in the case of electric vehicles’, *Res. Policy*, vol. 43, no. 2, pp. 284–300, Mar. 2014.

[17]Y. Cai, H. Wang, Q. Ye, and M. Ouyang, ‘Analysis of two typical EV business models based on EV taxi demonstrations in China’, presented at the 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 2013, pp. 1–6.

[18]J. García-Villalobos, I. Zamora, J. I. San Martín, F. J. Asensio, and V. Aperribay, ‘Plug-in electric vehicles in electric distribution networks: A review of smart charging approaches’, *Renew. Sustain. Energy Rev.*, vol. 38, pp. 717–731, Oct. 2014.

[19]J. Serradilla, J. Wardle, P. Blythe, and J. Gibbon, ‘An evidence-based approach for investment in rapid-charging infrastructure’, *Energy Policy*, vol. 106, pp. 514–524, Jul. 2017.

[20]Conserve Energy Future, ‘Advantages and Disadvantages of Electric Cars’. [Online]. Available: http://www.conserve-energy-future.com/advantages-and-disadvantages-of-electric-cars.php. [Accessed: 16-Nov-2017].

[21]B. Berman, ‘Electric Cars Pros and Cons’, *PluginCars.com*, 29-Sep-2016.

[22]P. Cazzola, M. Gorner, and L. Munuera, ‘Global EV Outlook 2017’. International Energy Agency, Jun-2017.

[23]J. Markkula, A. Rautiainen, and P. Järventausta, ‘The business case of electric vehicle quick charging—No more chicken or egg problem’, presented at the 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 2013, pp. 1–7.

[24]A. Schroeder and T. Traber, ‘The economics of fast charging infrastructure for electric vehicles’, *Energy Policy*, vol. 43, pp. 136–144, Apr. 2012.

[25]W. Vollers, R. Steinmetz, and Q. Han, ‘Sustainable business models for public charging points’, presented at the 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 2013, pp. 1–11.

[26]‘IEC 61851-1:2010. Electric vehicle conductive charging system - Part 1: General requirements’. International Electrotechnical Commission, 25-Nov-2010.

[27]E. Zabala *et al.*, ‘Business Opportunities for Interoperability Assessment of EV integration’. Cotevos project, 04-Nov-2016.

[28]K. Abkemeier and A. Mize, Eds., ‘Hybrid and Electric Vehicles. The Electric Drive Gains Traction’. Implementing Agreement for Co-operation on Hybrid and Electric Vehicle Technologies and Programmes. International Energy Agency, 2013.

[29]H. H. Wu, A. Gilchrist, K. Sealy, P. Israelsen, and J. Muhs, ‘A review on inductive charging for electric vehicles’, presented at the 2011 IEEE International Electric Machines & Drives Conference (IEMDC), Niagara Falls, Ontario, Canada, 2011, pp. 143–147.

[30]L. Cheah and A. Heywood, ‘The cost of vehicle electrification. A literature review’, presented at the The Electrification of the Transportation System: Issues and Opportunities, Cambridge, Massachusetts, U.S., 2010, pp. 1–5.

[31]B. Plumer, ‘What Better Place’s bankruptcy tells us about the future of electric cars’, *The Washington Post*, 27-May-2013.

[32]D. Cooper, ‘Tesla won’t build more battery swap stations’, *Engadget.com*, 06-Oct-2015.

[33]‘SAE J1772. Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler’. Society of Automotive Engineers, 13-Oct-2017.

[34]‘IEC 60309-1:1999+AMD1:2005+AMD2:2012 CSV. Plugs, socket-outlets and couplers for industrial purposes - Part 1: General requirements’. International Electrotechnical Commission, 08-Jun-2012.

[35]‘IEC 60309-2:1999+AMD1:2005+AMD2:2012 CSV. Plugs, socket-outlets and couplers for industrial purposes - Part 2: Dimensional interchangeability requirements for pin and contact-tube accessories’. International Electrotechnical Commission, 23-May-2012.

[36]‘IEC TR 60083:2015. Plugs and socket-outlets for domestic and similar general use standardized in member countries of IEC’. International Electrotechnical Commission, 28-Oct-2015.

