Deliverable 9.4 Part 2

Envisaged EU mobility models, role of involved entities, and Cost Benefit Analysis in the context of the European Clearing House mechanism

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List of Abbreviations

BM	Business Model
DSO	Distribution System Operator
EC	European Commission
EMO	Electricity Market Operator
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment (charger)
EVSP	Electric Vehicle Service Provider
ICE	Internal Combustion Engine
KPI	Key Performance Indicators
NPE	German National Platform for Electric Mobility
OEM	Original Equipment Manufacturer
O&M	Operation and Maintenance
PI	Performance Indicators
RFID	Radio-Frequency Identification
SOC	State of Charge
TCO	Total Cost of Ownership
TOU	Time of Use
TSO	Transmission System Operator
VAT	Value-Added Tax
WP	Work Package

For more information on roles, actors and their definition please refer to the GeM glossary[1].

[1] The electromobility glossary available at http://www.greenemotion-project.eu/

1 Executive summary

The business models (BM) analysis performed in Green eMotion seeks to identify the BMs most suited to facilitate large-scale electric vehicles (EV) roll-out in terms of social acceptance, commercial viability and system/environmental impact. After the first part of this deliverable [D9.4] made a detailed economic impact of the deployment of publicly accessible slow charging infrastructure in the whole ecosystem of actors, this second part assesses the impact on the main actors (EVSE Operators and EV customers) in four different charging services, to account for the different charging alternatives that EV customers may have for charging their EVs:

1. Traffic hotspot charging: Charging at a publicly accessible EVSE 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 traffic hotspot who, hence, acts both as EVSP and EVSE Operator (no roaming required and, thus, no marketplace).
2. Highway charging: Charging at a publicly accessible EVSE on private or public domain. The charging speed is assumed to be fast (50 kW). EV customers pay for EV charging, so it is assumed that they use the roaming agreement of their EVSP with the EVSE Operator (through a roaming agreement) to be able to charge their EVs.
3. Private home charging: Charging at a private EVSE. The charging speed is assumed to be slow (3.7 kW). EV customers themselves buy the EVSE required for charging their EVs (they act as EVSE Operator) and buy electricity directly from the Electricity retailer (which performs the EVSP role in this case), so there is no need for a roaming agreement.
4. Public charging spot for street side parking: Charging is made at a publicly accessible EVSE 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 EVSP and the EVSE Operator are subscribed.

The analysis presented in this second part of the deliverable looks further into the future (medium term), where the assumed number of EVs on the road is sufficient to support the development of public charging infrastructure.

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 each EVSE Operator, as well as the EVSP, 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 Internal Combustion Engine (ICE) vehicle driver.

Private home charging is expected to be the preferred charging alternative by those EV customers who can charge their EVs at home, while public charging spot for street side parking is likely to be the most used option for those EV customers without access to private home charging. As a result, the total cost of ownership (TCO) for EV customers is compared with the cost of owning an ICE vehicle with an equivalent usage rate. On the contrary, traffic hotspot charging and highway charging are expected to be used quite seldom by EV customers (almost only when they require extending their range and cannot use the other two services) and, hence, they are not likely to have a big impact on their TCO. Therefore, the relative cost of a single, equivalent trip for EV customers and for drivers of ICE vehicles is compared.

The analysis presented in this report shows that EV customers with private home charging availability are likely to be the early adopters of electric mobility, as long as they need to use their EVs regularly and subsidies for EV purchase exist. Then, as EV market grows, publicly accessible EVSE with semi-fast charging capabilities are likely to appear in cities and traffic hotspots. In the meantime, technology development is expected to increase driving ranges while reducing costs, so that highway charging can also be profitable in the medium term. Until these technological developments materialise, electric mobility should be supported by a favourable regulatory framework, both for EV customers and for the deployment of the charging infrastructure.

2 Introduction

2.1 Business models analysis in Green eMotion

The business models (BM) analysis performed in Green eMotion seeks to identify the BMs most suited to facilitate large-scale electric vehicles (EV) roll-out in terms of social acceptance, commercial viability and system/environmental impact.

The economic assessment presented in this report is based on the outcome of several workshops, meetings and phone conferences devoted to the BMs topic in Green eMotion. Among others, partners contributing to such discussions include vehicle manufacturers (BMW, Nissan, Daimler), electric utilities (RWE, Enel), equipment manufacturers (Siemens, Bosch) and ICT companies (IBM), which ensures the relevance of the data and assumptions considered in the analysis[2].

This document contains an evaluation of the economic performance of the BMs related to electric mobility within Green eMotion project[3], as part of Task 9.3. This evaluation is an **extension** of the analysis performed in the first part of this deliverable D9.4 [D9.4]. The reader is **strongly encouraged** to read the first part of the report before going into the details of this second part.

2.2 Electric mobility and regulatory and commercial frameworks

EV-related BMs are networked business models, in which several actors interrelate with each other and all call for a positive business case. Therefore, the BM analysis does not only focus on the actors who want to launch the business (e.g. Electric Vehicle Supply Equipment (EVSE) Operator or Electric Vehicle Service Provider (EVSP)), but also on all the players that must or can be involved across the value chain, including some regulated companies (such as Transmission System Operator (TSO), Distribution System Operator (DSO) or Electricity Market Operator (EMO)) and liberalized stakeholders (such as electricity retailers or producers).

The different connections between the different actors are presented **in Figure 1.**

[2] In addition to the meetings stated in the first part of this report, regular monthly teleconferences were held between core contributors to the document and with Task 9.5 participants throughout 2014. These teleconferences were further complemented with a final workshop in Munich (October 2014), where the final data assumptions were agreed between all participants. The conclusions were then presented to the rest of the consortium for their feedback and, where required, adapted accordingly.

[3] http://www.greenemotion-project.eu/ [access in February 2015].

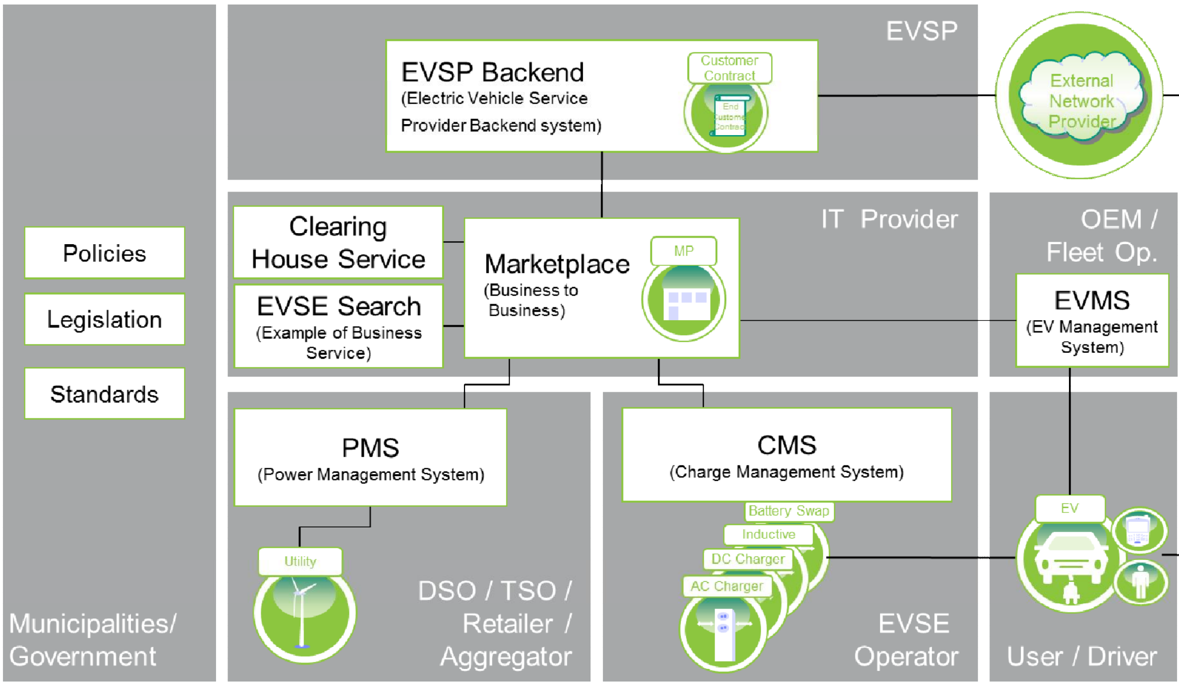

Figure 1: Green eMotion Building Blocks

The actors in this network may have different roles and responsibilities, and the relationships between them may also be different, i.e. different market models may exist [EURELECTRIC 2013]. Each market model creates different options for contractual arrangements between actors:

- Roaming may be necessary (when there is a complete unbundling of roles for the EVSP, EVSE Operator and DSO) or optional (if the EVSP is also the EVSE Operator, when EV customers use an EVSE operated by their EVSP would not need roaming, but they would if they charge in an EVSE operated by another EVSP).
- Charging service may include electricity or not, i.e. EV customers may receive an all-inclusive service from a single supplier (their EVSP provides access to charging infrastructure and electricity for charging the EV) or they may need to pay for access to the EVSE (either from the EVSP or from the EVSE operator) and for the electricity (e.g. by selecting their electricity retailer on the EVSE) separately.

Moreover there is a number of alternatives for the characteristics of the EV charging process, including:

- The place where charging takes place: publicly accessible EVSE in public domain (curb side), publicly accessible EVSE in private domain (malls, airports…), restricted-access EVSE in private domain (workplaces for charging employees' private cars or EV fleets) or private EVSE (home).
- The type of charging technology: conductive or inductive charging, battery swapping…
- The speed of charging: slow (e.g. 3.7 kW), semi-fast (11 kW or 22 kW) or fast (50 kW or more).

The contractual relationships between the different parties (in particular, between EVSPs and EVSE Operators) may also be of bilateral nature, or they may subscribe to a marketplace for selling and buying electric mobility services, including the clearing of the charging sessions. In the first case, EV customers will only be able to charge their EVs if their EVSP has a direct contract with the EVSE Operator of the EVSE in which they want to charge. In the second one, their EVSP has a contract with a third party (the marketplace operator) and they are able to charge in any EVSE operated by an EVSE Operator having a contract with the same third party. **Figure 2** below presents the difference between both approaches.

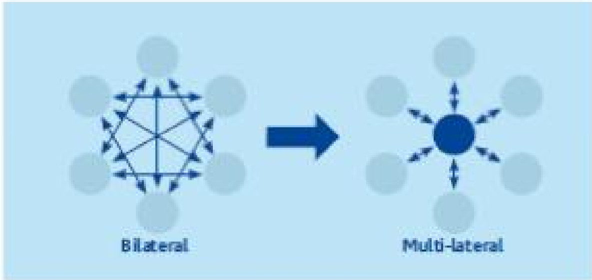

Figure 2: Bilateral versus multi-lateral contracting

Conducting a detailed analysis of all the alternatives would have been impossible, so certain choices were required to be made at the very early stage of the analysis. In order to adopt the most generic case, the unbundled market model is considered[4] in general. In the unbundled business model for the service "basic charging" the DSO, the electricity retailer, the EVSP and the EVSE operator are different legal entities. The outcomes presented here are therefore related to an unbundled business model where all actors are independent from each other.

Under this market model, roaming is required, so that the different actors have contracts in place that finally allow the EVSP to offer charging services to the EV customer (EV driver) using the EVSEs of the EVSE operator. As a result the EVSE operator has the possibility to bill the EVSP for the charging event. In this case, the most natural approach is to consider that electricity is included in the charging [EURELECTRIC 2013].

2.3 Scope and results in the first part of D9.4

In the first part of the deliverable [D9.4], the scope of the analysis was further narrowed by only considering slow (3.7 kW) publicly accessible charging infrastructure (either in public or private domain) and that both the EVSP and the EVSE Operator have a subscription to the marketplace.

In order to derive concrete numbers for the analysis of the business model, a mid-term basic business scenario was created. Therein it was assumed that the EVSP has 50 000 EV customers and the EVSE operator runs 10 000 EVSEs. The EV customers were assumed to charge once per day at public EVSEs. The average energy charged was 3 kWh, which was in line with the data collected in Green eMotion demo regions [Brady 2013]. The latter assumption means that the EV customer would charge publicly for an equivalent of 9100 km/year (calculated with an average value of 120 Wh/km), which is close to the annual average for European Union (EU) cars [EC 2013, 2].

The number of EV customers in the analysis was always expressed relative to one EVSP, meaning that we considered a market segment that was covered by one EVSP. If for example one country had several EVSPs, the number of EV customers in that country would be the sum of the EV customers of all EVSPs in that country. Likewise, the outcome was calculated for only one EVSE operator as an increase of their number would have increased the complexity of the business case analysis significantly.

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[4] 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.

These results in the first part of the deliverable led to the conclusion that the business case of slow, public charging as a stand-alone business (not linked to any other activity) can only be profitable within such mid-term business scenario that features highly frequented EVSEs located at points of interest or fast charging at highways, so that people are willing to pay for the usage and usage time is short enough to allow for several charging events per day. Outside of this niche, there does not appear to be a positive business case for developing the EV charging infrastructure.

In addition to the BM analysis discussed above, the first part of D9.4 also elaborated a structured set of key performance indicators (KPIs) and performance indicators (PIs), which can be used by the users of the Green eMotion marketplace to assess the quality and effectiveness of electric mobility services provided through the system. The defined performance indicators were grouped into four categories (cost, time, quality of service and service performance) that address varying operational and business aspects that may be of interest. A detailed description of the methodology used for the selection, description and specification of the PIs and KPIs for each use case was included.

2.4 Scope of the document

The analysis in the first part complied with the two conditions required at that time. On the one hand, it analysed a situation which was possible and important for the European Commission (EC), because the Directive for Alternative Fuels [OJ L307/1] was still under discussion. On the other hand, the scope was narrow enough so that results could be obtained, despite the complexity of the environment for the analysis.

Nevertheless, the large-scale roll-out of EVs will not only depend on publicly accessible (slow) charging infrastructure, but it also requires the existence of private charging and fast (between 22 kW and 50 kW, or even more in the future) and semi-fast (11 or 22 kW) charging on highways or traffic hotspots.

Therefore, this deliverable analyses other charging alternatives. In order to cover as broad a scope as possible, while being efficient from the point of view of effort invested into the analysis, four EV charging services are considered, to represent different alternatives EV customers may have for charging their EVs in the future (more details can be found in chapters 3 to 6, one per charging service):

1. Traffic hotspot charging: Charging at a publicly accessible EVSE 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 traffic hotspot who, hence, acts as EVSP and EVSE Operator at the same time (no roaming required and, thus, no marketplace).
2. Highway charging: Charging at a publicly accessible EVSE on private or public domain. The charging speed is assumed to be fast (50 kW). EV customers pay for EV charging, so it is assumed that they use the roaming agreement of their EVSP with the EVSE Operator (through a roaming agreement) to be able to charge their EVs.
3. Private home charging: Charging at a private EVSE. The charging speed is assumed to be slow (3.7 kW). EV customers themselves buy the EVSE required for charging their EVs (they act as EVSE Operator) and buy electricity directly from the Electricity retailer (which performs the EVSP role in this case), so there is no need for a roaming agreement.
4. Public charging spot for street side parking: Charging is made at a publicly accessible EVSE 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 EVSP and the EVSE Operator 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.

It is assumed that each charging service corresponds to one individual EVSE Operator[5]. In this way the main actors for the analysis are EV customers (who are the EVSE Operators of the private home charging service), the EVSP (who offers electric mobility services to EV customers in all charging alternatives and roaming services too in the highway and in the public charging spot for street side parking charging services), the traffic hotspot operator (who is the EVSP and the EVSE Operator in the traffic hotspot charging service), the highway charging EVSE Operator and the public charging spot operator.

Although the pace of electric mobility adoption is not as fast as expected at the beginning of the decade, the strong commitment by public bodies, electric utilities and original equipment manufacturers (OEMs) is slowly setting the conditions for a more massive adoption of EVs. In order to be able to have profitable BMs related to electric mobility, it is of paramount importance that there is an EV market behind them. The usage patterns considered in this report are, as stated in footnote 2, the result of expert opinions of Green eMotion partners for the medium term future perspective, when there is expected to be a critical mass of EVs necessary to allow for a visible demand of EV charging in publicly accessible EVSE.

2.5 Methodology

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 both the EVSE Operator and the EVSP use a pricing strategy which allows them recover their costs. Then, the effect on EV customers is compared with a similar situation for an Internal Combustion engine (ICE) vehicle driver. The main cost components for the different actors are presented in the subsections below.

2.5.1 Marketplace Operator

Starting from the KPI analysis in the first part of this deliverable, target values for the different KPIs were established in discussion with WP3 partners. This was done by defining target values for the quality of service and time related KPIs, and for three usage levels linked to three future horizon levels considered in the first part (service performance).

Table 1 and Table 2 present quality of service and time KPIs, respectively.

[5] Although more than one charging service could be offered by a single EVSE Operator, the only cost which does not depend on the number of EVSE (and, hence, can be reduced if more than one type of charging service is provided) is the cost of accessing the marketplace (see section 2.5.1). This cost can be relevant in the highway charging service, whose impact is assessed in sections 4.2.6, and in the public charging spot for street side parking, where several EVSE are already considered.

PI	Description	Value
PI- 61	Percentage of search results that cannot be fulfilled	2%
PI- 8	Percentage not sent roaming authorization	2%
PI-36	Percentage not granted charging reduction service requests	2%
PI-44	Successful logging of valid charging data to marketplace as a percentage of total events	95%
PI-46	No of requests for consumption data completed as a percentage of all requests received	95%
PI-101	Percentage of unsuccessful roaming charging process events	2%
PI-116	Percentage of failed attempts of EV car sharing user to make reservation to use an EV	10%
PI-81	Percentage of requested services not fulfilled due to a technical error	2%
PI-80	No of service transactions per day	As high as possible
PI-2	Time for identification and authorization	5 s
PI-35	Time to fulfil a charging reduction service request	2 s

Table 1: Target values for Quality of Service KPIs

PI	Description	Value (s)
PI- 2	Average time it takes to identify and authenticate a user	5
PI- 35	Response time for charging reduction services	2
PI-150	Elapsed time between EVSE operator request to marketplace response	1
PI-151	Elapsed time between marketplace operator request to Clearing House response	1
PI-152	Elapsed time between Clearing House request to marketplace response	1
PI-153	Elapsed time between marketplace request to EVSE operator response	1
PI-154	Elapsed time between EVSE operator request to EVSP response	1
PI-155	Elapsed time between EVSP operator request to Clearing House response	1
PI-156	Elapsed time between Clearing House operator request to EVSP response	1
PI-157	Elapsed time between EVSP operator request to EVSE response	1

Table 2: Target values for Time KPIs

Once these target values were established, cost estimates were made related to the marketplace and the Clearing House, as Table 3 shows. All the cost estimates (last four rows) depend on the number of transactions or on the number of users per EVSP using the marketplace or the Clearing House.