[37]K. Morrow, D. Karner, and J. Francfort, ‘Plug-in hybrid electric vehicle charging infrastructure review’. US Department of Energy-Vehicle Technologies Program, Nov-2008.

[38]‘IEC 62196-2:2016. Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories’. International Electrotechnical Commission, 18-Feb-2016.

[39]‘IEC 62196-3:2014. Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers’. International Electrotechnical Commission, 19-Jun-2014.

[40]‘Chademo Association’. [Online]. Available: https://www.chademo.com/. [Accessed: 16-Nov-2017].

[41]‘IEC 62196-1:2014. Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements’. International Electrotechnical Commission, 19-Jun-2014.

[42]J. F. Moore, *The Death of Competition: Leadership and Strategy in the Age of Business Ecosystems*, 1st ed. Harper Collins, 1997.

[43]J. F. Moore, ‘Business ecosystems and the view from the firm’, *Antitrust Bull.*, vol. 51, no. 1, pp. 31–75, Mar. 2006.

[44]Z. Guo, J. Deride, and Y. Fan, ‘Infrastructure planning for fast charging stations in a competitive market’, *Transp. Res. Part C Emerg. Technol.*, vol. 68, pp. 215–227, Jul. 2016.

[45]Smart Grid Coordination Group, ‘SG-CG/M490/J_ General Market Model Development. The conceptual model and its relation to market models for Smart Grids. Version 3.0’. CEN/CENELEC/ETSI, Nov-2014.

[46]T. Theisen and R. F. Marques, Eds., ‘Deploying publicly accessible charging infrastructure for electric vehicles: how to organise the market?’ Eurelectric, Jul-2013.

[47]The European Parliament and The Council of the European Union, ‘Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC’, *Official Journal of the European Union L 211*, pp. 55–93, 14-Aug-2009.

[48]‘The Harmonised Electricity Market Role Model’. ENTSO-E, Jan-2015.

[49]F. Zwicky and A. G. Wilson, *New methods of thought and procedure: Contributions to the symposium on methodologies*, 1st ed. New York: Springer-Verlag, 1967.

[50]A. Cacilo and M. Haag, ‘A comparison of European charging infrastructures for electric vehicles based on the project transport innovation deployment in Europe (TIDE)’, presented at the 2014 IEEE International Electric Vehicle Conference (IEVC), Florence, Italy, 2014, pp. 1–4.

[51]C. Corchero, S. Gonzalez-Villafranca, and M. Sanmarti, ‘European electric vehicle fleet: driving and charging data analysis’, presented at the 2014 IEEE International Electric Vehicle Conference (IEVC), Florence, Italy, 2014, pp. 1–6.

[52]R. Rodríguez-Sánchez, C. Madina, and E. Zabala, ‘Assessment of ICT-based Architectures for the integration of EVs in Smart Grids’, presented at the 2015 European Battery, Hybrid and Fuel Cell Electric Vehicle Congress (EEVC), Brussels, 2015, pp. 1–3.

[53]A. F. Jensen, E. Cherchi, and J. de Dios Ortúzar, ‘A long panel survey to elicit variation in preferences and attitudes in the choice of electric vehicles’, *Transportation*, vol. 41, no. 5, pp. 973–993, Sep. 2014.

[54]E. Cherchi *et al.*, ‘Deliverable D9.1 - Consumers’ preferences and attitudes to, demand for, and use of electric vehicles (EV)’. Green eMotion project, 30-Mar-2015.

[55]‘Promotion of electric vehicles. EU incentives & measures seen in a Danish context’. Ea Energy Analyses, Jan-2015.

[56]J. Todd, J. Chen, F. Clogston, and L. Thorstensen, ‘Creating the Clean Energy Economy: Analysis of the Electric Vehicle Industry’. International Economic Development Council, 2013.

[57]B. Nykvist and M. Nilsson, ‘Rapidly falling costs of battery packs for electric vehicles’, *Nat. Clim. Change*, vol. 5, no. 4, pp. 329–332, Apr. 2015.

[58]S. M. Knupfer, R. Hensley, P. Hertzke, and P. Schaufuss, ‘Electrifying insights: How automakers can drive electrified vehicle sales and profitability’. McKinsley & Company, Jan-2017.

[59]Renault, ‘Configurador Renault’. [Online]. Available: http://www.renault.es/gama-renault/gama-vehiculos-electricos/zoe/zoe/configurador/#/ze. [Accessed: 16-Nov-2017].

[60]U.S. Department of Energy and U.S. Environmental Protection Agency. U.S. Government, ‘FuelEconomy.gov - The official U.S. government source for fuel economy information.’ [Online]. Available: http://www.fueleconomy.gov. [Accessed: 16-Nov-2017].

[61]A. Santos, N. McGuckin, H. Y. Nakamoto, D. Gray, and S. Liss, ‘Summary of Travel Trends: 2009 National Household Travel Survey’. Federal Highway Administration. U.S. Department of Transportation, Jun-2011.

[62]OECD, *Environment at a Glance 2013*. Paris: OECD Publishing, 2013.

[63]U.S. Department of Energy and U.S. Environmental Protection Agency. U.S. Government, ‘2015 Tesla Model S (85 kW-hr battery pack)’. [Online]. Available: https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=35980. [Accessed: 16-Nov-2017].

[64]G. Harrison and C. Thiel, ‘An exploratory policy analysis of electric vehicle sales competition and sensitivity to infrastructure in Europe’, *Technol. Forecast. Soc. Change*, vol. 114, pp. 165–178, Jan. 2017.

[65]J. Neubauer and A. Pesaran, ‘A techno-economic analysis of BEVs with fast charging infrastructure’, presented at the 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 2013, pp. 1–12.

[66]S. D. Kämmerer, ‘Development and evaluation of a range anxiety-reducing business model for connected full electric vehicles’, Master thesis, Escola de Administração de Empresas de São Paulo, São Paulo, 2012.

[67]International Energy Agency, ‘European Union - 28: Balances for 2015’, 2017. [Online]. Available: https://www.iea.org/statistics/statisticssearch/report/?year=2015&country=EU28&product=Balances. [Accessed: 16-Nov-2017].

[68]The European Parliament and The Council of the European Union, ‘Directive (EU) 2015/1513 of The European Parliament and of The Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources’, *Official Journal of the European Union L 239*, pp. 1–29, 15-Sep-2015.

[69]Directorate-General for Climate Action. European Commission, ‘Driving Europe’s transition to a low-carbon economy’, 20-Jul-2016. [Online]. Available: https://ec.europa.eu/clima/news/articles/news_2016072001_en. [Accessed: 16-Nov-2017].

[70]European Commission, ‘July infringements package – Part 1: key decisions’. 13-Jul-2017.

[71]The European Parliament and The Council of the European Union, ‘Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community’s integrated approach to reduce CO2 emissions from light-duty vehicles’, *Official Journal of the European Union L 140*, pp. 1–15, 05-Jun-2009.

[72]‘New passenger car registrations by alternative fuel type in the European Union. Quarter 4 2015’. European Automobile Manufacturers Association, 05-Feb-2016.

[73]‘New passenger car registrations by alternative fuel type in the European Union. Quarter 4 2016’. European Automobile Manufacturers Association, 01-Feb-2017.

[74]‘Overview on Tax Incentives for Electric Vehicles in the EU’. European Automobile Manufacturers Association, 01-May-2017.

[75]Tax and Customs Administration. Ministry of Finance. Government of the Netherlands, ‘Bpm tariff passenger car’. [Online]. Available: https://www.belastingdienst.nl/wps/wcm/connect/bldcontenten/belastingdienst/individuals/cars/bpm/calculate_and_pay_bpm/bpm_tariff/bpm_tariff_passenger_car. [Accessed: 15-Nov-2017].

[76]Ministry of Finance. Government of the Netherlands, ‘Motor vehicle tax (mrb)’, 16-Apr-2014. [Online]. Available: https://www.government.nl/topics/car-and-motorcycle-taxes/motor-vehicle-tax-mrb. [Accessed: 16-Nov-2017].