PI	Description	Short-term	Medium term	Long-term
PI-140	Number of EVs	5000	50 000	250 000
PI-124	Number of charging stations	1000	10 000	50 000
PI-141	Number of roaming sessions per day	5000	50 000	250 000
PI-127	Marketplace staff cost and EBIT (€/month)	20 000	40 000	60 000
PI-128	Clearing house staff cost and EBIT (€/month)	10 000	25 000	30 000
PI-132	Market place access cost (€/month)	20 000	80 000	160 000
PI-7	Roaming charges (€/month)	10 000	40 000	80 000

Table 3: Estimates of marketplace and Clearing House costs for future demand scenarios

As stated in section 2.4, this second part of the deliverable is looking a bit ahead in the future (medium term), when there will be the critical EV mass necessary to allow for a visible demand of EV charging in publicly accessible EVSE. Hence, the conditions in second column in Table 3 are considered, so the total costs for the marketplace (addition of PI-127 and PI-132) are 120 000 €/month, i.e. 1 440 000 €/year.

In order to define the business model for the Green eMotion marketplace, interviews with representatives of existing marketplaces in Europe[6] were held. The costs of accessing them include a one-time subscription fee of about 5000 € and an annual fee of about 1600 €/year, for both EVSE Operators and EVSPs. On top of that, EVSPs must pay 25 €/customer and per year (up to 25 000 €/year maximum).

One of the marketplaces in commercial operation states that it has already more than 120 partners [HUBJECT 2014]. In order to cover the costs estimated in Table 3, each of them would need to pay about 12 000 €/year or, to see it in another way, if there are 50 EVSPs (with 1000 EV customers each) and 70 EVSE Operators, the incomes for the marketplace are enough to pay for the costs:

$$(50 * 25 * 1000) + (50 * 1600) + (70 * 1600) = 1\,442\,000\,€$$

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 prices already in place are considered in the analysis. 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 are calculated as follows:

$$Marketplace\ access\ cost = \frac{5000}{\frac{(1+5\%)^{20}-1}{7\% * (1+5\%)^{20}}} + 1600 = 2000\ €/year$$

2.5.2 EVSE Operator

The EVSE Operator has the role of managing the physical equipment (EVSE) to supply the charging process of the EV. Moreover, it also has the duty to monitor the charging session and monitor, maintain and control a certain EVSE. The EVSE Operator offers charging services (access to charging infrastructure, including energy) to the EVSP based on a B2B relationship, either directly or through an agreement with a third party (the marketplace operator, see **Figure 2**). It is the owner of all EVSE-related data.

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[6] www.hubject.com, http://www.e-clearing.net/ [access in February 2015].

2.5.2.1 Costs

According to [D9.4], the costs for the EVSE Operator in the most general case, are costs related to the charging infrastructure, i.e. EVSE amortisation and operation and maintenance (O&M) costs, electricity bill costs (including metering), communications costs and costs for accessing the marketplace, as well as staff costs and overheads. New assumptions are considered for these costs in this second part:

- All the issues related to the operation of the EVSE are outsourced to a third party (as RWE offers in Germany[7]) and the EVSE Operator is not a start-up, but an already existing company, so that staff and overhead costs are assumed to be negligible.
- The data related to EVSE investment and O&M costs are based on the reports prepared by the German National Platform for Electric Mobility (NPE). In these reports, e.g. [NPE 2014], communication costs are included in the annual O&M costs.
- Marketplace access cost is 2000 €/year (see section 2.5.1).

Therefore, the EVSE Operator has some fixed costs which do not depend on the number of EVSE (marketplace access cost), some other fixed costs which do depend on the number of EVSE, i.e. fixed costs per EVSE (amortisation, O&M, communications and the fixed part of the electricity bill) and some variable costs per charging session (variable part of the electricity bill).

The fixed costs per EVSE, excluding the fixed part of the electricity bill, include the following items:

- EVSE investment cost (including grid connection): In general, the EVSE lifetime can be assumed to be 7.5 years [NPE 2014] and a 7% discount rate[8] can also be assumed. In this case, the annual amortisation of an investment $EVSE_{Inv}$ results in:

$$Annual\ EVSE\ amortisation\ cost = \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}}$$

- Annual EVSE O&M costs ($EVSE_{O\&M}$) including communications (EVSE-EVSE backend and EVSE backend upstream).

The rest of the fixed costs, as well as the variable costs, are part of the electricity bill, which is calculated in different ways in the different countries. In order to see the differences that may arise due to electricity bill structure differences across EU Member States, Spain (base case), Germany and the Netherlands are considered in this report.

In general, the annual costs for an EVSE Operator with N EVSE are calculated according to the following formula:

$$Annual\ EVSE\ Operator's\ costs = \left\{ Electricity\ bill + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N + MP_{EVSEO}$$

The electricity bill in Spain consists of the following components in the most general case[9]:

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[7] https://www.rwe-mobility.com/web/cms/en/1241156/products-services/emobility-services/rwe-eoperate/ [access in February 2015].

[8] Almost the average value of the high (10%) and low (5%) values proposed in [D9.6].

[9] Price structures (tariffs) depend on the contracted power (connection size) [BOE-A-2001-20850].

- Power or capacity component: It depends on the maximum power to be demanded from the grid. Different prices (*Tp*, in €/kW.month) apply, depending on the connection size (*P*, in kW):

$$Power\ component = P * Tp * 12\ month/year$$

- Energy component: It depends on the consumed amount of electricity. Both the price and the number of periods depend on the connection size. For LV connections, a three-period time of use (ToU) tariff applies in general, i.e. there are three different prices within a day. Based on the data collected in the demo region Barcelona and Malaga [DR-ES1], 23% of charges are assumed to happen in peak times (summer peak times are 11:00-15:00, where 31% of the charges occur, and winter peak times are 18:00-22:00, where 15.5% of charges occur), 11% of charges in super off-peak times (0:00-8:00 both in summer and in winter) and the remaining 66% in regular off-peak times. Therefore, it can be calculated as:

$$Energy\ component = (23\% * Te_1 + 66\% * Te_2 + 11\% * Te_3) * E * C$$

  Where Te_i corresponds to the prices in the three different ToU periods, *E* is the average energy demand per charging session and *C* is the total number of charging session within a year.

- Electricity tax: It is calculated by applying 5.1127% to the addition of power and energy components.
- Meter renting: The prices for meter renting are different for single-phase and three-phase meters. In general, electricity supplies of more than 15 kW must be supplied at three-phase voltage [Schneider 2008] and lower connection capacities are supplied in single-phase. Meter cost (*M*) is usually provided in €/month.
- VAT: In Spain, VAT is 21% and it is applied to all the rest of components of the electricity bill. However, as the EVSE Operator is not the final customer, its costs can be claimed, so VAT is not included in EVSE Operator's calculations (except for private home charging service).

Therefore, the annual EVSE Operator costs are:

$$Annual\ EVSE\ Operator's\ costs\ in\ Spain = \left\{ \left[\left(\langle \{ (P * Tp * 12) + [(23\% * Te_1 + 66\% * Te_2 + 11\% * Te_3) * E * C] \} * (1 + 5.1127\%) \rangle + (M * 12) \right) * (1 + VAT) \right] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N + MP_{EVSEO} \quad (1)$$

In Germany, the electricity bill is made up of the following components:

- Connection cost: it is a one-time payment, which depends on the connection size. It is assumed to be included in the EVSE installation cost.
- Metering price: It consists of an initial payment (also included in EVSE installation cost) and a monthly payment (*M*).
- Energy term: It is a cost for the consumed electricity. The same price (*Te*) applies to all the hours.
- VAT: It is 19% in Germany.

And the annual costs of the EVSE Operator become:

$$\text{Annual EVSE Operator's costs in Germany} = \left\{ \left[\left((Te * E * C) + (M * 12)\right) * (1 + VAT)\right] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N + MP_{EVSEO}$$

(2)

In the Netherlands, the electricity bill includes the following components:

- Fixed cost (*F*): It is a cost for being connected to the electricity grid. It depends on the type of consumer (private or business) and on the connection size.
- Capacity payment (*P*): It is a price cost for the size of the connection to the grid. It depends on the type of consumer (private or business) and on the connection size.
- Energy payment: It is a cost for the energy consumed. Prices depend on the type of consumer (private or business) and on the connection size. A single-price ToU is the most common one (*E*).
- Reduction (*R*): It is a discount on the electricity bill. It depends on the type of consumer (private or business) and on whether it is for living or working function or not. As of 1 January 2015, there is no reduction for non-living or working function in the Netherlands[10].
- VAT: It is 21%, as in Spain.

Hence, annual costs for the EVSE Operator in the Netherlands are:

$$\text{Annual EVSE Operator's costs in the Netherlands} = \left\{ \left[(F + P + (Te * E * C) - R) * (1 + VAT)\right] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N + MP_{EVSEO}$$

(3)

2.5.2.2 Incomes

On the other hand, EVSE Operator's income mainly relies on the EV charging sessions made by EV customers, but some other sources of revenue (*OS*) might also be envisaged, like advertising or attracting EV customers to an existing shop or restaurant:

$$\text{Annual EVSE Operator's incomes} = (CP * C * N) + OS$$

(4)

The parameters in the formulas above take different values in the different charging services. Based on them, the charging service price to be requested by the EVSE Operator (*CP*) in each of them can be calculated.

[10] http://www.nuon.nl/mkb/tarieven/energiebelasting/ [access in February 2015]. The list of uses with living or working function can be found in http://www.nuon.nl/Images/voorbeeldlijst-objecten-met-en-zonder-verblijfsfunctie8-28384.pdf [access in February 2015].

2.5.3 EVSP

The EVSP offers electric mobility services to the end customers, which may include charging, search & find, routing and other services. It is the legal entity that the end-customer has a contract (B2C relationship) with for all services related to the EV. This provision of services, including the EV charging services (either at home, at work or at any other location), is the feature that characterises the EVSP. The EVSP is owner of the data of the EV customers in its portfolio. It is the B2B customer for the charging services sold by the EVSE operator.

The EVSP has some fixed costs and some variable costs.

Fixed costs are assumed to be recovered by means of an annual subscription fee to be charged to EV customers (which gives them the right to charge in the highway charging and in the public charging spot for street side parking charging services). Fixed costs include the following ones:

- Costs for accessing the marketplace: One-time subscription fee of 5000 € and an annual fee of 1600 €/year. As in the EVSE Operator case (see section 2.5.2), total annual cost of 2000 €/year can be assumed. On top of that, the EVSP must pay 25 €/customer and per year (up to a maximum payment of 25 000 €/year).
- Communications costs: they are assumed to be included in EVSP's regular Internet bill[11], so they are neglected.
- Staff and overhead costs: These costs strongly depend on the number of EV customers managed. The assumptions in the first part of this deliverable [D9.4] are used for the three countries, so, for an EV customer portfolio of about 5000 customers, these costs are in the range of 427 500 €/year, i.e. about 85.5 €/EV customer.
- Amortisation of radio-frequency identification (RFID) card: RFID card costs are about 20 €/card (including handling and delivery) [D9.4] and, although, card lifetime might be about 20 years, a shorter replacement period can be envisaged (about 5 years). Considering a 5% discount rate, the annual amortisation costs are calculated as follows:

$$Annual\ RFID\ card\ amortisation = \frac{20}{\frac{(1+5\%)^5-1}{5\% * (1+5\%)^5}} = 4.62\ €/year$$

Therefore, annual costs for an EVSP with 5000 customers can be calculated as:

$$\begin{aligned} &Annual\ EVSP\ costs \\ &\quad = Fixed\ cost\ of\ accessing\ the\ marketplace \\ &\quad + Cost\ of\ accessing\ the\ marketplace\ for\ the\ number\ of\ EV\ customers \\ &\quad + Staff\ and\ overhead\ costs + RFID\ card\ amortisation\ cost \\ &\quad = 2000€ + 25\ 000€ + 427\ 500€ + 4.62€ * 5000 = 477\ 600\ € \end{aligned}$$

This amount results in 95.52 €/EV customer which, adding 21% VAT, leads to a subscription price of 115.58 €/year. As a result, the subscription price is assumed to be 120 €/year (10 €/month).

On the other hand, variable costs are passed through directly to EV customers, who must, however, pay the value added tax (VAT) and therefore the EV charging price they pay is slightly higher than charging service price requested by the EVSE Operator.

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[11] Internet costs for small and medium enterprises are in the range of 25-50 €/month, http://www.movistar.es/empresas/ [access in February 2015]. For 5000 EV customers, this is less than 0.12 €/year per EV customer.

2.5.4 EV customers

EV customers also have some fixed and some variable costs, which depend on vehicle usage. In order to compare the total cost of ownership (TCO) for an EV and for an equivalent ICE vehicle, the same usage (annual mileage) and investment decisions (expected vehicle lifetime and discount rate) are considered. In the most general case, fixed costs include the following ones[12]:

- Vehicle amortisation cost: This cost depends, among others, on the type (*T*) of vehicle to be considered (EVs and gasoline and diesel ICE vehicles). Assuming a lifetime of 12 years and a discount rate of 7%, annual amortisation costs can be calculated as:

$$Vehicle\ amortisation\ cost_T = \frac{Vehicle\ price_T}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}}$$

- EVSP subscription price (*S*): As calculated in section 2.5.3 above, S=120 €/year.
- EVSE amortisation cost: This cost is only relevant in the case of private home charging service. Following the same assumptions as for the rest of EVSE Operators (see section 2.5.3 above), the annual amortisation of an investment $EVSE_{Inv}$ results in:

$$EVSE\ amortisation\ cost = \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}}$$

- Annual EVSE O&M costs ($EVSE_{O\&M}$) including communications (EVSE-EVSE backend and EVSE backend upstream): This cost is only relevant in the case of private home charging..

On the other hand, variable costs in the more general case for EV customers are the following ones:

- Fuel cost: This cost depends on the type of vehicle (*T*) and can be obtained by multiplying the target fuel consumption (FC_T) and the fuel prices (FP_T) by the annual mileage to be considered (*K*):

$$Fuel\ cost_T = FC_T * FP_T * K$$

- O&M cost: This cost also depends on the type of vehicle (*T*) and which are calculated by multiplying the O&M costs per kilometre (OM_T) by the annual mileage:

$$O\&M\ cost_T = OM_T * K$$

- EV charging cost: EV customers may use different types of charging services, so their annual EV charging cost depends on the EV charging cost in each service *i*, which is calculated by multiplying the number of times that EV customers use each service per year (U_i) by the EV charging price. As discussed in section 2.5.3, EV charging price is obtained by adding VAT to the charging service price requested by the EVSE Operator (CP_i). Therefore, EV charging cost is calculated as:

[12] Some other costs, like insurance, car vehicle tax… depend on many other parameters (e.g. insurance cost may depend on the coverage, age, gender, number of accidents in previous years…; car vehicle tax may depend on either engine size or fuel type and CO2 emissions, age, location…). It is not the aim of this analysis to enter into such details, so they are not included in this assessment.

$$EV\ charging\ cost = \sum_{i=1}^{4} U_i * CP_i * (1 + VAT)$$

By adding up the different cost components, the TCO for each type of vehicle can be calculated:

$$TCO = \frac{Vehicle\ price_T}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + S + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + (FC_T * FP_T * K) + (OM_T * K) + \sum_{i=1}^{4} U_i * CP_i * (1 + VAT)$$

Subscription price and costs related to private home EVSE (amortisation and O&M) only apply to EVs. Likewise, EV charging cost is only related to EVs, but ICE vehicles have the fuel cost. By taking the target fuel consumptions (FC_T) established by the EU legislation[13] and the O&M costs in [D9.6], the different TCOs become:

$$TCO_{EV} = \frac{Vehicle\ price_{EV}}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + S + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + (0.011€/km * K) + \sum_{i=1}^{4} U_i * CP_i * (1 + VAT)$$

$$TCO_{Gasoline} = \frac{Vehicle\ price_{Gasoline}}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + \left(\frac{5.6}{100} l/km * FP_{Gasoline} * K\right) + (0.033€/km * K)$$

$$TCO_{Diesel} = \frac{Vehicle\ price_{Diesel}}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + \left(\frac{4.9}{100} l/km * FP_{Diesel} * K\right) + (0.036€/km * K)$$

(5)

Private home charging is expected to be the preferred charging option by those EV customers who can charge their EVs at home [Nissan 2015, 1], while public charging spot for street side parking is likely to be the most used alternative for those EV customers without access to private home charging. As a result, the impact of these charging services in EV customers' TCO is higher and, thus, both fixed and variable costs must be included in the analysis.

On the contrary, traffic hotspot charging and highway charging are expected to be used quite seldom by EV customers and, hence, they are not likely to have a big impact on their TCO. Therefore, instead of looking at the whole TCO, the relative costs of an equivalent trip for EV customers and for drivers of ICE vehicles are compared. EV cost is lower when the following condition is met:

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

The distance that EV customers are able to drive after they charge their EV depends on the amount of energy charged (*Ei*) and on the efficiency of the trip (*EFi*):

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

[13] http://ec.europa.eu/clima/policies/transport/vehicles/cars/ [access in February 2015].

Therefore, EVs are competitive with gasoline and/or diesel vehicles if the following conditions are met:

$$For\ gasoline:\ \left(0.011\ €/km * \frac{Ei}{EFi}\right) + CP_i * (1 + VAT) \leq \left(\frac{5.6\ l}{100\ km} * FP_{Gasoline} * \frac{Ei}{EFi}\right) + \left(0.033\ €/km * \frac{Ei}{EFi}\right)$$

$$For\ diesel:\ \left(0.011\ €/km * \frac{Ei}{EFi}\right) + CP_i * (1 + VAT) \leq \left(\frac{4.9\ l}{100\ km} * FP_{Diesel} * \frac{Ei}{EFi}\right) + \left(0.036\ €/km * \frac{Ei}{EFi}\right)$$

Then, the maximum charging service price that EVSE Operators can request and which makes EVs competitive against ICE vehicles is calculated as:

$$For\ gasoline:\ CP_i \leq \left(\frac{5.6 * FP_{Gasoline}}{100} + 0.022\right) * \frac{Ei}{EFi * (1 + VAT)}$$

$$For\ diesel:\ CP_i \leq \left(\frac{4.9 * FP_{Diesel}}{100} + 0.025\right) * \frac{Ei}{EFi * (1 + VAT)}$$

(6)

As in the case of the electricity bill structure (see section 2.5.2.1), the prices for vehicle purchase and for fossil fuels are different across Europe. Again, the prices for Spain (base case), Germany and the Netherlands are considered.

2.5.4.1 Spain

Vehicle purchase cost strongly depends on the type of vehicle, brand and model. The best-seller EVs in Spain are Nissan Leaf, BMW i3 and Renault Zoe [Baeza 2014], which fall into three different car categories (C-segment medium cars, A-segment mini cars and B-segment small cars). If B-segment is taken as a typical EV category, best-sellers in this category are Seat Ibiza, Volkswagen Polo and Opel Corsa [Aniacam 2015]. Despite the difficulties in comparing different models, the average price for the gasoline version (5 doors, 75 CV) is about 12 000 €[14] and the diesel version is about 13 800 €, which is in line with the 1900 € difference assumed in [D9.6]. Both prices include a PIVE-6 plan subsidy of 2000 €[15]. Regarding EVs, the main price difference between EVs and gasoline ICE vehicles is battery cost, which is about 11 000 € (optimistic scenario forecast for 2015 in [D9.6]). EVs have an additional MOVELE plan subsidy of 6500 €[16], which leaves an extra cost for the EV of about 4500 €, i.e. about 16 500 €.