[77]C. Thiel, J. Krause, and P. Dilara, *Electric vehicles in the EU from 2010 to 2014 - is full scale commercialisation near?* Luxembourg: Publications Office of the European Union, 2015.

[78]U.K. Government, ‘Low-emission vehicles eligible for a plug-in grant’. [Online]. Available: https://www.gov.uk/plug-in-car-van-grants/what-youll-get. [Accessed: 16-Nov-2017].

[79]U.K. Government, ‘Vehicles exempt from vehicle tax’. [Online]. Available: https://www.gov.uk/vehicle-exempt-from-vehicle-tax. [Accessed: 16-Nov-2017].

[80]Transport for London, ‘Electric vehicles & rapid charging’. [Online]. Available: https://tfl.gov.uk/modes/driving/electric-vehicles-and-rapid-charging. [Accessed: 16-Nov-2017].

[81]P. Mock and Z. Yang, ‘Driving electrification: A global comparison of fiscal incentive policy for electric vehicles’. International Council on Clean Transportation, 05-May-2014.

[82]C. Madina *et al.*, ‘Deliverable D9.4, Part 2. Envisaged EU mobility models, role of involved entities, and Cost Benefit Analysis in the context of the European Clearing House mechanism’. Green eMotion project, 27-Feb-2015.

[83]German National Platform for Electromobility (NPE), ‘Targets and approach at a glance. The measures’. [Online]. Available: http://nationale-plattform-elektromobilitaet.de/en/background/the-measures/#tabs. [Accessed: 16-Nov-2017].

[84]‘Aides 2017 pour les véhicules électriques - Voitures, utilitaires, camions, bus...’ [Online]. Available: http://www.avem.fr/index.php?page=aides&cat=ev. [Accessed: 17-May-2017].

[85]Directorate-General for Mobility and Transport. European Commission, ‘White Paper on Transport. Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system’. Publications Office of the European Union, 2011.

[86]Ministerio de Industria, Turismo y Comercio. Gobierno de España, ‘Real Decreto 647/2011, de 9 de mayo, por el que se regula la actividad de gestor de cargas del sistema para la realización de servicios de recarga energética’, *Boletín Oficial del Estado nº 122*, Madrid, pp. 51098–51113, 23-May-2011.

[87]C. Madina *et al.*, ‘Deliverable D7.1 - EV-Grid integration best scenario and its investment strategies’. PlanGridEV project, 21-Mar-2016.

[88]Eurostat. European Commission, ‘General government gross debt - annual data’. [Online]. Available: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=teina225. [Accessed: 15-Nov-2017].

[89]Directorate-General for Climate Action. European Commission, ‘Reducing CO2 emissions from passenger cars’. [Online]. Available: https://ec.europa.eu/clima/policies/transport/vehicles/cars_en. [Accessed: 16-Nov-2017].

[90]Directorate-General Taxation and Customs Union. European Commission, ‘Excise Duty Tables. Part II - Energy products and Electricity’. European Commission, Jul-2016.

[91]Norwegian Electric Vehicle Association (Elbil), ‘Norwegian EV market’, 30-Sep-2017. [Online]. Available: http://elbil.no/english/norwegian-ev-market/. [Accessed: 16-Nov-2017].

[92]Norwegian Electric Vehicle Association (Elbil), ‘Norwegian EV policy’. [Online]. Available: http://elbil.no/english/norwegian-ev-policy/. [Accessed: 16-Nov-2017].

[93]A. Doyle and N. Adomaitis, ‘Norway shows the way with electric cars, but at what cost?’, *Reuters*, Oslo, 13-Mar-2013.

[94]U.S. Department of Energy. U.S. Government, ‘President Obama Launches EV-Everywhere Challenge as Part of Energy Department’s Clean Energy Grand Challenges’, 07-Mar-2012. [Online]. Available: https://energy.gov/articles/president-obama-launches-ev-everywhere-challenge-part-energy-department-s-clean-energy. [Accessed: 16-Nov-2017].

[95]U.S. Department of Energy. U.S. Government, ‘About Electric Vehicles’. [Online]. Available: https://energy.gov/eere/electricvehicles/about-electric-vehicles. [Accessed: 16-Nov-2017].

[96]Internal Revenue Service. U.S. Department of Treasury. U.S. Government, ‘Plug-In Electric Drive Vehicle Credit (IRC 30D)’, 17-Aug-2017. [Online]. Available: https://www.irs.gov/businesses/plug-in-electric-vehicle-credit-irc-30-and-irc-30d. [Accessed: 16-Nov-2017].

[97]S. Shepard, ‘Electric Vehicles and the Clean Power Plan’, *Navigant Research*, 24-Aug-2015.

[98]D. J. Trump, ‘Presidential Executive Order on Promoting Energy Independence and Economic Growth’. Office of the Press Secretary. The White House, 28-Mar-2017.

[99]U.S. Department of Energy and U.S. Environmental Protection Agency. U.S. Government, ‘New Fuel Economy and Environment Label’. [Online]. Available: https://www.fueleconomy.gov/feg/Find.do?action=bt1. [Accessed: 16-Nov-2017].

[100]D. Anair and A. Mahmassani, ‘State of charge. Electric Vehicles’ Global Warming Emissions and Fuel-Cost Savings across the United States’. Union of Concerned Scientists, Jun-2012.

[101]U.S. Census Bureau. Department of Commerce. U.S. Government, ‘Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2016 (NST-EST2016-01)’, Dec-2016. [Online]. Available: https://www2.census.gov/programs-surveys/popest/tables/2010-2016/state/totals/nst-est2016-01.xlsx. [Accessed: 16-Nov-2017].

[102]‘Statistics for Publication. January through December 2016’. Department of Motor Vehicles. State of California, Mar-2017.

[103]‘California’s 2030 Climate Commitments: Cutting Petroleum Use in Half by 2030’. California Environmental Protection Agency, 03-Aug-2015.

[104]‘Facts about The Advanced Clean Cars Program’. Air Resources Board. California Environmental Protection Agency, 09-Nov-2011.

[105]Air Resources Board. California Environmental Protection Agency, ‘California Code of Regulations. § 1962.1. Zero-Emission Vehicle standards for 2009 through 2017 model year. Passenger cars, light-duty trucks and medium-duty vehicles’. 01-Jan-2016.

[106]California State Legislature, ‘Health & Safety Code. § 43211. Sale of noncomplying vehicle; Penalty’. 2016.

[107]Air Resources Board. California Environmental Protection Agency, ‘California Code of Regulations. § 1962.2. Zero-Emission Vehicle standards for 2018 and subsequent model year. Passenger cars, light-duty trucks and medium-duty vehicles’. 01-Jan-2016.

[108]Air Resources Board. California Environmental Protection Agency, ‘DriveClean’. [Online]. Available: http://www.driveclean.ca.gov/pev/Incentives.php. [Accessed: 16-Nov-2017].

[109]Internal Revenue Service. U.S. Department of Treasury. U.S. Government, ‘Qualified Vehicles Acquired after 12-31-2009’, 02-Nov-2017. [Online]. Available: https://www.irs.gov/businesses/qualified-vehicles-acquired-after-12-31-2009. [Accessed: 16-Nov-2017].

[110]Internal Revenue Service. U.S. Department of Treasury. U.S. Government, ‘IRC 30D – Plug-In Electric Drive Motor Vehicle Credit Quarterly Sales’, 06-Nov-2017. [Online]. Available: https://www.irs.gov/businesses/irc-30d-plug-in-electric-drive-motor-vehicle-credit-quarterly-sales. [Accessed: 16-Nov-2017].

[111]Xinhua, ‘China to quadruple new energy vehicle production by 2020’, *China Daily*, Beijing, 16-Jan-2017.

[112]‘China renews electric vehicle subsidies excluding hybrids’, *Bloomberg*, 18-Sep-2013.

[113]EV volumes, ‘China Plug-in Sales 2016 Q4 and Full Year’. [Online]. Available: http://www.ev-volumes.com/country/china/. [Accessed: 16-Nov-2017].