On the other hand, gasoline fuel costs are 1.438 €/l and diesel fuel cost 1.331 €/l [MINETUR 2014]. Therefore, equations (5) become:

$$TCO_{Gasoline} = \frac{12\ 000\ €}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + \left(\frac{5.6}{100} l/km * 1.438\ €/l * K\right) + 0.033\ €/km * K \sim 1511 + 0.113528 * K$$

$$TCO_{Diesel} = \frac{13\ 800\ €}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + \left(\frac{4.9}{100} l/km * 1.331\ €/l * K\right) + 0.036\ €/km * K \sim 1738 + 0.101219 * K$$

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[14] http://www.seat.es/, http://www.volkswagen.es, http://www.opel.es/ [access in January 2015].

[15] In 2014, all efficient passenger cars (EVs and ICE cars) could ask for a 2000 € discount in Spain ([BOE-A-2014-6684]).

[16] The 6500 € subsidy in Plan MOVELE [BOE-A-2014-6176] can be combined with the 2000 € subsidy in Plan PIVE-6 (see footnote 15). The budget for Plan MOVELE was completely requested in 2014 for the first time since 2009. The conditions for 2015 are still unknown.

$$TCO_{EV} = \frac{16\,500\ €}{\frac{(1+7\%)^{12}-1}{7\%*(1+7\%)^{12}}} + 120\ € + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\%*(1+7\%)^{7.5}}} + EVSE_{O\&M} + (0.011\ €/km * K) + \sum_{i=1}^{4} U_i * CP_i * (1+VAT) \sim 2198 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\%*(1+7\%)^{7.5}}} + EVSE_{O\&M} + \sum_{i=1}^{4} U_i * CP_i * (1+VAT)$$

(7)

When the relative cost for EV customers of the charging event is compared with refuelling cost of an equivalent trip with an ICE vehicle (traffic hotspot and highway charging services), equations (6) result:

$$For\ gasoline: CP_i \le \frac{Ei}{EFi} * 0.084733\ €/km$$

$$For\ diesel: CP_i \le \frac{Ei}{EFi} * 0.074561\ €/km$$

(8)

2.5.4.2 Germany

Performing the same market survey as in Spain, the average price for the gasoline version of the models considered (Seat Ibiza, Volkswagen Polo and Opel Corsa) is about 13 150 €, and the diesel version is about 2400 € more expensive on average (15 550 €). There are no direct subsidies for EV purchase in Germany, so, assuming the same difference as in Spain (11 000 €), EVs would cost 24 150 €.

Fuel costs in Germany are 1.586 €/l and 1.384 €/l for gasoline and diesel, respectively [MINETUR 2014], which make equations (5) and (6):

$$TCO_{Gasoline} = \frac{13\,150\ €}{\frac{(1+7\%)^{12}-1}{7\%*(1+7\%)^{12}}} + \left(\frac{5.6}{100} l/km * 1.586 €/l * K\right) + 0.033\ €/km * K \sim 1656 + 0.121816 * K$$

$$TCO_{Diesel} = \frac{15\,550\ €}{\frac{(1+7\%)^{12}-1}{7\%*(1+7\%)^{12}}} + \left(\frac{4.9}{100} l/km * 1.384\ €/l * K\right) + 0.036\ €/km * K \sim 1958 + 0.103816 * K$$

$$TCO_{EV} = \frac{24\,150\ €}{\frac{(1+7\%)^{12}-1}{7\%*(1+7\%)^{12}}} + 120\ € + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\%*(1+7\%)^{7.5}}} + EVSE_{O\&M} + (0.011\ €/km * K) + \sum_{i=1}^{4} U_i * CP_i * (1+VAT) \sim 3161 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\%*(1+7\%)^{7.5}}} + EVSE_{O\&M} + \sum_{i=1}^{4} U_i * CP_i * (1+VAT)$$

(9)

$$For\ gasoline: CP_i \leq \frac{Ei}{EFi} * 0.093123\ €/km$$

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.077997\ €/km$$

(10)

2.5.4.3 The Netherlands

By looking at the prices of the models considered in the other two countries, ICE car prices (both gasoline and diesel) in the Netherlands are about 3000 € more expensive than in Germany. Again, there are no direct subsidies for EV purchase in the Netherlands, so, EVs are assumed to be 11 000 € more expensive than gasoline ICE vehicles.

Fuel costs in the Netherlands are 1.753 €/l and 1.433 €/l for gasoline and diesel, respectively [MINETUR 2014], which make equations (5) and (6):

$$TCO_{Gasoline} = \frac{16\,150\ €}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + \left(\frac{5.6}{100} l/km * 1.753€/l * K\right) + 0.033\ €/km * K \sim 2033 + 0.131168 * K$$

$$TCO_{Diesel} = \frac{18\,550\ €}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + \left(\frac{4.9}{100} l/km * 1.433\ €/l * K\right) + 0.036\ €/km * K \sim 2335 + 0.106217 * K$$

$$TCO_{EV} = \frac{27\,150\ €}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + 120\ € + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + (0.011\ €/km * K) + \sum_{i=1}^{4} U_i * CP_i * (1+VAT) \sim 3538 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + \sum_{i=1}^{4} U_i * CP_i * (1+VAT)$$

(11)

$$For\ gasoline: CP_i \leq \frac{Ei}{EFi} * 0.099312\ €/km$$

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.078692\ €/km$$

(12)

3 Traffic hotspot charging service

This charging service is used by EV customers when they charge at a publicly accessible EVSE on private domain and which is located in a traffic hotspot, either because it is a point of interest or a much frequented place. Being a traffic hotspot, it is very likely that such a place already has a big demand for parking and, hence, it is assumed that there is an already existing direct payment system. As a result, the traffic hotspot operator is at the same time the EVSE Operator and the EVSP (no roaming required and, thus, no marketplace). The effect of these assumptions is assessed in section 3.2.4.

The charging speed is assumed to be semi-fast (22 kW, although it could also charge at 11 kW if needed) and the EVSE is assumed to have two outlets. One single EVSE is assumed[17].

The maximum amount of energy to be charged by an EV is obtained as 70% of the battery size, from an initial state of charge (SOC) of 30% to a maximum SOC of 100% [NPE 2010].

Table 4 below presents the sizes of the batteries of some pure EVs sold by the OEMs in the Green eMotion project consortium:

EV model	Battery size (kWh)	Range (km)	Consumption (Wh/km)
BMW i3	18.8	160	118
Nissan Leaf	24	199	121
Renault Zoe	22	210	105
Smart (fortwo) Electric Drive	17	140	121

Table 4: Battery sizes and ranges of the EVs sold by OEMs in Green eMotion[18]

Therefore, the maximum amount of energy to be charged would be between 11.90 kWh and 16.8 kWh per session (70% of 17 kWh and 24 kWh, respectively). The amount of energy to be charged in an average traffic hotspot charging event depends on the primary use of the traffic hotspot (football stadium, museum, airport, train station…).

Moreover, plug-in hybrid vehicles may also use this charging service, but their batteries have usually lower capacities. In order to consider all the aspects, 10 kWh per charging session is considered for the average charging session in the traffic hotspot.

Based on the data in Table 4, EV efficiency can be calculated by dividing the battery size by the driving range. Except Renault Zoe (who has a lower consumption), the other three EVs have a consumption in the range of 120 Wh/km, so that is the efficiency considered.

3.1 Base case

In this service, the relative cost for EV customers of the charging event must be compared with refuelling cost of an equivalent trip with an ICE vehicle and, hence, equations (8) are used.

Table 5 presents the different parameters to be used in equations (1) and (8):

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[17] As there is no need to connect to the marketplace, results can be obtained on a per EVSE basis (see equation (1)) and, hence, the total number of EVSE does not affect them.

[18] http://goelectricstations.com/electric-cars.html [access in February 2015].

Parameter	Value	Unit	Reference
P	2*22	kW	Scenario description
E	10	kWh	
EF	120	Wh/km	
N	1	EVSE	
VAT	0	%	EVSE Operator is not the final customer
MP_{EVSEO}	0	€/year	No marketplace required
Tp	6.832399	€/kW/month	[Endesa 2014]
Te_1	0.122383	€/kWh	
Te_2	0.096216	€/kWh	
Te_3	0.065923	€/kWh	
M	1.36	€/month	[BOE-A-2011-14782]
$EVSE_{Inv}$	10 500	€/EVSE	[NPE 2014]
$EVSE_{O\&M}$	1 725	€/EVSE/year	

Table 5: Values for the parameters in the Traffic Hotspot charging service (base case)

The maximum charging service price to be requested by the EVSE Operator so that EV customers have a mileage cost which is competitive against ICE vehicles is calculated by using equations (8):

$$For\ gasoline: CP_i \leq \frac{Ei}{EFi} * 0.084733\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.084733\ €/km = 7.0611\ €/session$$

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.074561\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.074561\ €/km = 6.2134\ €/session$$

Therefore, by adding 21% VAT, the maximum EV charging prices for EV customers to have a competitive mileage cost with gasoline and diesel are 8.54 € and 7.52 € per charging session, respectively.

The costs for the EVSE Operator are obtained by using equation (1):

$$Annual\ EVSE\ Operator's\ costs\ in\ Spain$$
$$= \left\{ \left[\left(\langle \{ (P * Tp * 12) + [(23\% * Te_1 + 66\% * Te_2 + 11\% * Te_3) * E * C] \} * (1 + 5.1127\%) \rangle + (M * 12) \right) * (1 + VAT) \right] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N + MP_{EVSEO}$$
$$= \left\{ \left[\left(\langle \{ (44 * 6.832399 * 12) + [(23\% * 0.122383 + 66\% * 0.096216 + 11\% * 0.065923) * 10 * C] \} * (1 + 5.1127\%) \rangle + (1.36 * 12) \right) * (1 + 0\%) \right] + \frac{10\ 500}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + 1\ 725 \right\} * 1 + 0 = 7380.16 + 1.0396 * C$$

The incomes for the EVSE Operator are obtained by using equation (4):

$$Annual\ EVSE\ Operator's\ incomes = (CP * C * N) + OS = (CP * C * 1) + OS$$

If no additional sources of income are considered (OS=0), the minimum number of charging sessions per EVSE to have a positive result (income > cost) can be calculated by:

$$(Gasoline)\ 7.0611 * C = 7380.16 + 1.0396 * C \Leftrightarrow C \sim 1226\ sessions/year \Rightarrow 3.36\ sessions/day$$

$$(Diesel)\ 6.2134 * C = 7380.16 + 1.0396 * C \Leftrightarrow C \sim 1427\ sessions/year \Longrightarrow 3.91\ sessions/day$$

(13)

This means that, if each EVSE installed for traffic hotspot charging by an EVSE Operator is used to charge more than 3.91 (3.36) times per day on average, i.e. 1.96 (1.68) charging sessions per outlet and per day, there is room for a pricing strategy that allows the EVSE Operator to recover its costs and still offer a competitive mileage cost for EV customers in comparison with diesel (gasoline) ICE cars. If there are enough EVs on the road, this target usage does not seem to be very difficult to reach in a traffic hotspot.

For lower usage rates, the EVSE Operator will still be able to offer competitive prices to EV customers if other sources of revenue are found. There are a number of alternatives to get these additional revenues, although the best candidate seems to be the use of the EVSE for advertisement purposes. Out of the all alternatives for advertising existing at the moment, the one with the shape closer to an EVSE is the phone booth. The same price applies to phone booths of 60x140 cm, 110x80 cm and 45x250 cm surfaces, which are close to the dimensions of EVSE available in the market (e.g. 53x190 cm [ABB 2014], 80x200 cm [Efacec 2014]), so the same price as for phone booths is assumed for EVSE adverstising. Depending on the phone booth location and the actual advertising surface, its price can range between about 4000 € (in small cities, with the regular advertising surface) and almost 10 000 € (in Madrid, Barcelona and Seville for “integral” surfaces in the four sides of the booth)[19]. In traffic hotspots and taking into account the added-value of being advertised in an EVSE (innovation, sustainability…), it is quite likely that the EVSE Operator can negotiate quite good conditions for advertising.

In case the EVSE Operator obtains incomes for advertising in the upper range (OS=10 000 €/year per EVSE), such amount would be enough to pay for all the costs of the EVSE, even if it is never used (7380.16 €/year).

In the lower range (OS=4000 €/year per EVSE), it would still need to recover part of the fixed costs (about 3380.16 €/year) and the variable costs per charging session. Then, C is calculated as:

$$(Gasoline)\ 7.0611 * C + 4000 = 7380.16 + 1.0396 * C \Leftrightarrow C \sim 562\ sessions/year \Longrightarrow 1.54\ sessions/day$$

$$(Diesel)\ 6.2134 * C + 4000 = 7380.16 + 1.0396 * C \Leftrightarrow C \sim 654\ sessions/year \Longrightarrow 1.79\ sessions/day$$

Therefore, less than 1 charging session per outlet and per day is required to offer competitive prices to EV customers when the EVSE has an income from advertising, which is even more likely to happen in traffic hotspots.

Due to the importance of having several charging sessions per day, the billing scheme must be carefully designed. A billing scheme which only considers time is not likely to be accepted by EV customers, as the price would result too high:

$$EV\ charging\ price_{Time} = CP * (1 + VAT) * \frac{P/2}{E}$$

[19] http://www.oblicua.es/publicidad-exterior/publicidad-cabinas-telefonicas.htm [access in February 2015].

$$(Gasoline)\ EV\ charging\ price_{Time} = 7.0611\ €/session * (1 + 21\%) * \frac{22\ kW}{10\ kWh/session} = 18.80\ €/h$$

$$(Diesel)\ EV\ charging\ price_{Time} = 6.2134\ €/session * (1 + 21\%) * \frac{22\ kW}{10\ kWh/session} = 16.54\ €/h$$

An alternative is to charge per electricity consumption while charging and combine it with a time-based tariff for the rest of the time that the EV is connected to the EVSE. The price while charging would be:

$$EV\ charging\ price_{kWh} = \frac{CP * (1 + VAT)}{E}$$

$$(Gasoline)\ EV\ charging\ price_{kWh} = \frac{7.0611\ €/session * (1 + 21\%)}{10\ kWh/session} = 0.8544\ €/kWh$$

$$(Diesel)\ EV\ charging\ price_{kWh} = \frac{6.2134\ €/session * (1 + 21\%)}{10\ kWh/session} = 0.7518\ €/kWh$$

The time-based tariff should be designed so that it is attractive enough for EV customers to use the traffic hotspot EVSE for charging their EVs, but it also prevents them from being connected to the EVSE for too long. This time-based tariff could be on top of the regular parking tariff of the traffic hotspot (i.e. only for EVs) or it could be socialised among all the users of the traffic hotspot parking space.

3.2 Sensitivity analysis

3.2.1 EVSE amortisation

The EVSE investment cost and the EVSE lifetime data are taken from the latest NPE report [NPE 2014] and are valid for 2013. Although there might be cases where EVSE investment costs are higher (e.g. situations in which the distribution grid must be strongly reinforced, or places where more complicated civil works are needed), future prices are expected to decline. Likewise, future EVSE is expected to last longer (even if there might be cases where lifetime is reduced by e.g. vandalism).

As the base case for the traffic hotspot charging service already presents quite good conditions for a positive business case and the conditions for EVSE amortisation are expected to improve, no sensitivity analysis is performed on this parameter.

3.2.2 Battery size

The battery size considered in the base case is based on existing EVs (see Table 4). However, this size is expected to increase in the future to allow EVs to drive a longer range[20]. The impact of battery size is mainly in the average energy to be recharged per charging session: as batteries increase in size, EV customers request more energy per charge, but they also charge less often. If, for example, an average of 20 kWh per charging session is assumed (E=20 kWh), maximum CP doubles:

$$For\ gasoline{:}\ CP_i \le \frac{Ei}{EFi} * 0.084733\ €/km = \frac{20\ kWh}{120\ Wh/km} * 0.084733\ €/km = 14.1222\ €/session$$

$$For\ diesel{:}\ CP_i \le \frac{Ei}{EFi} * 0.074561\ €/km = \frac{20\ kWh}{120\ Wh/km} * 0.074561\ €/km = 12.4268\ €/session$$

[20] Green eMotion partners expect the possibility to have 40 kWh-battery EVs in the market as early as in 2016 and battery sizes of up to 80 kWh are expected for longer term.

However, EVSE Operator's variable costs double too:

$$[(23\% * 0.122383 + 66\% * 0.096216 + 11\% * 0.065923) * 20 * C] * (1 + 5.1127\%) = 2.0792 * C$$

Therefore, in the case of diesel vehicles (the effect is the same for gasoline), C can be calculated as:

$$12.4268 * C = 7380.16 + 2.0792 * C \Leftrightarrow 2 * 6.2134 * C = 7380.16 + 2 * 1.0396 * C \Leftrightarrow C = 713.2 \sim 714\ charging\ sessions\ per\ year$$

As a result, if the energy demand per charging session is doubled, the required EVSE usage rate is halved. As demonstrated in the formula above, this ratio is linear, so if battery size is 80 kWh and 40 kWh are charged on average, 357 charging sessions per EVSE and per year would be needed, i.e. about 1 charging session per day.

Taking into account that bigger battery sizes will allow EV customers charge less frequently, the battery size seems to be a non-critical parameter on EVSE Operator's business model. What really affects the business case is EV customer behaviour, that is, whether EV customers with bigger batteries would use traffic hotspots to charge their vehicles more often (as EV customers gain more confidence in EVs and, hence, more EVs are sold and each of them is used more frequently) or more seldom (even if the EV market and usage increases, most EV customers use private home charging for satisfying their mobility needs).

3.2.3 EV efficiency

The EV efficiency considered in the base case is based on the calculated efficiencies of EVs in Table 4. However, these efficiencies are better than the official efficiencies by EV manufacturers when available (Nissan Leaf's official efficiency is 150 Wh/km [Nissan 2015, 2] and BMW i3's efficiency 129 Wh/km[21]). At lower efficiencies, the driving range with the same 10 kWh charging session is reduced, which affects the maximum allowable CP to compete with ICE. By considering 150 Wh/km and in the worst case (diesel):

$$CP_{Traffic\ hotspot} \leq \frac{10\ kWh}{150\ Wh/km} * 0.074561\ €/km = 4.971\ €/charging\ session$$

In this case, by calculating C:

$$4.971 * C = 7380.16 + 1.0396 * C \Leftrightarrow C = 1877.36 \sim 1878\ charging\ sessions\ per\ year$$

Under these conditions, more than 5.14 charging sessions per EVSE and per day on average are required for the EVSE Operator to offer competitive prices to EV customers.

As in the case of the battery size, two opposite effects happen at the same time when EV efficiency is lower (higher consumption) and, hence, driving range is reduced. On the one hand, a lower driving range results in a higher mileage cost and, hence, the price per charging session needs to be lower to be able to compete with ICE vehicles, which only happens when EVSE are used more frequently. On the other hand, as driving range decreases, EV customers need to charge more often, which results in a more frequent EVSE usage.

Again, the important aspect is EV customer behaviour, since lower efficiencies may lead to more (if efficiency does not impact EV market development and EV customers use traffic hotspots to charge their vehicles as an additional resource to private home charging) or less frequent usages of EVSE (if EV customers are more reluctant to buy an EV for their lower driving range).

[21] http://www.bmw.com/com/en/newvehicles/i/i3/2013/showroom/technical_data.html [access in February 2015].

3.2.4 Additional costs for the EVSE Operator

In a traffic hotspot, it is quite likely that EVSE operation is not the main business for the EVSE operator. Therefore, it is quite likely that the assumption of outsourcing EVSE operation is fulfilled (see footnote 7) and, hence, no additional staff costs are needed for operating the EVSE.

Likewise, the assumption of having a traffic hotspot operator who performs the EVSP and the EVSE Operator roles, by means of an existing direct payment system, is quite sensible. This assumption removes the need for having a connection to a marketplace. Even if the direct payment system does not exist, its cost is around 400 €[22] i.e., for a 7.5 years lifetime and a 7% discount rate, about 70.36 €/EVSE and per year. In this case, the required usage rate for EVSE Operators to offer competitive prices to EV customers against ICE vehicles is:

$$(Gasoline)\ 7.0611 * C = 7380.16 + 70.36 + 1.0396 * C \Leftrightarrow C \sim 1238\ sessions/year \Rightarrow 3.39\ sessions/day$$

$$(Diesel)\ 6.2134 * C = 7380.16 + 70.36 + 1.0396 * C \Leftrightarrow C \sim 1441\ sessions/year \Longrightarrow 3.95\ sessions/day$$

Therefore, the impact is just about 12-14 charging sessions per year and per EVSE more in this case, i.e. about 1 charging session more per EVSE and per month, compared to the base case, which is not significant.

On the other hand, if it is assumed that, instead of acting as an EVSP too, the traffic hotspot EVSE Operator offers access to other EVSPs through the marketplace, the additional costs to be considered are the ones calculated in section 2.5.1, i.e. 2000 €/year.

In this case, the required EVSE usage rate so that the traffic hotspot operator offers competitive prices to EV customers is calculated as follows:

$$(Gasoline)\ 7.0611 * C = 7380.16 + 2000 + 1.0396 * C \Leftrightarrow C \sim 1558\ sessions/year \Rightarrow 4.26\ sessions/day$$

$$(Diesel)\ 6.2134 * C = 7380.16 + 2000 + 1.0396 * C \Leftrightarrow C \sim 1813\ sessions/year \Longrightarrow 4.97\ sessions/day$$

The increase in this case is about 1 more charging session per day, so the effect is more evident. However, if there are two or more EVSE in the traffic hotspot, the additional cost of accessing the marketplace can be divided among all of them. For example, for 3 EVSE, the required usage rate is reduced to:

$$(Gasoline)\ 7.0611 * C = 7380.16 + \frac{2000}{3} + 1.0396 * C \Leftrightarrow C \sim 1336\ sessions/year \Rightarrow 3.66\ sessions/day$$

$$(Diesel)\ 6.2134 * C = 7380.16 + \frac{2000}{3} + 1.0396 * C \Leftrightarrow C \sim 1555\ sessions/year \Longrightarrow 4.26\ sessions/day$$

This is about one more charging session every three days than in the base case.

3.2.5 Other countries

As discussed in section 2.5, the differences that may arise between different EU Member States are assessed by calculating the results for Spain (base case), Germany and the Netherlands. In the traffic hotspot charging service, the differences in the electricity bill structure and in the fossil fuel prices are considered to be relevant.

[22] Estimation of Green eMotion partners

3.2.5.1 Germany

The main parameters to be used for the economic assessment of the traffic hotspot EVSE Operator in Germany are listed in Table 6.

Parameter	Value	Unit	Reference
E	10	kWh	Scenario description
EF	120	Wh/km	
N	1	EVSE	
VAT	0	%	EVSE Operator is not the final customer
MP_{EVSEO}	0	€/year	No marketplace required
Te	0.25	€/kWh	Data provided by RWE
M	8.60	€/month	
$EVSE_{Inv}$	10 500	€/EVSE	[NPE 2014]
$EVSE_{O\&M}$	1 725	€/EVSE/year	

Table 6: Values for the parameters in the Traffic Hotspot charging service (Germany)

The maximum charging service price to be requested by a German traffic hotspot EVSE Operator so that EV customers have a mileage cost which is competitive against ICE vehicles is calculated by using equations (10):

$$For\ gasoline: CP_i \leq \frac{Ei}{EFi} * 0.093123\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.093123\ €/km = 7.76025\ €/session$$

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.077997\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.077997\ €/km = 6.49975\ €/session$$

Therefore, by adding 19% VAT, the maximum EV charging prices for EV customers to have a competitive mileage cost with gasoline and diesel are 9.23 € and 7.73 € per charging session, respectively.

The costs for a traffic hotspot EVSE Operator in Germany are obtained by using equation (2):

$$Annual\ EVSE\ Operator's\ costs\ in\ Germany = \left\{ \left[\left((Te * E * C) + (M * 12) \right) * (1 + VAT) \right] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N + MP_{EVSEO}$$

$$= \left\{ \left[\left((0.25 * 10 * C) + (8.60 * 12) \right) * (1 + 0\%) \right] + \frac{10\,500}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + 1725 \right\} * 1 + 0$$

$$= 3675.10 + 2.50 * C$$

The incomes for the EVSE Operator are obtained by using equation (4):

$$Annual\ EVSE\ Operator's\ incomes = (CP * C * N) + OS = (CP * C * 1) + OS$$

If no additional sources of income are considered (OS=0), the minimum number of charging sessions per EVSE to have a positive result (income > cost) can be calculated as shown below, for both gasoline and diesel ICE vehicles:

$$(Gasoline)\ 7.76025 * C = 3675.10 + 2.50 * C \Leftrightarrow C \sim 699\ sessions/year \Rightarrow 1.92\ sessions/day$$

$$(Diesel)\ 6.49975 * C = 3675.10 + 2.50 * C \Leftrightarrow C \sim 919\ sessions/year \Longrightarrow 2.52\ sessions/day$$

This means that if each EVSE installed for traffic hotspot charging by an EVSE Operator are used to charge more than 2.52 (1.92) times per day on average, i.e. 1.26 (0.96) charging sessions per outlet and per day, there is room for a pricing strategy that allows the EVSE Operator recover its costs and still offer a competitive mileage cost for EV customers in comparison with diesel (gasoline) vehicles. If there are enough EVs on the road, this target usage does not seem to be very difficult to reach in a traffic hotspot, where vehicles are expected to drive very often.

Similarly, EVSEs not used at all cost EVSE Operators 3675 € per year, which is lowest annual price for advertising in phone booth in a Spanish city, so it is quite likely that a traffic hotspot in Germany can obtain more than that amount for advertising in an EVSE and, hence, that the EVSE Operator is able to offer an EV charging price which is competitive for EV customers (lower mileage cost than ICE vehicles), and still make a profit even with very low usage rates.

3.2.5.2 The Netherlands

The main parameters to be used in the assessment for the operation of traffic hotspot EVSE in the Netherlands are listed in Table 7. According to footnote 10, the traffic hotspot is assumed to be a manned parking garage, so it is considered to have a living or working function.

Parameter	Value	Unit	Reference
E	10	kWh	Scenario description
EF	120	Wh/km	
N	1	EVSE	
VAT	0	%	EVSE Operator is not the final customer
MP_{EVSEO}	0	€/year	No marketplace required
F	54	€/year	Prices for a three-phase, 80 A, connection[23]
Te	0.1874	€/kWh	
R	311.84	€/year	
P	1614.2855	€/year	Grid fees for a 3 x 80 A connection[24]
$EVSE_{Inv}$	10 500	€/EVSE	[NPE 2014]
$EVSE_{O\&M}$	1 725	€/EVSE/year	

Table 7: Values for the parameters in the Traffic Hotspot charging service (The Netherlands)

The costs for a traffic hotspot EVSE Operator in the Netherlands are obtained by using equation (3):

[23] http://www.nuon.nl/mkb/lightbox/tarieven-flexibel.jsp [access in February 2015].

[24] https://www.enexis.nl/consument/diensten-en-tarieven/tarieven/elektriciteit/periodieke-netwerktarieven-e?pageid=44 [access in February 2015].

$$Annual\ EVSE\ Operator's\ costs\ in\ the\ Netherlands = \left\{ [(F + P + (Te * E * C) - R) * (1 + VAT)] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N + MP_{EVSEO}$$

$$= [(54 + 1614.2855 + (0.1874 * 10 * C) - 311.84) * (1 + 0\%)] + \frac{10\,500}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + 1725$$

$$= 4928.31 + 1.874 * C$$

The incomes for the EVSE Operator are obtained by using equation (4):

$$Annual\ EVSE\ Operator's\ incomes = (CP * C * N) + OS = (CP * C * 1) + OS$$

If no additional sources of income are considered (OS=0), the minimum number of charging sessions per EVSE to have a positive result (income > cost) can be calculated by:

$$(Gasoline)\ 8.276 * C = 4928.31 + 1.874 * C \Leftrightarrow C \sim 771\ sessions/year \Rightarrow 2.11\ sessions/day$$

$$(Diesel)\ 6.55767 * C = 4928.31 + 1.874 * C \Leftrightarrow C \sim 1052\ sessions/year \Longrightarrow 2.88\ sessions/day$$

This means that the EVSE Operator needs to have each EVSE used more than 2.88 (2.11) times per day on average, i.e. 1.44 (1.06) charging sessions per outlet and per day, to recover its costs and still be able to offer a competitive mileage cost for EV customers in comparison with diesel (gasoline) vehicles.

These target usage rates are between the required usage in Germany and in Spain, so it does not seem to be very difficult to reach in a traffic hotspot if there are enough EVs on the road.

Again, advertising seems a good way to recover EVSE costs for lower usage rates. The prices for advertising in bus shelters in the Netherlands (about 105 €/week[25]) are similar to the ones in Spanish small cities (106 €/week in Girona[26]). Therefore, the incomes for advertising in the Netherlands are assumed to be the same as for Spain. If the EVSE Operator is able to negotiate a good price for advertising in its EVSE (even in the lower range of 4000 €), it can offer competitive EV charging prices to EV customers so that these have lower mileage costs than ICE vehicles even at low EVSE usage rates:

$$6.5577 * C + 4000 = 4928.31 + 1.874 * C \Leftrightarrow C = 198.20 \sim 199\ charging\ sessions\ per\ year$$

This is less than 0.55 charging sessions per EVSE and per day, i.e. about 2 uses per outlet per week, to be competitive against diesel vehicles. The required usage to compete against gasoline vehicles is even lower (about 0.40 usages per EVSE and per day).

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25 http://www.exterionmedia.com/nl/onze-mogelijkheden/onze-pakketten/landelijk-adverteren/ns-pakketten/ns-abri-pakket/ [access in February 2015].

26 http://www.oblicua.es/publicidad-exterior/mupis.htm [access in February 2015].

4 Highway charging service

This charging service represents the situation in which EV customers charge at a publicly accessible EVSE on private or public domain and which is located in a highway, most likely in an existing fuel filling station. The aim of this EVSE is to allow EV customers to have a fast (in general, more than 22 kW, being typically 50 kW DC or 43 kW AC) charging session, so that they can continue their trip.

Although direct payment may also be available[27], EV customers are assumed to use the roaming agreement of their EVSP with the highway EVSE Operator (through the marketplace) to be able to charge their EVs. Due to the initial stage of EV market, it is assumed that the filling station has only one EVSE.

In fast charging, there is some hysteresis effect when the battery is close to its full load, so it is only able to charge at fast speed until 80% of SOC [NPE 2010]. As the minimum SOC is considered to remain 30%, 50% of the battery charging is considered in this charging service.

The fast charging service is expected to be used to charge as much energy as possible (to allow for the longest driving range), so keeping the assumption of a 24 kWh battery (see Table 4), average charging session demand is 12 kWh.

Driving speed is expected to be higher in highways than in the rest of charging services, so the efficiency in this case is lower (EFI=150 Wh/km[28]), due to the effect of speed in efficiency [DOE 2014].

4.1 Base case

Table 8 presents the different parameters to be used in equations (1) and (8).

As in the traffic hotspot charging service, the relative cost for EV customers of the highway charging event must be compared with refuelling cost of an equivalent trip with an ICE vehicle. The maximum charging service price to be requested by the EVSE Operator so that EV customers have a mileage cost which is competitive against ICE vehicles is calculated by using equations (8):

$$For\ gasoline: CP_i \leq \frac{Ei}{EFi} * 0.084733\ €/km = \frac{12\ kWh}{150\ Wh/km} * 0.084733\ €/km = 6.77864\ €/session$$

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.074561\ €/km = \frac{12\ kWh}{150\ Wh/km} * 0.074561\ €/km = 5.96488\ €/session$$

Therefore, by adding 21% VAT, the maximum EV charging prices for EV customers to have a competitive mileage cost against gasoline and diesel are 8.20 € and 7.22 € per charging session, respectively.

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[27] In fact, “All recharging points accessible to the public shall also provide for the possibility for electric vehicle users to recharge on an ad hoc basis without entering into a contract with the electricity supplier or operator concerned” [OJ L307/1].

[28] This is Nissan Leaf’s consumption at 80 km/h [DOE 2014].

Parameter	Value	Unit	Reference
P	50	kW	Scenario description
E	12	kWh	
EF	150	Wh/km	
N	1	EVSE	
VAT	0	%	EVSE Operator is not the final customer
MP_{EVSEO}	2000	€/year	See section 2.5.1
Tp	6.832399	€/kW/month	[Endesa 2014]
Te_1	0.122383	€/kWh	
Te_2	0.096216	€/kWh	
Te_3	0.065923	€/kWh	
M	1.36	€/month	[BOE-A-2011-14782]
$EVSE_{Inv}$	27 150	€/EVSE	[NPE 2014]
$EVSE_{O\&M}$	3 075	€/EVSE/year	

Table 8: Values for the parameters in the Highway charging service (base case)

The costs and incomes for the EVSE Operator are obtained by using equations (1) and (4), respectively :

$$\begin{aligned} &Annual\ EVSE\ Operator's\ costs\ in\ Spain \\ &= \Big\{ [(\langle\{(P*Tp*12) + [(23\%*Te_1 + 66\%*Te_2 + 11\%*Te_3)*E*C]\}*(1+5.1127\%)\rangle \\ &+ (M*12)\rangle*(1+VAT)] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\%*(1+7\%)^{7.5}}} + EVSE_{O\&M}\Big\} * N + MP_{EVSEO} \\ &= \Big\{ [(\langle\{(50*6.832399*12) \\ &+ [(23\%*0.122383 + 66\%*0.096216 + 11\%*0.065923)*12*C]\}*(1+5.1127\%)\rangle \\ &+ (1.36*12)\rangle*(1+0\%)] + \frac{27\ 150}{\frac{(1+7\%)^{7.5}-1}{7\%*(1+7\%)^{7.5}}} + 3\ 075\Big\} * 1 + 2000 \\ &= 14175.89 + 1.24751 * C \end{aligned}$$

$$Annual\ EVSE\ Operator's\ incomes = (CP*C*N) + OS = (CP*C*1) + OS$$

If no additional sources of income are considered (OS=0), the minimum number of charging sessions per EVSE to have a positive result (income > cost) can be calculated by:

$$(Gasoline)\ 6.77864*C = 14175.89 + 1.24751*C \Leftrightarrow C \sim 2563\ sessions/year \Rightarrow 7.02\ sessions/day$$

$$(Diesel)\ 5.96488*C = 14175.89 + 1.24751*C \Leftrightarrow C \sim 3005\ sessions/year \Longrightarrow 8.23\ sessions/day \quad (14)$$

This means that the highway EVSE needs to be used to charge more than 8.23 (7.02) times per day on average, in order for the EVSE Operator to offer a competitive mileage cost for EV customers in comparison with diesel (gasoline) vehicles.

Even with a high penetration of EVs on the road, this target usage seems to be quite difficult to reach in a highway EVSE, especially considering that each charging sessions takes about 15 minutes (12 kWh / 50kW) to be completed, i.e. the EVSE must be in use about 4 hours per day on average. Taking into account that highway EVSEs are expected to be used with a strong seasonal component (used more often in summer and in weekends) and that the number of EVSE per filling station is likely to be dimensioned to satisfy peak demand, the average number of charging sessions per EVSE and per day is expected to be quite low, even if it can be increased with dual charging (see section 4.2.7).

Therefore, the EVSE Operator needs to look for additional sources of revenue. As in the traffic hotspot charging case, advertising seems to be a good option. In this case, however, the impact of the advertisement is expected to be lower than in the traffic hotspot, because, on the contrary to the advertisements in cities (as in the traffic hotspot case), highway advertisements need to have a big surface to be visible from the main track of the highway, which is not the case of EVSE located in a filling station or similar. Therefore, the price for advertising in highway EVSEs is likely to be lower than in the traffic hotspot case[29]. If the expected income is in the lower range of the advertisement options for phone booths (about 4000 €/year), the required EVSE usage to offer competitive prices to EV customers can be reduced to:

$$(Gasoline)\ 6.77864 * C + 4000 = 14175.89 + 1.24751 * C \Leftrightarrow C \sim 1840\ sessions/year \Rightarrow 5.04\ sessions/day$$

$$(Diesel)\ 5.96488 * C + 4000 = 14175.89 + 1.24751 * C \Leftrightarrow C \sim 2158\ sessions/year \Longrightarrow 5.91\ sessions/day$$

In the upper price ranges (about 10 000 €/year), just 2.07 and 2.43 charging sessions per EVSE and per day would be enough for the EVSE Operator to offer competitive prices against gasoline and diesel vehicles, respectively.

Another good alternative for the highway charging case is the attraction of clients to an existing shop or restaurant. A shop located in an existing filling station sells about 0.0421 € per litre customers fill in, leaving a commercial margin of about 30%[30]. Taking into account that the average Spanish driver fills in about 29.5 litres when they go to a filling station[31], the margin per filling is about 0.3726 €. However, highway EVSE need more time to charge the EV than filling pumps need to top up the tanks of ICE vehicles, so it is more likely that EV customers use that extra time to eat or drink in the restaurant or to buy something in the shop than drivers of ICE vehicles do [Deirdre 2014].

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[29] For example, the effect of the potential impact can be seen in the price difference for advertising in an airport and in rail stations in the Netherlands: the price for Schiphol airport is more than double the price in Dutch railways stations (250 € per face and per week, compared to 105 € per face and per week), http://www.exterionmedia.com/nl/onze-mogelijkheden/onze-pakketten/landelijk-adverteren/schiphol-pakket/ [access in February 2015].

[30] https://mundopetroleo.com/resources/repository/PARTICIPACIONES/Las_diferentes_cuentas_explotacion.pdf [access in February 2015].

[31] http://www.libertaddigital.com/economia/los-espanoles-echan-3-litros-menos-de-combustible-en-cada-repostaje-1276417460/ [access in February 2015].