[114]EV obsession, ‘China EV Sales, Subsidies, & Targets’. [Online]. Available: https://evobsession.com/11199-2/. [Accessed: 16-Nov-2017].

[115]J. Spring, ‘Tesla CEO says negotiating with China on local production. CORRECTED-(OFFICIAL)-UPDATE 2’, *Reuters*, Shanghai, China, 24-Oct-2015.

[116]J. Motavalli, ‘China to Subsidize Electric Cars and Hybrids’, *The New York Times*, 02-Jun-2010.

[117]S. Howell, H. Lee, and A. Heal, ‘Leapfrogging or stalling out? Electric vehicles in China’, *HKS Work. Pap.*, no. RWP14-035, pp. 1–67, May 2014.

[118]General Office of the Chinese State Council, ‘State Council’s Notice on Issuing the Development Plan of Energy-saving and New-energy Vehicle Industry (2012-2020)’. 09-Jul-2012.

[119]General Office of the Chinese State Council, ‘Notice on Continuing to Promote the Application of New Energy Vehicles’. 13-Sep-2013.

[120]Mariordo, *Graph showing historical cumulative sales of new energy vehicles (NEVs) in China from 2011 to 2016*. 2017.

[121]W. Short, D. J. Packey, and T. Holt, *A manual for the economic evaluation of energy efficiency and renewable energy technologies*. Golden, Colorado, U.S.: National Renewable Energy Laboratory, 2005.

[122]A. Damodaran, *Investment Valuation: Tools and Techniques for Determining the Value of Any Asset*, 2nd ed. New York, U.S.: John Wiley & Sons, 2002.

[123]V. Giordano, I. Onyeji, G. Fulli, M. Sánchez Jiménez, and C. Filiou, *Guidelines for conducting a cost-benefit analysis for Smart Grid projects*. Luxembourg: Publications Office of the European Union, 2012.

[124]EU Science Hub. European Commission, 'JRC in brief', 18-Jul-2016. [Online]. Available: https://ec.europa.eu/jrc/en/about/jrc-in-brief. [Accessed: 16-Nov-2017].

[125]ENTSO-E, 'Who is ENTSO-E?' [Online]. Available: https://www.entsoe.eu/about-entso-e/Pages/default.aspx. [Accessed: 16-Nov-2017].

[126]The European Parliament and The Council of the European Union, 'Regulation (EU) No 347/2013 of The European Parliament and of The Council of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009', *Official Journal of the European Union L 115*, pp. 39–75, 25-Apr-2013.

[127]'ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects'. ENTSO-E, 05-Feb-2015.

[128]'ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects (CBA 2.0). Draft for public consultation 25 April – 31 May'. ENTSO-E, 25-Apr-2016.

[129]Directorate-General for Climate Action. European Commission, '2020 climate & energy package'. [Online]. Available: https://ec.europa.eu/clima/policies/strategies/2020_en. [Accessed: 16-Nov-2017].

[130]European Commission, *Energy roadmap 2050*. Luxembourg: Publications Office of the European Union, 2012.

[131]A. Afuah, *Business models : a strategic management approach*, 1st ed. Boston ; London: McGraw-Hill/Irwin, 2004.

[132]J. Magretta, 'Why business models matter?', *Harvard Business Review*, pp. 3–8, May-2002.

[133]C. Weiller, A. Shang, A. Neely, and Y. Shi, 'Competing and Co-existing Business Models for EV: Lessons from International Case Studies', presented at the 2013 World Electric Vehicle Symposium and Exhibition (EVS27), Barcelona, Spain, 2013, pp. 1–12.

[134]A. Osterwalder, Y. Pigneur, and C. L. Tucci, 'Clarifying business models: Origins, present, and future of the concept', *Commun. Assoc. Inf. Syst.*, vol. 16, no. 1, pp. 1–25, Jul. 2005.

[135]J. Gordijn, A. Osterwalder, and Y. Pigneur, 'Comparing two business model ontologies for designing e-business models and value constellations', presented at the 18th Bled eConference 2005, Bled, Slovenia, 2005, p. 15.