Assuming an additional expenditure of 5 €/charging session (either in the shop or in the restaurant) on average, the extra income would be 1.50 €/charging session (30% margin). In this case, the required number of charging sessions to offer competitive prices with diesel vehicles (the same can be done for gasoline) is calculated according to:

$$5.96488 * C + Ad + 1.50 * C = 14175.89 + 1.24751 * C$$

Therefore, if the income from advertising (*Ad*) is:

- Ad = 0 €/year (no advertising) ➔ C = 2280 charging sessions/year ~ 6.25 sessions/day.
- Ad = 4000 €/year (lower price range) ➔ C = 1637 charging sessions/year ~ 4.48 sessions/day.
- Ad = 10 000 €/year (upper price range) ➔ C = 672 charging sessions/year ~ 1.84 sessions/day.

Based on these figures, it can be concluded that the highway EVSE Operator needs to obtain a good advertising contract and to be able to attract EV consumers to other businesses (shop/restaurant) close to the EVSE in order to be able to offer prices that make electric mobility competitive with traditional ICE vehicles (7.22-8.20 €/charging session) and have a profitable business case.

An additional constraint is that, on the contrary to existing filling stations, which are the only alternative for filling up ICE vehicles, highway charging is a complement of private home charging (for EV customers who can charge at home) and with public charging spot for street side parking (for EV customers who cannot) for long-distance trips. As EV customers can charge their vehicles (at a cheaper price) overnight, highway charging is expected to be mainly used by:

- Long-distance travellers: In general, they will use highway charging along their trip. They are likely to start their trip with a full battery, therefore, charging time is expected to take place in non-rush hours (around noon or early afternoon). This is a very good customer segment, as they will probably have lunch while charging and, hence, increase restaurant sales. On the contrary, they may take up the EVSE for more time than just charging time. Some kind of valet service might be required in this case.
- EV customers with high daily distance requirements (taxis, delivery fleets…): This customer segment is more likely to request the charging service quite spread throughout the day, although it will probably be more concentrated in the morning. It is also likely that they use filling stations located in roads or outside the city centre, rather than highway stations, so they may not fit well in this charging service. In addition, they may also have base stations where they will be able to charge at cheaper prices.
- EV customers that cannot charge overnight, either because they do not have access to home charging or because they cannot always find a free public charging spot. These EV customers are expected to charge in rush hours, either in the morning or in the evening. Morning users may use the restaurant for having breakfast, while evening users may use it for having a drink. Although they will take up the EVSE for a shorter time, compared to customers having lunch, a valet service may also be required for these customers.

Therefore, the profitability of the highway charging service is not as clear as the one in the traffic hotspot at the moment (with the present EV market, when there are more EVs on the road, it may be the opposite) and it is dependent on the types of EV customers it may serve to. Highway filling stations which can attract different types of EV customers (with different charging patterns, as discussed above, so that the EVSE have several usages along the day), in areas with enough EVs on the road and which can negotiate good prices for advertising, may have a positive business case.

In early stages of EVSE deployment, highway fast charging can also be used by the filling station owner for self-advertising purposes and, this way, attract more drivers of ICE vehicles to his/her fuel pumps, shops and restaurants.

In a highway EVSE, the billing scheme might be a time-based or an energy-based system, which may also offer different prices depending on the charging speed or type (AC vs. DC).

Due to the importance of having several charging sessions per day, the billing scheme must be carefully designed. A billing scheme which only considers time is not likely to be accepted by EV customers, as the price would result too high:

$$EV\ charging\ price_{Time} = CP * (1 + VAT) * \frac{P}{E}$$

$$(Gasoline)\ EV\ charging\ price_{Time} = 6.77864\ €/session * (1 + 21\%) * \frac{50\ kW}{12\ kWh/session} = 34.18\ €/h$$

$$(Diesel)\ EV\ charging\ price_{Time} = 5.96488\ €/session * (1 + 21\%) * \frac{50\ kW}{12\ kWh/session} = 30.07\ €/h$$

An alternative is to charge per electricity consumption while charging and combine it with a time-based tariff for the rest of the time that the EV is connected to the EVSE. The maximum price per kWh (so that EVs have a mileage cost competitive against ICE vehicles) can be calculated as follows:

$$EV\ charging\ price_{kWh} = \frac{CP * (1 + VAT)}{E}$$

$$(Gasoline)\ EV\ charging\ price_{kWh} = \frac{6.77864\ €/session * (1 + 21\%)}{12\ kWh/session} = 0.6835\ €/kWh$$

$$(Diesel)\ EV\ charging\ price_{kWh} = \frac{5.96488\ €/session * (1 + 21\%)}{12\ kWh/session} = 0.6015\ €/kWh$$

4.2 Sensitivity analysis

4.2.1 EVSE amortisation cost

The EVSE investment cost and the EVSE lifetime data are taken from the latest NPE report [NPE 2014], which are valid for 2013. Although there might be cases where EVSE investment costs are higher (e.g. situations in which the distribution grid must be strongly reinforced, or places where more complicated civil works are needed), future prices are expected to decline. Likewise, future EVSE is expected to last longer (even if there might be cases where lifetime is reduced by e.g. vandalism).

Therefore, under the assumptions of a 10% reduction in hardware costs (2000 €) and a lifetime extension to 10 years, the amortisation cost is reduced to:

$$Annual\ amortisation = \frac{25\,150\ €/EVSE}{\frac{(1 + 7\%)^{10} - 1}{7\% * (1 + 7\%)^{10}}} = 3580.79\ €/EVSE.year$$

This results in an annual amortisation cost about 1200 €/EVSE lower than in the base case, so the required EVSE usage to offer competitive prices to EV customers against diesel vehicles is also reduced to about 7.5 charging sessions per day, which is still too high:

$$5.96488 * C = 12981.14 + 1.24751 * C \Leftrightarrow C\sim 2752\ sessions/year \Longrightarrow 7.54\ sessions/day$$

Therefore, the EVSE Operator still needs to negotiate a good advertising contract (e.g. 4000 €/year) and to have an attached shop or restaurant, so that it can offer competitive prices under expected EVSE usage rates:

$$5.96488 * C + 4000 + 1.50 * C = 12981.14 + 1.24751 * C \Leftrightarrow C\sim 1445\ sessions/year \Longrightarrow 3.95\ sessions/day$$

4.2.2 Battery size

As discussed in the traffic hotspot case (see section 3.2.2), the battery size affects the amount of energy to be charged per session. Assuming again that the amount of energy to be charged per session is doubled (24 kWh), the maximum charging price that the EVSE Operator can request so that EV customers have a competitive mileage cost with ICE vehicles is also doubled:

$$For\ gasoline: CP_i \leq \frac{Ei}{EFi} * 0.084733\ €/km = \frac{24\ kWh}{150\ Wh/km} * 0.084733\ €/km = 13.5573\ €/session$$

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.074561\ €/km = \frac{24\ kWh}{150\ Wh/km} * 0.074561\ €/km = 11.9298\ €/session$$

EVSE Operator's variable costs also double to 2.49502 €/session, so the required amount of charging sessions for EVSE Operators to offer competitive prices against diesel vehicles is calculated according to the following formula:

$$11.9298 * C + Ad + Shop = 14175.89 + 2.49502 * C$$

For different incomes from advertisement (*Ad*) and shop/restaurant (*Shop*), the minimum average number of charging sessions per day is presented in Table 9 below.

	Shop = 0 €/session	Shop = 1.5 €/session
Ad = 0 €/year	4.12	3.55
Ad = 4000 €/year	2.95	2.55
Ad = 10 000 €/year	1.21	1.05

Table 9: Highway EVSE usage requirements for different co-financing alternatives (bigger battery size)

As a result, if battery size increases and, hence, the amount of electricity demanded per charging session, less frequent EVSE usage is needed for the EVSE Operator to be able to offer EV charging prices which make EV mileage cost competitive with ICE vehicles. On the contrary to the traffic hotspot case (where there was not clear whether battery size increase has a positive or a negative effect on the business case), an increase in EV battery size is expected to have a positive impact in the highway charging service, as the EV market is expected to grow, together with EV customers' confidence to make longer trips and, hence, use highway charging more often. Moreover, if bigger batteries are a good signal for EV customers to overcome range anxiety and help increase EV market, these usage rates could be obtained in more locations than in the base case.

However, unless charging power is also increased (e.g. 100 kW, which would lead to higher electricity bill and EVSE amortisation and O&M costs, although not double the price considered in the base case) charging time would reach almost half an hour. Therefore, the valet service seems a must in this case to allow for several charging sessions per day.

4.2.3 EV efficiency

Unless disruptive EV designs can be found to overcome air resistance, EV efficiency is not expected to be better than the one in the base case. Quite on the contrary, it is likely that existing EVs have lower efficiencies while driving at highway speed. If efficiency is 180 Wh/km (Nissan Leaf's consumption at about 100 km/h [DOE 2014]), a 12 kWh charging event provides a driving range of about 67 km. As a result, EV mileage cost rises (shorter distance travel with the same expenditure) and, thus, it needs lower EV charging prices to be competitive against ICE vehicles and, hence, more charging sessions per day:

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.074561\ €/km = \frac{12\ kWh}{180\ \frac{Wh}{km}} * 0.074561\ €/km = 4.9707\ €/session$$

$$4.9707 * C = 14175.89 + 1.24751 * C \Leftrightarrow C \sim 3808\ sessions/year \Longrightarrow 10.43\ sessions/day$$

Moreover, this lower EV efficiency (compared to the base case) may become an additional annoyance for EV customers. For a 100 km round-trip, EV customers would need to charge twice, even if they charged at home before departure.

However, if EV battery sizes increase (as discussed in subsection 4.2.2), it is likely that EVs are used more often for highway travelling, as the same 100 km round trip would require just one charging event (of about 30 minutes: 24 kWh/50 kW) if the battery is filled up at the beginning of the journey. If EV customers spend the 30-minute charging period having a meal at a cost of about 15 € on average (1.5 people per vehicle [EEA 2010] and about 10 €/person[32]), the benefit would be 4.50 €/charging session (30% of the expenditure). If, in addition, the EVSE Operator can obtain an advertising contract of e.g. 4000 €/EVSE per year, competitive prices can be offered to EV customers with:

$$4.9707 * C + 4.50 * C + 4000 = 14175.89 + 1.24751 * C \Leftrightarrow C \sim 1238\ sessions/year \Longrightarrow 3.39\ sessions/day$$

4.2.4 Additional costs for the EVSE Operator

As in the traffic hotspot charging service, no additional fixed costs for the highway EVSE operator are taken into account. In a highway filling station, shop or restaurant, EVSE operation is not the main business for the EVSE operator. Therefore, it is quite likely that the assumption of outsourcing EVSE operation is fulfilled (see footnote 7) and, hence, no additional staff costs is needed for operating the EVSE.

However, there might be additional costs for the valet service. Therefore, the EVSE Operator should assess whether the increased EVSE usage rate pays for the additional costs of the service.

4.2.5 Other countries

As discussed in section 2.5, the differences that may arise between different EU Member States are assessed by calculating the results for Spain (base case), Germany and the Netherlands.

4.2.5.1 Germany

The main parameters to be used in Germany are listed in Table 10.

Parameter	Value	Unit	Reference
E	12	kWh	Scenario description
EF	150	Wh/km	
N	1	EVSE	
VAT	0	%	EVSE Operator is not the final customer
MP_{EVSEO}	2000	€/year	See section 2.5.1
Te	0.25	€/kWh	Data provided by RWE
M	8.60	€/month	
$EVSE_{Inv}$	27 150	€/EVSE	[NPE 2014]
$EVSE_{O\&M}$	3 075	€/EVSE/year	

Table 10: Values for the parameters in the Highway charging service (Germany)

[32] http://www.numbeo.com/cost-of-living/country_result.jsp?country=Spain [access in February 2015].

The maximum charging service price to be requested by a German highway EVSE Operator so that EV customers have a mileage cost competitive against ICE vehicles is calculated by using equations (10):

$$For\ gasoline: CP_i \leq \frac{Ei}{EFi} * 0.093123\ €/km = \frac{12\ kWh}{150\ Wh/km} * 0.093123\ €/km = 7.44984\ €/session$$

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.077997\ €/km = \frac{12\ kWh}{150\ Wh/km} * 0.077997\ €/km = 6.23976\ €/session$$

Therefore, by adding 19% VAT, the maximum EV charging prices for EV customers to have a competitive mileage cost with gasoline and diesel vehicles are 8.87 € and 7.43 € per charging session, respectively. As in the case of Spain, the billing scheme might be a time-based or an energy-based system, which may also offer different prices depending on the charging speed or type (AC vs. DC).

The costs for a traffic hotspot EVSE Operator in Germany are obtained by using equation (2):

$$\begin{aligned} &Annual\ EVSE\ Operator's\ costs\ in\ Germany \\ &= \left\{ \left[\left((Te * E * C) + (M * 12) \right) * (1 + VAT) \right] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N \\ &+ MP_{EVSEO} \\ &= \left\{ \left[\left((0.25 * 12 * C) + (8.60 * 12) \right) * (1 + 0\%) \right] + \frac{27\ 150}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + 3075 \right\} * 1 + 2000 \\ &= 9953.74 + 3 * C \end{aligned}$$

The incomes for the EVSE Operator are obtained by using equation (4):

$$Annual\ EVSE\ Operator's\ incomes = (CP * C * N) + OS = (CP * C * 1) + OS$$

If no additional sources of income are considered (OS=0), the minimum number of charging sessions per EVSE to have a positive result (income > cost) can be calculated by:

$$(Gasoline)\ 7.44984 * C = 9953.74 + 3 * C \Leftrightarrow C \sim 2237\ sessions/year \Rightarrow 6.13\ sessions/day$$

$$(Diesel)\ 6.23976 * C = 9953.74 + 3 * C \Leftrightarrow C \sim 3073\ sessions/year \Longrightarrow 8.42\ sessions/day$$

This means that the highway EVSE needs to be used to charge more than 8.42 (6.13) times per day on average, in order for the EVSE Operator to offer a competitive mileage cost for EV customers in comparison with diesel (gasoline) vehicles. These figures are in line with the results for Spain (better for gasoline and slightly worse for diesel vehicles) so the EVSE Operator needs to look for additional sources of revenue. Again, advertising seems a good option for increasing EVSE incomes. If the prices for phone booth advertising in Spain are considered, the upper range (10 000 €/year per EVSE) would allow recovering all EVSE Operator's fixed costs, but, as discussed in section 4.1, the expected income in highway EVSE advertising is likely to be lower. In the lower range (4000 €/year per EVSE), the required EVSE usage to offer competitive prices to EV customers can be reduced to lower values:

$$(Gasoline)\ 7.44984 * C + 4000 = 9953.74 + 3 * C \Leftrightarrow C \sim 1338\ sessions/year \Rightarrow 3.67\ sessions/day$$

$$(Diesel)\ 6.23976 * C + 4000 = 9953.74 + 3 * C \Leftrightarrow C \sim 1838\ sessions/year \Longrightarrow 5.03\ sessions/day$$

On the other hand, the shop and restaurant business in Germany seems to be a growing market. In good locations, the turnover per filling station ranges between 94 000 €/year and 162 000 €/year [FS 2014]. Assuming the same 30% margin as in Spain, and considering 6-8 pumps per filling station, the benefit per pump is about 4700-6000 €. Without advertising incomes, this extra income reduces to the required EVSE usage to even more modest usage rates:

$$(Gasoline)\ 7.44984 * C + 6000 = 9953.74 + 3 * C \Leftrightarrow C \sim 889\ sessions/year \Rightarrow 2.43\ sessions/day$$

$$(Diesel)\ 6.23976 * C + 6000 = 9953.74 + 3 * C \Leftrightarrow C \sim 1221\ sessions/year \Longrightarrow 3.34\ sessions/day$$

If advertising is added to the income of shops and restaurants, it allows recovering all the fixed costs per EVSE, even in the lower advertising income range.

Although this EVSE usage rate is higher than in Spain, it is still low enough so that it can be reached in early stages of electric mobility deployment in areas with enough EVs on the road and where EV customers need to drive relatively long distances.

4.2.5.2 The Netherlands

A highway EVSE cannot be assumed to be used for living or working function, so there is no reduction in the electricity bill, as shown in Table 11, together with the rest of the parameters to be used in this analysis.

The maximum charging service price to be requested by the EVSE Operator so that Dutch EV customers have a mileage cost which is competitive against ICE vehicles is calculated by using equations (12):

$$For\ gasoline: CP_i \leq \frac{Ei}{EFi} * 0.093123\ €/km = \frac{12\ kWh}{150\ Wh/km} * 0.099312\ €/km = 7.94496\ €/session$$

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.078692\ €/km = \frac{12\ kWh}{150\ Wh/km} * 0.078692\ €/km = 6.29536\ €/session$$

Therefore, by adding 21% VAT, the maximum EV charging prices for EV customers to have a competitive mileage cost with gasoline and diesel are 9.61 € and 7.62 € per charging session, respectively.

Parameter	Value	Unit	Reference
E	12	kWh	Scenario description
EF	150	Wh/km	
N	1	EVSE	
VAT	0	%	EVSE Operator is not the final customer
MP_{EVSEO}	2000	€/year	See section 2.5.1
F	54	€/year	Prices for a three-phase, 80 A, connection[33]
Te	0.1874	€/kWh	
R	0	€/year	
P	1614.2855	€/year	Grid fees for a 3 x 80 A connection[34]
$EVSE_{Inv}$	27 150	€/EVSE	[NPE 2014]
$EVSE_{O\&M}$	3 075	€/EVSE/year	

Table 11: Values for the parameters in the Highway charging service (The Netherlands)

[33] http://www.nuon.nl/mkb/lightbox/tarieven-flexibel.jsp [access in February 2015].

[34] https://www.enexis.nl/consument/diensten-en-tarieven/tarieven/elektriciteit/periodieke-netwerktarieven-e?pageid=44 [access in February 2015].

The costs for a highway EVSE Operator in the Netherlands are obtained by using equation (3):

$$Annual\ EVSE\ Operator's\ costs\ in\ the\ Netherlands = \left\{[(F + P + (Te * E * C) - R) * (1 + VAT)] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M}\right\} * N + MP_{EVSEO}$$

$$= \left\{[(54 + 1614.2855 + (0.1874 * 12 * C) - 0) * (1 + 0\%)] + \frac{27\,150}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + 3075\right\} * 1 + 2000 = 11518.80 + 2.2488 * C$$

The incomes for the EVSE Operator are obtained by using equation (4):

$$Annual\ EVSE\ Operator's\ incomes = (CP * C * N) + OS = (CP * C * 1) + OS$$

If no additional sources of income are considered (OS=0), the minimum number of charging sessions per EVSE to have a positive result (income > cost) can be calculated by:

$$(Gasoline)\ 7.94496 * C = 11518.80 + 2.2488 * C \Leftrightarrow C \sim 2022\ sessions/year \Rightarrow 5.54\ sessions/day$$

$$(Diesel)\ 6.29536 * C = 11518.80 + 2.2488 * C \Leftrightarrow C \sim 2847\ sessions/year \Longrightarrow 7.80\ sessions/day$$

This means that the highway EVSE needs to be used to charge more than 7.80 (5.54) times per day on average, in order for the EVSE Operator to offer a competitive mileage cost for EV customers in comparison with diesel (gasoline) vehicles. Although these values are the best among the three countries analysed, the EVSE Operator still needs to look for additional sources of revenue and, again, advertising seems a good option. As discussed in section 4.1, the expected income in highway EVSE advertising is likely to be in the lower range of the prices considered for traffic hotspots (4000 €/year per EVSE). In this case, the required EVSE usage to offer competitive prices to EV customers can be reduced:

$$(Gasoline)\ 7.94496 * C + 4000 = 11518.80 + 2.2488 * C \Leftrightarrow C \sim 1320\ sessions/year \Rightarrow 3.62\ sessions/day$$

$$(Diesel)\ 6.29536 * C + 4000 = 11518.80 + 2.2488 * C \Leftrightarrow C \sim 1858\ sessions/year \Longrightarrow 5.09\ sessions/day$$

These usage rates are almost the same as for Germany when the same advertising income is considered. In order to further improve EVSE Operator's business performance, additional incomes from a shop or a restaurant would be more than welcome. The average expenditure of drivers in the Netherlands is 7.80 €/filling [FS 2014], which, assuming the same benefit rate as in Spain (30%), leaves 2.34 €/session. In this case, the required EVSE usage rate so that the EVSE Operator can recover its costs and still offer EV customers a price for EV charging which makes their mileage cost be the same as the cost of an equivalent trip with an ICE vehicle is calculated as follows:

$$(Gasoline)\ 7.94496 * C + 4000 + 2.34 * C = 11518.80 + 2.2488 * C \Leftrightarrow C \sim 936\ sessions/year \Rightarrow 2.56\ sessions/day$$

$$(Diesel)\ 6.29536 * C + 4000 + 2.34 * C = 11518.80 + 2.2488 * C \Leftrightarrow C \sim 1177\ sessions/year \Longrightarrow 3.23\ sessions/day$$

As in the case of Germany, this EVSE usage rate is higher than in Spain, but it is still low enough so that it can be reached in early stages of electric mobility deployment in areas where there are enough EVs on the road and EV customers' driving patterns require driving relatively long distances.

4.2.6 Number of EVSE

Table 12[35] presents the distribution of the main players in the Spanish filling station market. In 2013, all the big ten wholesalers had more than 0.75% of market share in Spain.

Brand	Stations	Share
REPSOL	3615	34.68%
CEPSA	1516	14.54%
BP	675	6.48%
GALP	620	5.95%
DISA	534	5.12%
MEROIL	192	1.84%
SARAS	112	1.07%
ESERGUI	102	0.98%
PETROCAT	84	0.81%
REPOSTAR	80	0.77%
Malls/supermarkets	295	2.83%
Other	2599	24.93%
TOTAL	10 424	100%

Table 12: Number of filling stations per owner in Spain (December 2013)

At the moment, about 3% of the EVSE installed in Spain are located in filling stations[36]. In 2020, there will be 82 000 publicly accessible EVSE in Spain [EC 2013, 1], so, assuming the same 3%, 2500 EVSE will be installed in filling stations for highway fast charging[37].

If main stakeholders install EVSE according to their market share, the top ten will have at least 19 EVSE in 2020, which means that having access to the marketplace costs them about 105 € per year and per EVSE (less than 1% of annual costs), compared to 2000 € in the base case (see section 2.5.2). Therefore, the fixed costs per EVSE are reduced in 1895 €/year and, hence:

$$(Diesel) 5.96488 * C = 14175.89 - 1895 + 1.24751 * C \Leftrightarrow C \sim 2604\ sessions/year \Longrightarrow 7.13\ sessions/day$$

Although this EVSE usage is still quite high, there is a clear portfolio effect, as the complete removal of the marketplace access costs would only further decrease the required EVSE usage to 7.07 charging sessions per day.

35 http://www.invertia.com/noticias/surtidores-consumo-espana-tiene-gasolineras-2934188.htm [access in February 2015].

36 http://www.electromaps.com/puntos-de-recarga/espana?TipoP=10 [access in February 2015].

37 The objective of publicly accessible EVSE in Spain seems to be quite optimistic, but it is the official one. On the contrary, fast charging is likely to account for more than 3% of publicly accessible EVSE in the future, so the total number might be quite well estimated.

4.2.7 Dual charging

There is already some equipment in the market [ABB 2014], [Circontrol 2014], [Efacec 2014] which allows for dual charging, i.e. a single EVSE allows for charging both at fast charging and at semi-fast charging. If the EVSE Operator installs this type of equipment, it can serve both DC fast (at 50 kW) and AC fast (43 kW) or semi-fast charging sessions (22 kW). The EVSE prices considered in this deliverable are taken from the latest NPE report [NPE 2014], in particular from illustration 25 in page 51, which does not consider this type of equipment. Therefore, its costs are estimated as the costs of an EVSE with fast charging capabilities, plus half the hardware cost of a two-outlet 22 kW EVSE. In this case, amortisation cost is calculated according to the following formula:

$$Annual\ EVSE\ amortisation\ cost = \frac{27\,150€ + \frac{6000\ €}{2}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} = 4775.54€/year + 527.68€/year$$

Likewise, EVSE O&M cost is assumed to be the O&M cost of a fast EVSE, plus half the maintenance cost of a semi-fast EVSE[38]:

$$Annual\ EVSE\ O\&M\ cost = 3075€/year + \frac{500}{2}€/year = 3075€/year + 250€/year$$

In addition, the power component of the electricity bill needs to be increased, as the contracted power needs to be 72 kW (50 kW + 22 kW). In this case, total cost of the power component (including electricity tax) is calculated as follows:

$$Power\ component = (50+22)kW * 6.832399€/kW/month * 12month/year * (1+5.1127\%)$$
$$= 4309.03\ €/year + 1895.97\ €/year$$

Therefore, the additional cost of the EVSE with dual charging capabilities, compared to the fast EVSE is 2673.65 €/year (527.68 + 250 + 1895.97).

Although semi-fast charging sessions do not have the same hysteresis effect as fast charging sessions and, hence, they could be used to charge up to 70% of the battery, 12 kWh/charging session is considered for both types of charging events. Under this assumption, the energy component of the electricity bill remains the same, as long as C represents the total charging events in the EVSE, i.e. the addition of fast and semi-fast charging sessions.

By adding these additional 2673.65 € to the annual costs calculated in the base case (section 4.1), EVSE Operator's costs become:

$$Annual\ EVSE\ Operator's\ costs\ in\ Spain = 14175.89 + 2673.65 + 1.24751 * C = 16849.54 + 1.24751 * C$$

As the cost per kilometre for EV customers is compared with an equivalent trip with an ICE vehicle, the same price is considered for both the fast and the semi-fast charging sessions[39].

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[38] The O&M costs of a semi-fast EVSE (1725 € in total, see Table 5) consist of Special use permit (which is assumed not to be applicable in a highway EVSE), maintenance cost (500 €/year) and other costs (communications, IT systems…) whose price is the same for both types of EVSE and, hence, which are assumed to be covered by fast EVSE O&M cost.

[39] It is likely that the price for DC charging is more expensive than for AC charging, as the value provided to EV customers is higher (shorter charging time), but the comparison with the equivalent ICE vehicle trip does not take this effect into account.

In this case, the minimum number of charging sessions to cover EVSE Operator's costs and still offer a competitive price to EV customers is calculated as follows:

$$(Gasoline)\ 6.77864 * C = 16849.54 + 1.24751 * C \Leftrightarrow C\sim 3047\ sessions/year \Longrightarrow 8.35\ sessions/day$$

$$(Diesel)\ 5.96488 * C = 16849.54 + 1.24751 * C \Leftrightarrow C\sim 3572\ sessions/year \Longrightarrow 9.79\ sessions/day$$

Although the required number of charging sessions per day is higher than in the base case, in the EVSE considered here two charging sessions can take place at the same time, so the required usage per EVSE outlet is almost halved. Moreover, not all existing EVs allow for DC charging, so the portfolio of potential users of the EVSE is increased.

If advertising and shop/restaurant can provide additional revenues, the number of charging sessions required can be reduced. The following assumptions are made:

- Advertising: 4000 €/per EVSE and per year (like a regular advertising surface in a phone booth of a small city, i.e. the lower range of potential income).
- Restaurant: 3 €/charging session. This is the average value of 4.5 €/charging session (EV charging at 22 kW needs about 30 minutes to charge 12 kWh, which can be used by EV customers to have a meal, see end of section 4.2.3) and 1.5 €/charging (the amount assumed for EV customers using fast charging speed).
- Shop: 0.3726 €/charging session (the same expenditure as in existing filling stations, see section 4.1).

The required number of charging sessions to offer prices which are competitive against diesel is then:

$$(5.96488 * C) + 4000 + 3 * C + 0.3726 * C = 16849.54 + (1.24751 * C) \Leftrightarrow C = 1589\ sessions/year \sim 4.35\ sessions/day$$

This leads to about 4.35 charging sessions per EVSE and per day, or 2.17 charging session per outlet and per day, which still seems a bit high under present EV market, but not so difficult to reach when EV market deploys. Moreover, if battery sizes are increased (see section 4.2.2), the amount of energy to charge doubles (24 kWh) and the variable cost part of EVSE Operator's cost too (2.49502*C), but also the maximum charging service price and the expected income in the restaurant (as average profit can rise from 3 €/charging session to 4.5 €/session). In that case:

$$(2 * 5.96488 * C) + 4000 + 4.5 * C + 0.3726 * C = 16849.54 + (2 * 1.24751 * C) \Leftrightarrow C = 899\ sessions/year \sim 2.46\ sessions/day$$

In an area with enough EVs and with the battery technology allowing longer driving ranges, having two fast charging sessions per day and one semi-fast charging session every two days on average seems much more likely to happen.

5 Private home charging service

This service presents the case of charging at a private EVSE. The charging speed is assumed to be slow (3.7 kW[40]). EV customers themselves are assumed to buy the EVSE required for charging their EVs (so they act as EVSE Operator) and buy electricity directly from the Electricity retailer (which performs the EVSP role in this case). As a result, there is no need for a marketplace in this charging service.

Although EV customers already have an existing supply point for their home electricity consumption, it is assumed that electricity supply for the EV is made through a new supply contract. As a result, the power term needs to be dimensioned to satisfy maximum EV power demand (4.6 kW), whereas including the EV on the existing supply contract may have avoided any extension[41]. On the other hand, the EV contract may use the super-valley tariff (which offers cheaper prices overnight) without having to pay more expensive prices for the electricity consumed at home during the day. Moreover, this way they can have a mobility contract with the Electricity retailer, so that it is their EVSP for EV charging outside home.

Driving patterns are expected to be equivalent to the traffic hotspot charging service, so the same efficiency (120 Wh/km) is assumed and the maximum amount of energy to be charged by the EV is obtained as 70% of the battery size, from an initial SOC of 30% to a maximum SOC of 100% [NPE 2010]. Hence, it is assumed that each charging session requests 10 kWh of electricity.

5.1 Base case

Table 13 presents the different parameters to be used in this charging service:

Parameter	Value	Unit	Reference
P	4.6	kW	Scenario description
E	10	kWh	
EF	120	Wh/km	
K	19 000	km/year	[Nissan 2015, 1]
VAT	21	%	EV customers are final customers
MP_{EVSEO}	0	€/year	No marketplace required
Tp	3.503619	€/kW/month	[BOE-A-2014-1053]
Te_3	0.044146	€/kWh	
M	0.81	€/month	[BOE-A-2011-14782]
$EVSE_{Inv}$	1900	€/EVSE	Estimation
$EVSE_{O\&M}$	50	€/EVSE/year	

Table 13: Values for the parameters in the Private Home charging service (base case)

[40] In central and northern European countries, bigger connections allow for faster charging speeds.

[41] Power contracts in Spain are limited in 5 A steps, so a regular supply at 230V, single-phase, must have at least 20 A (4.6 kW, cos phi=1) to be able to supply 3.7 kW, which is the typical home contract in Spain. Hence, if overnight home electricity consumption is low, EVs can be charged with existing connection.

The EVSE investment cost considered in the base case is lower than the one proposed by German National Platform for Electric Mobility (NPE) for 2013 [NPE 2014], because the technical characteristics (mainly, communication and metering requirements) of the EVSE considered in that report may not be needed by EV customers. A sensitivity analysis on this parameters is presented in section 5.2.1.

On the contrary to the two charging services discussed so far, private home is expected to be the preferred charging alternative for those EV customers who can charge their EVs at home. As a result, the impact of this charging service in EV customers' TCO is higher and, thus, both fixed and variable costs must be included in the analysis, so equations (7) are used. Based on them, the TCOs are calculated as:

$$TCO_{Gasoline} = 1511 + 0.113528 * K = 1511 + 0.113528 * 19000 = 3668.03\ €/year$$

$$TCO_{Diesel} = 1738 + 0.101219 * K = 1738 + 0.101219 * 19000 = 3661.16\ €/year$$

$$\begin{aligned} TCO_{EV} &= 2198 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + EV\ charging\ cost \\ &= 2198 + 0.011 * 19000 + \frac{1900}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + 50 + EV\ charging\ cost \\ &= 2791.20 + EV\ charging\ cost \end{aligned}$$

The EV charging cost in this case is the addition of the cost resulting from private home charging service and the cost of charging outside home.

Equation (1) is used to calculate the electricity bill, but having 100% of charging events made at night:

$$\begin{aligned} &Electricity\ bill\ (private\ home\ charging\ in\ Spain) \\ &= \left[\left(\langle\{(P * Tp * 12) + [(100\% * Te_3) * E * C]\} * (1 + 5.1127\%)\rangle + (M * 12)\right) * (1 + VAT)\right] \\ &= \left[\left(\langle\{(4.6 * 3.503619 * 12) + [(100\% * 0.044146) * 10 * C]\} * (1 + 5.1127\%)\rangle \right.\right. \\ &\left.\left. + (0.81 * 12)\right) * (1 + 21\%)\right] = 257.74 + 0.56148 * C \end{aligned}$$

If it is assumed that EV customers charge at home one out of two days, C is 180 charging sessions. In that case, the annual electricity bill becomes 358.81 €/year and the distance that can be driven due to home charging is 15 000 km/year:

$$Distance\ driven\ due\ to\ home\ charging = \frac{180\ session/year * 10\ kWh/session}{120\ Wh/km} = 15000\ km/year$$

The remaining 4000 km must be driven by charging outside home. The maximum charging service price that EVSE Operators can ask so that the relative cost of the charging event for EV customers can be compared with the refuelling cost of an equivalent trip with an ICE vehicle is provided by equations (8):

$$For\ gasoline: CP_i \le \frac{Ei}{EFi} * 0.084733\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.084733\ €/km = 7.0611\ €/session$$

$$For\ diesel: CP_i \le \frac{Ei}{EFi} * 0.074561\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.074561\ €/km = 6.2134\ €/session$$

The worst case scenario for EV customers is when they compare their TCO with diesel vehicles (which is lower than the TCO for gasoline vehicles), but EVSE Operators for public charging services (traffic hotspot and highway charging) establish the charging service price so that the relative cost of the charging event for EV customers is the same as the cost of an equivalent trip with a gasoline vehicle (which is higher than for a diesel vehicle, as shown just above). In that case, EV customers' TCO becomes about 3490 €/year, which is about 175 € lower than the cost of owning a diesel vehicle:

$$\begin{aligned} TCO_{EV} &= 2791.20 + EV\ charging\ cost = 2791.20 + (257.74 + 0.56148 * 180) + (4000 * 0.084733) \\ &= 3488.94\ €/year \end{aligned}$$

The minimum private home charging service usage rate for EV customers to have a lower TCO than ICE vehicles can be calculated as:

$$TCO_{Gasoline} = TCO_{EV} = 2791.20 + EV\ charging\ cost \Leftrightarrow 3668.03$$
$$= 2791.20 + (257.74 + 0.56148 * C) + \left[\left(19000 - \frac{C * 10}{0.120}\right) * 0.084733\right] \Leftrightarrow C$$
$$= 152.45 \sim 153\ sessions/year$$

This means that about 12 700 km must be driven out of home charging, i.e. about two thirds of the annual mileage must rely on private home charging for EVs to have a TCO lower than ICE vehicles.

5.2 Sensitivity analysis

Under the conditions considered in the base case, the purchase of an EV and the use of private home charging would be beneficial for EV customers. However, there are uncertainties over some parameters which may affect such conditions and, hence, must be assessed.

5.2.1 EVSE investment cost

The EVSE investment cost considered in the base case is lower than the one proposed by German National Platform for Electric Mobility (NPE) for 2013 [NPE 2014], because the technical characteristics (mainly, communication and metering requirements) of the EVSE considered in that report may not be needed by EV customers. However, if such technical requirements are established by national regulation, the cost of EVSE for private home charging must be in line with the values in NPE, and, hence, annual EVSE O&M costs rise up to 1175 €/year and annual EVSE amortisation costs become:

$$Annual\ amortisation = \frac{2500\ €/EVSE}{\frac{(1 + 7\%)^{7.5} - 1}{7\% * (1 + 7\%)^{7.5}}} = 439.74\ €/year$$

The increase in EVSE investment cost would not affect the advantages of EVs over ICE vehicles, as the difference is about 105.54 €/year higher, which is lower than the TCO difference. On the contrary, much higher O&M costs (1175 €/year vs. 50 €/year) due to communication capabilities do change the situation and EV ownership become more expensive than ICE vehicle ownership.

Therefore, regulators must weigh the advantages of imposing more strict technical conditions for private home charging against the additional costs for EV customers.

5.2.2 Annual mileage

The annual mileage considered in the base case is based on the reported mileage by Nissan Leaf users in Spain [Nissan 2015, 1], but the average mileage of Spanish drivers is much lower (9928 km/year). If the annual mileage is assumed to be 10 000 km/year, the TCOs for ICE vehicles result:

$$TCO_{Gasoline} = 1511 + 0.113528 * K = 1511 + 0.113528 * 10000 = 2646.28\ €/year$$

$$TCO_{Diesel} = 1738 + 0.101219 * K = 1738 + 0.101219 * 10000 = 2750.19\ €/year$$

Assuming the same distribution of charges as in the base case (80% of mileage is based on private home charging, while publicly accessible EVSE are used to cover the remaining 20% of mileage), the number of private home charging events can be calculated as:

$$Private\ home\ charging\ sessions = \frac{10\,000\ km/year * 80\%\ private * 0.120\ kWh/km}{10\ kWh/session} = 96\ sessions/year$$

This number of sessions results in an annual mileage of 8000 km driven due to private home charging and a home charging electricity bill of 311.64 €/year:

$$Electricity\ bill\ (private\ home\ charging\ in\ Spain) = 257.74 + 0.56148 * C = 311.64\ €/year$$

The remaining 2000 km must be driven by charging outside home, but, even if all charging sessions outside home were for free, the TCOs would be:

$$TCO_{EV} = 2198 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + EV\ charging\ cost$$
$$= 2198 + 0.011 * 10000 + \frac{1900}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + 50 + 311.08 = 3003.84\ €/year$$

In this case, EV becomes more expensive than ICE vehicles. However, it is remarkable that, for the average Spanish driver, gasoline vehicles are cheaper than diesel vehicles, but diesel is the dominant fuel in Spain, both in terms of total number of vehicles [DGT 2014] and in new registrations[42].

Nevertheless, the average mileage of new cars (less than 5 years old) is almost as high as the one by Nissan Leaf drivers (18500 km/year[43]), so the mileage assumed in the base case seems to be more relevant in the case of electric mobility.