[136]A. Osterwalder and Y. Pigneur, *Business model generation: a handbook for visionaries, game changers, and challengers*. Hoboken, New Jersey, U.S.: Wiley, 2010.

[137]J. Gordijn, 'Value-based requirements engineering: exploring innovative e-commerce ideas.', PhD thesis, Vrije Universiteit Amsterdam, Amsterdam, 2002.

[138]J. Gordijn and J. M. Akkermans, 'Value-based requirements engineering: exploring innovative e-commerce ideas', *Requir. Eng.*, vol. 8, no. 2, pp. 114–134, Jul. 2003.

[139]'BUSMOD project'. [Online]. Available: http://e3value.few.vu.nl/projects/ourprojects/busmod/. [Accessed: 16-Nov-2017].

[140]V. Kartseva, J. Soetendal, J. Gordijn, H. Akkermans, and J. Schildwacht, ‘Distributed Generation Business Modelling’. Busmod project, 02-Apr-2004.

[141]Eurostat. European Commission, ‘Energy dependence’. [Online]. Available: http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=tsdcc310&language=en. [Accessed: 15-Nov-2017].

[142]I. S. Bayram, A. Tajer, M. Abdallah, and K. Qaraqe, ‘Capacity Planning Frameworks for Electric Vehicle Charging Stations With Multiclass Customers’, *IEEE Trans. Smart Grid*, vol. 6, no. 4, pp. 1934–1943, Jul. 2015.

[143]S. Habib, M. Kamran, and U. Rashid, ‘Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks – A review’, *J. Power Sources*, vol. 277, pp. 205–214, Mar. 2015.

[144]H. Lund and W. Kempton, ‘Integration of renewable energy into the transport and electricity sectors through V2G’, *Energy Policy*, vol. 36, no. 9, pp. 3578–3587, Sep. 2008.

[145]S. Beer *et al.*, ‘An Economic Analysis of Used Electric Vehicle Batteries Integrated Into Commercial Building Microgrids’, *IEEE Trans. Smart Grid*, vol. 3, no. 1, pp. 517–525, Mar. 2012.

[146]K. F. Punch, *Introduction to Social Research. Quantitative and Qualitative Approaches*, 2nd ed. London: SAGE Publications Ltd., 2005.

[147]Investopedia, ‘Anchoring’. [Online]. Available: http://www.investopedia.com/terms/a/anchoring.asp. [Accessed: 16-Nov-2017].

[148]M. G. Richard, ‘Nissan’s LEAF Creates a New “Anchor” for Electric Car Pricing, Forcing Others to Match It’, *TreeHugger*, 01-Apr-2010.

[149]C. Madina *et al.*, ‘Deliverable D9.4, Part 1. Envisaged EU mobility models, role of involved entities, and Cost Benefit Analysis in the context of the European Clearing House mechanism’. Green eMotion project, 15-Aug-2014.

[150]C. Madina *et al.*, ‘Economic assessment of strategies to deploy publicly accessible charging infrastructure’, presented at the 2015 World Electric Vehicle Symposium and Exhibition (EVS28), Goyang, Korea, 2015, pp. 1–11.

[151]C. Madina, I. Zamora, and E. Zabala, ‘Methodology for assessing electric vehicle charging infrastructure business models’, *Energy Policy*, vol. 89, pp. 284–293, Feb. 2016.

[152]‘Green eMotion Project’. [Online]. Available: http://www.greenemotion-project.eu/. [Accessed: 16-Nov-2017].

[153]T. Theisen and R. F. Marques, Eds., ‘Market models for the Roll-Out of Electric Vehicle Public Charging Infrastructure. A EURELECTRIC concept paper’. Eurelectric, Sep-2010.

[154]‘Second Report of the National Platform for Electromobility’. German National Platform for Electromobility (NPE), May-2011.

[155]RWE, ‘RWE eOperate’. [Online]. Available: https://www.rwe-mobility.com/web/cms/en/1241156/products-services/emobility-services/rwe-eoperate/. [Accessed: 16-Nov-2017].

[156]‘Hubject’. [Online]. Available: https://www.hubject.com/en/. [Accessed: 16-Nov-2017].