5.2.3 EV efficiency

If EV efficiency is assumed to be higher than in the base case (as discussed in section 3.2.3), the required energy amount to drive the same annual mileage increases. Assuming a 150 Wh/km efficiency and the same annual mileage as in the base case (19 000 km/year), the required electricity amount is 2850 kWh/year (19 000 km/year * 0.150 kWh/km).

If it is assumed that EV customers charge at home one out of two days, the private home charging electricity bill remains the same. On the contrary, the amount of kilometres driven from home charging is lower: 12 000 km per year (180 charging sessions/year * 10 kWh/charging session / 150 Wh/km), so EV customers need to drive 7000 km/year by charging outside home.

Again, if the worst case scenario is considered (EV charging price for charging outside home is set to compete with gasoline vehicles):

$$TCO_{EV} = 2791.2 + EV\ charging\ cost = 2791.2 + (257.74 + 0.56148 * 180) + (7000 * 0.084733)$$
$$= 3743.14\ €/year$$

The TCO is about 80 € more expensive for EVs than for ICE vehicles. Even if the EV charging price for charging outside home is set to compete with diesel vehicles, the TCO for EVs is still higher (3671.93 €/year) than for ICE vehicles, but almost negligible (just about 10 €/year).

On the contrary, if the same proportion of home charging is considered (80%), EV customers charge 2280 kWh/year (80% * 2850 kWh/year) at home, i.e. they make 228 charging sessions at home (10 kWh/charging session), and 3800 km/year (19000 km/year * 20%) are driven by charging outside home. In this case, the TCO for EVs is lower than for ICE vehicles:

$$TCO_{EV} = 2791.2 + EV\ charging\ cost = 2791.2 + (257.74 + 0.56148 * 228) + (3800 * 0.084733)$$
$$= 3498.94\ €/year$$

In this case, the TCO is about 160 € cheaper for EVs than for ICE vehicles, which emphasises the importance of EV customers charging at home as much as possible to have a positive TCO.

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[42] Almost twice as many diesel vehicles are still sold compared to gasoline [Aniacam 2015].

[43] http://www.ioncomunicacion.es/noticia.php?id=%2015818 [access in February 2015].

5.2.4 Other countries

The differences that may arise between different EU Member States are assessed by calculating the results for Spain (base case), Germany and the Netherlands. The differences in the electricity bill structure and in the prices for fossil fuels are considered, but also the average distance driven per year. As in the base case, the EVSE investment and O&M costs are lower than the ones in [NPE 2014], as the technical characteristics of the EVSE considered in that report may not be needed by EV customers.

5.2.4.1 Germany

The main parameters to be used in Germany are listed in Table 14.

Parameter	Value	Unit	Reference
E	10	kWh	Scenario description
EF	120	Wh/km	
N	1	EVSE	
K	15 000	km/year	[Nissan 2015, 1]
VAT	19	%	EV Customers are final customers
MP_{EVSEO}	0	€/year	No marketplace required
Te	0.25	€/kWh	Data provided by RWE
M	8.60	€/month	
$EVSE_{Inv}$	1900	€/EVSE	Estimation
$EVSE_{O\&M}$	50	€/EVSE/year	

Table 14: Values for the parameters in the Private Home charging service (Germany)

The formula to consider both fixed and variable costs in Germany is presented in equations (9):

$$TCO_{EV} = 3161 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + EV\ charging\ cost$$

The EV charging cost in this case is the addition of the cost resulting from private home charging service and the cost of charging outside home. When charging at home, EV customers act as EVSE Operators, so equation (2) can be used:

$$Annual\ EVSE\ Operator's\ costs\ in\ Germany$$
$$= \left\{\left[\left((Te * E * C) + (M * 12)\right) * (1 + VAT)\right] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M}\right\} * N + MP_{EVSEO}$$
$$= \left\{\left[\left((0.25 * 10 * C) + (8.60 * 12)\right) * (1 + 19\%)\right] + \frac{1900}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + 50\right\} * 1 + 0$$
$$= 507.01 + 2.975 * C$$

If it is assumed that EV customers charge at home one out of two days, C=180 charging sessions. In that case, the cost for EV customers as home EVSE Operators becomes 1042.51 €/year; while the distance that can be driven due to home charging is 15 000 km/year, i.e. total annual mileage, so they would not need to charge outside home. In this case, the TCO for EV customers results in:

$$TCO_{EV} = 3161 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + EV\ charging\ cost$$
$$= 3161 + 0.011 * 15000 + 1042.51 = 4368.51\ €/year$$

Equations (9) also give the TCO for ICE vehicles:

$$TCO_{Gasoline} = 1656 + 0.121816 * K = 3483.24\ €/year$$
$$TCO_{Diesel} = 1958 + 0.103816 * K = 3515.19\ €/year$$

The lack of subsidies for direct EV purchase, together with the lower average annual mileage considered in Germany, make EV ownership much more expensive than owning ICE vehicles. In order to have the same TCO as gasoline, the EV cannot be more than about 5000-5200 € more expensive than the equivalent gasoline vehicle (so a direct subsidy of about 6800-7000 € would be needed).

In Germany, most new cars are company cars (62% [Mock 2014]): the company offers its employees a car (which can be used for private purposes too) and it pays all related charges, usually including fuel costs. Then, the company claims vehicle costs as business expenditures and can reduce its profit tax. Therefore, the reduction in profit tax should be about 885 €/year (4368 €/year - 3483 €/year) per EV for companies to be interested in offering EVs to its employees in the worst case scenario (if the TCO must be comparable for EVs and gasoline vehicles, which is the lowest one in Germany).

5.2.4.2 The Netherlands

The main parameters to be used in the Netherlands are listed in Table 15.

Parameter	Value	Unit	Reference
E	10	kWh	Scenario description
EF	120	Wh/km	
N	1	EVSE	
K	19 000	km/year	[44]
VAT	21	%	EV Customers are final customers
MP_{EVSEO}	0	€/year	No marketplace required
F	0	€/year	The regular domestic connection in the Netherlands is 3x25 A, which more than enough to include EV charging within the regular home electricity supply contract.
P	0	€/year	
R	0	€/year	
Te	0.2189	€/kWh	Prices for domestic customers[45]
$EVSE_{Inv}$	1900	€/EVSE	Estimation
$EVSE_{O\&M}$	50	€/EVSE/year	

Table 15: Values for the parameters in the Private Home charging service (The Netherlands)

[44] Average mileage in the Netherlands is about 9200 km/year [OECD 2014], which is very close to the Spanish average. Hence, the same 19 000 km/year as in Spain are assumed for EV customers.

[45] https://www.nuon.nl/energie/vaste-prijs-energie/prijzen.jsp [access in February 2015].

The formulas to consider both fixed and variable costs in the Netherlands are presented in equations (11):

$$TCO_{Gasoline} = 2033 + 0.131168 * K = 4525.19 \text{ €}/year$$

$$TCO_{Diesel} = 2335 + 0.106217 * K = 4353.12 \text{ €}/year$$

$$TCO_{EV} = 3538 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + EV\ charging\ cost$$

Again, EV charging cost is the addition of the cost resulting from private home charging service and the cost of charging outside home. When charging at home, EV customers act as EVSE Operators, so equation (3) can be used:

$$Annual\ EVSE\ Operator's\ costs\ in\ the\ Netherlands = \left\{[(F + P + (Te * E * C) - R) * (1 + VAT)] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M}\right\} * N + MP_{EVSEO}$$

$$= \left\{[(0 + 0 + (0.2189 * 10 * C) - 0) * (1 + 21\%)] + \frac{1900}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + 50\right\} * 1 + 0$$

$$= 384.20 + 2.265 * C$$

Assuming that EV customers charge at home one out of two days (C=180 charging sessions), they are able to drive 15 000 km/year, so they must charge in other public charging services to drive another 4000 km/year. According to equations (12), the costs per kilometre are 0.099312 and 0.078692 €/km for gasoline and diesel vehicles, respectively. Even if EV charging price for outside home sessions is set to be competitive against diesel vehicles, EV customers' TCO becomes:

$$TCO_{EV} = 3538 + 0.011 * 19000 + 384.20 + 2.265 * 180 + 0.078692 * 4000 = 4853.63 \text{ €}/year$$

If EV charging price for outside home sessions is set to be competitive with gasoline vehicles, the TCO is even higher (4935.25 €/year), so EV ownership is more expensive than ICE vehicle ownership in the Netherlands, among others, because there are no subsidies for direct EV purchase. In order to have the same TCO as gasoline, the EV cannot be more than between 6375 € (worst case scenario[46]) and 8400 € (best case scenario) more expensive than the equivalent gasoline vehicles (so a direct subsidy of between 2600-4625 € would be needed).

As in Germany, company cars are also very common in the Netherlands. The reduction in profit tax for the company should be about 582 €/year (4935.25 €/year - 4353 €/year) per EV for companies to be interested in offering EVs to its employees in the worst case scenario.

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[46] In this case, the worst case scenario is when the TCO is compared with diesel vehicles (which is the lowest one in the Netherlands) and EVSE Operators set the EV charging price for outside home sessions to be competitive against gasoline vehicles (which is higher than prices to compete with diesel). The best case scenario is just the opposite: TCO is compared to gasoline and EV charging price is set to compete against diesel.

5.2.5 EV purchase cost

The base case EV purchase cost is based on the expected battery price in 2015 under the optimistic scenario in [D9.6] and the subsidy existing in Spain in 2014, due to the difficulty in comparing ICE models with equivalent EV models in the market.

By taking for example, Volkswagen e-Golf, retail price difference compared to the gasoline version is about 15 800 € (35 500 € vs. 19 690 €[47]), i.e. 11 300 € more than in the base case, see equation (7). In this case, the additional annual amortisation cost for the EV can be calculated as:

$$Annual\ amortisation\ of\ EV = \frac{11\,300\ €}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} = 1422.69 \sim 1423\ €/year$$

Therefore, EV TCO becomes about 4912 €/year (3489 + 1423 €/year), which is about 1250 €/year more than cost of owning an ICE vehicle.

Under the same assumptions as in the base case, the EV purchase price should not be more than about 5870 € more expensive than the price for a gasoline vehicle (4070 € more expensive than a diesel vehicle) to have a comparable TCO (TCO difference between gasoline and diesel is just about 7 €, so they are assumed to be equivalent):

$$\begin{aligned} TCO_{Diesel} = TCO_{EV} \\ &= TCO_{EV,base\ case} - Annual\ amortisation_{EV,base\ case} + Annual\ amortisation_{Gasoline} \\ &+ Annual\ amortisation_{EV,addition} \Leftrightarrow 3661.16\ €/year \\ &= 3488.98\ €/year - \frac{16\,500}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + \frac{12\,000}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} + \frac{EV\ add-on\ cost}{\frac{(1+7\%)^{12}-1}{7\% * (1+7\%)^{12}}} \\ &\Leftrightarrow EV\ add-on\ cost = 5867.91\ € \end{aligned}$$

This add-on cost is lower than the price gap in the example of Volkswagen Golf. Although many other implications are taken into account when designing the subsidy policy, public bodies must ensure that any subsidy must be efficient.

For example, the prices in the example above have a 2000 € subsidy from PIVE-6 for both versions, so there is no subsidy gap for the EV. On the contrary, if the subsidy from MOVELE 2014 (6500 €) is extended to 2015 and the PIVE subsidy is removed for ICE vehicles, price gap can be reduced to 7300 € (15 800 € - 6500 € - 2000 €). Then, if the PIVE budget not used by ICE vehicles is invested to increase the subsidy to EVs, price gap would be low enough to allow a positive TCO for EVs, but EV subsidy would rise to 10 500 €, which may be a bit high.

5.2.6 EV charging included in regular home electricity bill

In the base case, EV charging is assumed to require a new electricity supply contract. If, on the contrary, it is assumed that the electricity to charge the EV is taken from the regular home electricity supply contract, there is no additional power component[48] and meter renting, but the energy cost is higher, as most Spanish households have a single-period tariff, so, although EVs are charged overnight, the price for EV charging is the regular price [BOE-A-2014-1053]. Hence, the new electricity bill components (related to EV charging) can be calculated as follows:

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[47] http://www.volkswagen.es [access in February 2015].

[48] A typical home contract in Spain has a contracted power of 4.6 kW (see footnote 41), which is enough to charge EVs overnight, as home electricity consumption is assumed to be minimal.

$$Electricity\ bill\ (private\ home\ charging\ in\ Spain) = \left[\left(\langle\{(P * Tp * 12) + [(100\% * Te_3) * E * C]\} * (1 + 5.1127\%)\rangle + (M * 12)\right) * (1 + VAT)\right] = \left[\left(\langle\{(0 * 3.503619 * 12) + [(100\% * 0.124107) * 10 * C]\} * (1 + 5.1127\%)\rangle + (0 * 12)\right) * (1 + 21\%)\right] = 1.5785 * C$$

If C=180 charging events, the additional electricity bill becomes 284.12 €/year, which is about 75 € cheaper than in the base case. If the overnight home electricity consumption cannot be neglected and, hence, the contracted power must be increased in one step (5 A, i.e. 1.15 kW), the electricity bill rises to 345.61 €/year, which is still lower than in the base case (358.81 €/year), but the are some other costs (one-time fee for having a bigger connection, the costs of the operator who changes the limitation and protection devices in the home electric installation) which would make the costs higher than in the base case.

5.2.7 More expensive prices in public EVSE

In early stages of EV deployment, the usage rates of publicly accessible EVSE (such as traffic hotspot or highway charging services) may not be enough for EVSE Operators to competitive prices against gasoline or diesel vehicles for equivalent trips, as presented in chapters 3 and 4.

However, when EV customers drive most of their annual mileage by charging at home, their TCO can be about 180 € lower than the cost of owning an ICE vehicle, as presented in the base case (section 5.1). In this case, EV customers may accept to pay a bit more for charging sessions made outside home, as their TCO is still lower than the cost of ICE vehicles.

If it is assumed that they pay 80 € more for the 4000 km driven from public charging (to have a TCO that still is 100 €/year lower than for ICE vehicles), each charging session would cost[49]:

$$Additional\ price_{Traffic\ hotspot} = \frac{80\ €}{4000\ km} * \frac{10\ kWh/session}{0.120\ kWh/km} = 1.67\ €/session$$

$$Additional\ price_{Highway} = \frac{80\ €}{4000\ km} * \frac{12\ kWh/session}{0.150\ kWh/km} = 1.60\ €/session$$

If the traffic hotspot EVSE Operator can ask for 1.67 €/session more (which is just profit, as no additional costs are needed), the required EVSE usage can be calculated as (based on equation (13)):

$$(Gasoline)\ 7.0611 * C + 1.67 * C = 7380.16 + 1.0396 * C \Leftrightarrow C\sim 960\ sessions/year \Rightarrow 2.62\ sessions/day$$

$$(Diesel)\ 6.2134 * C + 1.67 * C = 7380.16 + 1.0396 * C \Leftrightarrow C\sim 1079\ sessions/year \Longrightarrow 2.96\ sessions/day$$

Therefore, the required EVSE usage to offer these prices is reduced below 3 sessions per day on average. If advertising is also taken into account, even in the lower range (4000 €/EVSE per year), the required EVSE usage is reduced to about 1.20-1.35 charging sessions per EVSE and per day (about two charges every three days per outlet).

As for the highway EVSE Operator, starting from equation (14), the additional income results in:

$$(Gasoline)\ 6.77864 * C + 1.60 * C = 14175.89 + 1.24751 * C \Leftrightarrow C\sim 1988\ sessions/year \Rightarrow 5.45\ sessions/day$$

[49] For example, if EV customers charge 18 times in a traffic hotspot, they can drive 1500 km (18 sessions * 10 kWh/session /0.12 kWh/km) and they spend 30 € (18 sessions * 1.67 €/session). Hence, they must drive another 2500 km from highway charging, so they charge 31.25 times (2500 km * 0.150 kWh/km / 12 kWh/session), which costs them 50 € (31.25 sessions * 1.60 €/session).

$$(Diesel)\ 5.96488 * C + 1.60 * C = 14175.89 + 1.24751 * C \Leftrightarrow C \sim 2245\ sessions/year$$
$$\Longrightarrow 6.15\ sessions/day$$

Although these usage rates are still high, the combination of advertising (4000 €/EVSE per year) and the additional income from an attached shop or restaurant (1.50 €/charging session) can reduce them to 3.23-3.57 sessions per EVSE and per day, which is much more likely to happen.

6 Public charging spot for street side parking

This charging service presents the case of charging at a publicly accessible EVSE on public domain. The charging speed is assumed to be semi-fast (22 kW, although it could also charge at 11 kW if needed) and the EVSE is assumed to have two outlets. EV customers are assumed to use the roaming agreement of their EVSP with the public EVSE Operator (through the marketplace) to be able to charge their EVs.

It is assumed that the EVSE has two different usage patterns. On the one hand, it is used by EV customers who do not have access to private home charging for overnight charging, while, on the other, it is used by other EV customers to charge their EVs during the day. The price to be requested to each type of customer is different, as the costs for the charging sessions and the value provided to them also differ. Therefore, a price for daytime charging and another price for overnight charging are envisaged.

This is the most complex charging service, as it involves the higher number of stakeholders: EV customers who use it as their preferred charging option (EV customers without access to private home charging who use this charging service for overnight charging[50]), EV customers who use this charging service sporadically (EV customers with access to private home charging and use this alternative just to increase their range during the day, as in the traffic hotspot charging service) and the EVSE Operator.

The maximum amount of energy to be charged by an EV is obtained as 70% of the battery size, from an initial SOC of 30% to a maximum SOC of 100% [NPE 2010], as in the traffic hotspot and private home charging services. Hence, it is assumed that each charging session requests 10 kWh of electricity. Likewise, EV efficiency is assumed to be the same as in those charging services, i.e. 120 Wh/km, as driving patterns are expected to be equivalent.

In order to estimate the number of public charging spots for street side parking, the following assumptions are made:

- The EC Directive for Alternative Fuels [OJ L307/1] indicated that "the appropriate average number of recharging points accessible to the public should be equivalent to at least one recharging point per 10 cars". Taking into account that 5000 EV customers were considered in section 2.5.3, 500 EV customers who cannot charge in private home are considered.
- In order to be consistent with the charging patterns in the private home charging service, it is assumed that 180 overnight charging events per year are made by those EV customers in the public charging spots for street side parking. Therefore, 90 000 overnight charging events are assumed for the whole public charging spot portfolio.
- Since it is not likely that each outlet can be used more than once per night (EV customers are not expected to unplug their EVs in the middle of the night), the total number of overnight charging events per EVSE is 730 (1 events/day/outlet * 2 outlets/EVSE * 365 days).

Based on these assumptions, the minimum number of EVSE is 124 (90 000 charging sessions per year / 730 charging sessions per EVSE and per year).

The process to obtain the required EVSE usage rate in this charging service is presented in **Figure 3** below:

[50] As overnight charging is of paramount importance for these EV customers, public authorities may limit the availability of this charging option to residents.