[157]‘e-clearing.net’. [Online]. Available: http://www.e-clearing.net/. [Accessed: 16-Nov-2017].

[158]‘Interim Report of the National Platform for Electromobility’. German National Platform for Electromobility (NPE), Nov-2010.

[159]‘Progress Report 2014. Review of Pre-Market phase’. German National Platform for Electromobility (NPE), Dec-2014.

[160]Movistar, ‘Ofertas Fibra Optica y ADSL, Empresas’. [Online]. Available: https://www.movistar.es/empresas/banda-ancha/. [Accessed: 16-Nov-2017].

[161]Inditar, ‘Tarjetas Impresas chip de proximidad o RFID’. [Online]. Available: http://shop.inditar.com/categories/tarjetas-de-pvc-impresas/impresas-con-chip-proximidad-o-rfid.html. [Accessed: 16-Nov-2017].

[162]Ministerio de Economía. Gobierno de España, ‘Real Decreto 1164/2001, de 26 de octubre, por el que se establecen tarifas de acceso a las redes de transporte y distribución de energía eléctrica (texto consolidado)’, *Boletín Oficial del Estado nº 268*, Madrid, pp. 40618–40629, 08-Nov-2001.

[163]Ministerio de Industria, Turismo y Comercio. Gobierno de España, ‘Orden ITC/3801/2008, de 26 de diciembre, por la que se revisan las tarifas eléctricas a partir de 1 de enero de 2009.’, *Boletín Oficial del Estado nº 315*, Madrid, pp. 52672–52685, 31-Dec-2008.

[164]Jefatura del Estado, ‘Ley 38/1992, de 28 de diciembre, de Impuestos Especiales (texto consolidado)’, *Boletín Oficial del Estado nº 312*, Madrid, pp. 44305–44331, 29-Dec-1992.

[165]Endesa, ‘Tarifa Preferente para empresas’. [Online]. Available: https://www.endesaclientes.com/empresas/tarifa-preferente.html. [Accessed: 16-Nov-2017].

[166]Ministerio de Industria, Turismo y Comercio. Gobierno de España, ‘Real Decreto 1053/2014, de 12 de diciembre, por el que se aprueba una nueva Instrucción Técnica Complementaria (ITC) BT 52 “Instalaciones con fines especiales. Infraestructura para la recarga de vehículos eléctricos”, del Reglamento electrotécnico para baja tensión, aprobado por Real Decreto 842/2002, de 2 de agosto, y se modifican otras instrucciones técnicas complementarias del mismo’, *Boletín Oficial del Estado nº 316*, Madrid, pp. 107446–107481, 31-Dec-2014.

[167]Ministerio de Industria, Turismo y Comercio. Gobierno de España, ‘Orden IET/1491/2013, de 1 de agosto, por la que se revisan los peajes de acceso de energía eléctrica para su aplicación a partir de agosto de 2013 y por la que se revisan determinadas tarifas y primas de las instalaciones del régimen especial para el segundo trimestre de 2013’, *Boletín Oficial del Estado nº 185*, Madrid, pp. 56729–56738, 03-Aug-2013.

[168]‘Report on 800 Volt Fast Charging and Thermal Management’. International Quality & Productivity Center, Nov-2016.

[169]Ford Media Center, ‘BMW Group, Daimler AG, Ford Motor Company and Volkswagen Group with Audi and Porsche Plan a Joint Venture for Ultra-Fast, High-Power Charging Along Major Highways in Europe’, 29-Nov-2016. [Online]. Available: https://media.ford.com/content/fordmedia/fna/us/en/news/2016/11/29/bmw-daimler-

ford-volkswagen-audi-porsche-plan-ultra-fast-charging-major-europe-highways.html. [Accessed: 16-Nov-2017].

[170]Directorate-General for Energy. European Commission, ‘Commission proposes new rules for consumer centred clean energy transition’, 30-Nov-2016. [Online]. Available: https://ec.europa.eu/energy/en/news/commission-proposes-new-rules-consumer-centred-clean-energy-transition. [Accessed: 15-Nov-2017].