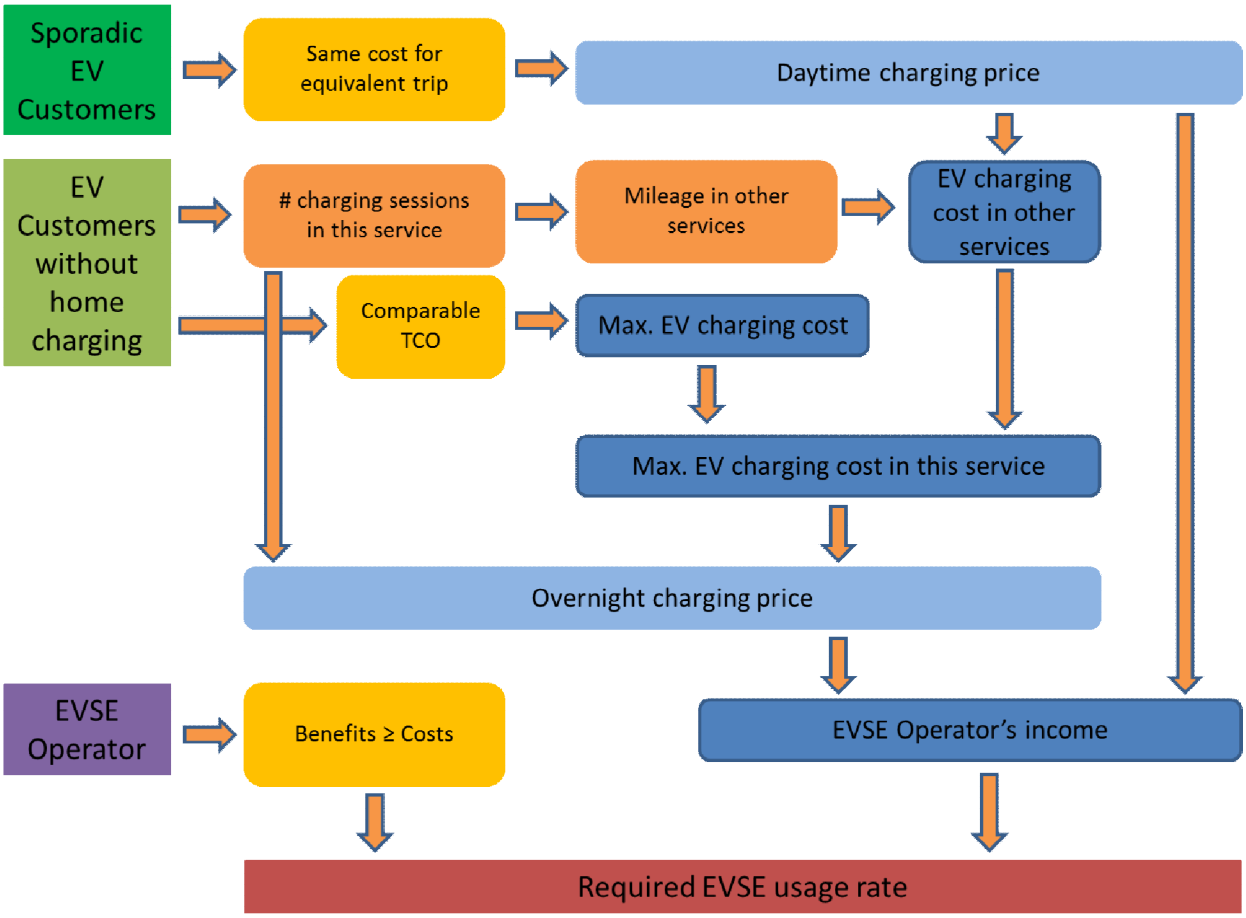

Figure 3: Process to obtain the required public charging spot for street side parking usage rate

In the case of EV customers who use this alternative for daytime charging (sporadic EV customers in **Figure 3**), the relative cost for EV customers of the charging event must be compared with refuelling cost of an equivalent trip with an ICE vehicle. This way, the maximum daytime charging service price to be requested by the EVSE Operator is calculated.

On the contrary, for EV customers who use the public charging spot for street side parking very frequently (EV customers without home charging in **Figure 3**), the whole TCO must be analysed, so that it is comparable to the TCO of an ICE vehicle. By considering all the fixed costs for EV customers, the maximum EV charging cost is calculated. Then, based on the number of charging sessions in the public charging spot for street side parking, the number of kilometres that must be driven by using other charging services is calculated, which, considering the cost of an equivalent trip with an ICE vehicle, allows calculating the EV charging cost in other charging services. The difference between the maximum total cost of EV charging and the EV charging cost in other charging options is the maximum EV charging cost in the public charging spot for street side parking service. The overnight charging price is calculated by dividing this maximum EV charging cost in this service by the number of charging sessions in it.

Then, both the daytime charging and the overnight charging prices are used to calculate EVSE Operator's income, as a function of the number of charging sessions per EVSE. The EVSE Operator aims at having more benefits than costs, so, by calculating the costs as a function of the number of charging sessions per EVSE, the required EVSE usage is calculated.

6.1 Base case

Table 16 presents the different parameters to be used in this charging service:

Parameter	Value	Unit	Reference
P	2*22	kW	Scenario description
E	10	kWh	
EF	120	Wh/km	
N	124	EVSE	
K	19 000	km/year	[Nissan 2015, 1]
VAT	0	%	EVSE Operator is not the final customer
MP_{EVSEO}	2000	€/year	See section 2.5.1
Tp	6.832399	€/kW/month	[Endesa 2014]
Te_1	0.122383	€/kWh	
Te_2	0.096216	€/kWh	
Te_3	0.065923	€/kWh	
M	1.36	€/month	[BOE-A-2011-14782]
$EVSE_{Inv}$	10 500	€/EVSE	[NPE 2014]
$EVSE_{O\&M}$	1 725	€/EVSE/year	

Table 16: Values for the parameters in the Public charging spot for street side parking service (base case)

As discussed above, EV customers who use this charging service for daytime charging must have a cost per charging event which is comparable to the refuelling cost of an equivalent trip with an ICE vehicle. The maximum daytime charging service price to be requested by the EVSE Operator to meet this requirement is calculated by using equations (8):

$$For\ gasoline: CP_i \leq \frac{Ei}{EFi} * 0.084733\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.084733\ €/km = 7.0611\ €/session$$

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.074561\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.074561\ €/km = 6.2134\ €/session$$

Therefore, by adding 21% VAT, the maximum daytime EV charging prices for EV customers to have a competitive mileage cost with gasoline and diesel are 8.54 € and 7.52 € per charging session, respectively.

In order to calculate the TCO for EV customers who use the public charging spot for street side parking very frequently, equations (7) must be used, but taking into account that EV customers are not EVSE Operators in this case, so the terms including $EVSE_{Inv}$ and $EVSE_{O\&M}$ must not be considered:

$$TCO_{Gasoline} = 1511 + 0.113528 * K = 1511 + 0.113528 * 19000 = 3668.03\ €/year$$

$$TCO_{Diesel} = 1738 + 0.101219 * K = 1738 + 0.101219 * 19000 = 3661.16\ €/year$$

$$TCO_{EV} = 2198 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + EV\ charging\ cost$$
$$= 2198 + 0.011 * 19000 + EV\ charging\ cost = 2407 + EV\ charging\ cost$$

Therefore, EV charging cost for EV customers must not be higher than 1254.16 €/year (3661.16 €/year – 2407 €/year), so that their TCO is comparable to owning a diesel vehicle (for gasoline vehicle, it is just about 7 € more). As EV customers are the final customers, they must pay VAT, so the net EV charging cost for EV customers cannot exceed 1036.50 €/year.

As discussed in the private home charging service, 180 charging sessions per year, at 10 kWh per charging session and with an EV efficiency of 120 Wh/km, allow EV customers to drive 15 000 km (see section 5.1), so another 4000 km must be driven from other public charging services (traffic hotspot and highway charging). As in the private home charging service, the worst case scenario for EV customers is when the price for charging their EV in traffic hotspots and highway EVSE is established so that the relative cost of the charging event for them is compared with the refuelling cost of an equivalent trip with a gasoline vehicle:

$$EV\ charging\ cost\ in\ other\ services = 0.084733\ €/km * 4000\ km/year = 338.93\ €/year$$

This means that the cost for EV customers when charging in public charging spots for street side parking must not exceed 697.57 €/year (1036.50 - 338.93 €/year) for 180 charging sessions, i.e. an overnight charging price of 3.875 €/session.

According to the prices for overnight (3.875 €/session) and daytime charging (6.2134 €/session, to be competitive with diesel vehicles), reminding that there are the same number of charging sessions in each period and assuming that there are no additional sources of income, the incomes for the EVSE Operator are:

$$Annual\ EVSE\ Operator's\ incomes = (CP * C * N) + OS = \left(6.2134 * \frac{C}{2} * 124\right) + \left(3.875 * \frac{C}{2} * 124\right) + 0$$
$$= 625.48 * C$$

When dealing with the costs for the EVSE Operator, equation (1) must be used, but some changes are required. This charging alternative is assumed to be the preferred one by EV customers who cannot charge in their private home, so the charging session distribution considered in other charging services cannot be used. It is assumed that half of the charges are made for overnight charging and the same daytime charging distribution as in the other charging services is used (23% vs.66%, i.e. about three times more in off-peak times).

Therefore, S_1=12.5%, S_2=37.5% and S_3=50% and, thus, equation (1) becomes:

$$Annual\ EVSE\ Operator's\ costs\ in\ Spain$$
$$= \left\{ \Big[\Big(\big\langle \{ (P * Tp * 12) + [(12.5\% * Te_1 + 37.5\% * Te_2 + 50\% * Te_3) * E * C] \} \right.$$
$$\left. * (1 + 5.1127\%) \big\rangle + (M * 12) \Big) * (1 + VAT) \Big] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N$$
$$+ MP_{EVSEO}$$
$$= \left\{ \Big[\Big(\big\langle \{ (44 * 6.832399 * 12) \right.$$
$$+ [(12.5\% * 0.122383 + 37.5\% * 0.096216 + 50\% * 0.065923) * 10 * C] \} * (1 + 5.1127\%) \big\rangle$$
$$\left. + (1.36 * 12) \Big) * (1 + 0\%) \Big] + \frac{10\,500}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + 1\,725 \right\} * 124 + 2000$$
$$= 917140 + 109.93 * C$$

EVSE Operator's incomes equal costs when:

$$625.48 * C = 917140 + 109.93 * C \Leftrightarrow C = 1778.95\, sessions/year \sim 4.87\, sessions/day$$

This EVSE usage rate means that the EVSE must be used every day for more than 2 overnight charging sessions per EVSE (1 session per outlet) and another 2 daytime charging sessions, which is too high, even in the medium term horizon considered in this deliverable.

In order to be able to reduce the required EVSE usage to the assumptions considered, additional sources of income are required. The expected impact of an advertisement located in a public charging spot for street side parking is lower than the one in a traffic hotspot and, in addition, the EVSE Operator may not succeed in having advertisements placed in all its EVSE, or discounts in the price may be offered for big volumes, as the one considered in the analysis (124 EVSE). As a result, the advertisement income is assumed to be in the lower range of the prices in phone booths (see section 3.1). When the income from advertising is 4000 €/EVSE per year, the required EVSE usage is reduced to:

$$625.48 * C + OS = 917140 + 109.93 * C \Leftrightarrow 625.48 * C + 4000 * 124 = 917140 + 109.93 * C \Leftrightarrow C = 816.88\, sessions/year \sim 2.24\, session/day$$

Taking into account that the number of EVSE has been calculated to satisfy the overnight demand (only half the EV customers charge every night and two EV customers can be charged at the same time in a single EVSE), this EVSE usage rate may seem reachable. However, it must be taken into account that, due to the dispersion in EV customer preferences and EVSE location, it is quite likely that some EVSE are occupied almost every night (and, hence, EV customers do not charge overnight but the day after, either by using this charging service or another one) while some other EVSE are idle for most of the time. Moreover, at least in the early stages of EV deployment, it is not reasonable to think that public spot charging for street side parking will be massively used for daytime charging. An additional argument in this sense is the fact that most EV customers are likely to connect their EVs in the evening and that they select whether they want to have their EV charged as soon as possible (which would be a daytime charging in period 2) or at the cheapest price (overnight charging in period 3); in any case, the outlet would be occupied for the whole night, reducing the EVSE availability for further charging sessions.

As in the case of the traffic hotspot charging service, the billing scheme must be carefully designed to have as many charging sessions per day as possible due to the importance of having as many charging sessions per day as possible. A billing scheme which only considers time results in too high prices for daytime charging (the price for overnight charging would be 3.875 €/session + 21% VAT ~ 4.69 €/night):

$$EV\ charging\ price_{Time} = CP * (1 + VAT) * \frac{P/2}{E}$$

$$(Gasoline)\ EV\ charging\ price_{Time} = 7.0611\ €/session * (1 + 21\%) * \frac{22\ kW}{10\ kWh/session} = 18.80\ €/h$$

$$(Diesel)\ EV\ charging\ price_{Time} = 6.2134\ €/session * (1 + 21\%) * \frac{22\ kW}{10\ kWh/session} = 16.54\ €/h$$

Therefore, a mixed approach which charges for electricity and time (see end of section 3.1) is more likely to be accepted by EV customers. The maximum price per kWh (so that EVs have a mileage cost competitive against ICE vehicles) can be calculated as follows:

$$EV\ charging\ price_{kWh} = \frac{CP * (1 + VAT)}{E} = \frac{6.2134\ €/session * (1 + 21\%)}{10\ kWh/session} = 0.7518\ €/kWh$$

The time-based tariff should be designed so that it is not too high for EV customers (as public bodies want to promote electric mobility and they are the owners of the parking space) but, at the same time, it is not too low in order to encourage EV customers to leave the EVSE free once they have their EV charged.

6.2 Sensitivity analysis

6.2.1 EVSE amortisation

The EVSE investment cost and the EVSE lifetime data are taken from the latest NPE report [NPE 2014] and are valid for 2013. Although there might be cases where EVSE investment costs are higher (e.g. situations in which the distribution grid must be strongly reinforced, or places where more complicated civil works are needed), future prices are expected to decline. Likewise, future EVSE is expected to last longer due to technological improvement. Moreover, public charging spots for street side parking are expected to be bought in larger volumes that traffic hotspot EVSE, which can reduce their investment cost per unit.

On the contrary, public charging spots for street side parking are more likely to suffer vandalism than EVSE in traffic hotspots and, hence, they are expected to have a shorter lifetime than those.

With all these effects in mind, the assumed EVSE amortisation rate is assumed to be quite conservative, so no sensitivity analysis is performed on this parameter.

6.2.2 Annual mileage

As in the private home charging case, the annual mileage considered in the base case is based on the reported mileage by Nissan Leaf users in Spain [Nissan 2015, 1], but the average mileage of Spanish drivers is significantly lower (9928 km/year).

If 10 000 km/year are considered, the TCOs result:

$$TCO_{Gasoline} = 1511 + 0.113528 * K = 1511 + 0.113528 * 10000 = 2646.28\ €/year$$

$$TCO_{Diesel} = 1738 + 0.101219 * K = 1738 + 0.101219 * 10000 = 2750.19\ €/year$$

$$TCO_{EV} = 2198 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + EV\ charging\ cost$$

$$= 2198 + 0.011 * 10000 + EV\ charging\ cost = 2308 + EV\ charging\ cost$$

By comparing the TCOs, EV charging cost for EV customers must not be higher than 338.25 €/year (2646.28 €/year – 2308 €/year), so that their TCO is comparable to owning a diesel vehicle (for gasoline vehicle, it is about 442.19 €).

Assuming the same distribution of charges as in the base case (80% of mileage is based on public charging spot for street side parking, while traffic hotspots and highway EVSE are used to cover the remaining 20% of mileage), EV customers drive 2000 km by charging in traffic hotspot of highway EVSE and 8000 km by charging in street side EVSE. The worst case scenario for EV customers is when the price for charging their EV in traffic hotspots and highway EVSE is established so that the relative cost of the charging event for them is compared with the refuelling cost of an equivalent trip with a gasoline vehicle:

$$EV\ charging\ cost\ in\ other\ services = 0.084733\ €/km * 2000\ km/year = 169.47\ €/year$$

By adding 21% VAT, this results in 205.43 €/year, so the maximum EV charging cost in public charging spots for street side parking is 132.82 €/year (338.25 €/year - 205.43 €/year). Again, this amount includes VAT, so net amount is 109.77 €/year. Consequently, the number of overnight charging events can be calculated as:

$$Overnight\ charging\ sessions = \frac{10\,000\ km/year * 80\%\ overnight * 0.120\ kWh/km}{10\ kWh/session} = 96\ sessions/year$$

This usage rate results in a charging price of 1.14 €/session, which is one-third the price in the base case, so the required EVSE usage must be much higher:

$$917140 + 109.93 * C = \left(6.2134 * \frac{C}{2} * 124\right) + \left(1.14 * \frac{C}{2} * 124\right) \Leftrightarrow C = 2650.84\ sessions/year \sim 7.26\ sessions/day$$

Consequently, the momentum for EV customers with lower annual mileages is much further in time than for EV customers with higher mileage rates.

6.2.3 EV efficiency

If EV efficiency is lower than in the base case (see section 3.2.3 for discussion) more energy is required to drive the same number of kilometres.

By keeping the assumption that EV customers charge at home one out of two days, but increasing EV consumption to 150 Wh/km, the amount of kilometres driven from overnight charging is lower: 12 000 km per year (180 charging sessions/year * 10 kWh/charging session / 150 Wh/km), so EV customers need to drive 7000 km/year by using other charging services, at a cost of about 593.13 €/year:

$$EV\ charging\ cost\ in\ other\ services = 0.084733\ €/km * 7000\ km/year = 593.13\ €/year$$

As in the base case, the net EV charging cost for EV customers cannot exceed 1036.50 €/year, so the cost of charging in public charging spots for street side parking cannot be higher than 443.37 €/year (1036.50-593.13 €/year) for 180 charging sessions, i.e. 2.463 €/session.

The EVSE Operator's costs and incomes are the same, as long as:

$$917140 + 109.93 * C = \left(6.2134 * \frac{C}{2} * 124\right) + \left(2.463 * \frac{C}{2} * 124\right) \Leftrightarrow C = 2142.77\ sessions/year \sim 5.87\ sessions/day$$

Under the assumption of having the same number of charging session in daytime and overnight, this usage rate cannot be reached, as more than one overnight charging session per outlet is required. Even if the same cost for the EVSE Operator is assumed (which is not the case as electricity is more expensive in daytime charging), two daytime charging sessions per day and per outlet would be required, which is very unlikely to happen in the short to medium term. Therefore, additional sources of revenue are absolutely required.

6.2.4 Other countries

The differences that may arise between different EU Member States are assessed by calculating the results for Spain (base case), Germany and the Netherlands. The main differences considered are the electricity bill structure and the prices for fossil fuels (as in the three charging services above), but also the average distance driven per year.

6.2.4.1 Germany

The process to be followed is the same as described in **Figure 3** and, unless otherwise stated, the values in Table 6 (section 3.2.5.1) are used, except the number of EVSE, which is N=124 as discussed in section 6.1 and the mileage K=15 000 km/year must also be considered.

In the case of EV customers who use this charging service during daytime (sporadic use), the relative cost of the charging event must be compared with refuelling cost of an equivalent trip with an ICE vehicle. The worst case scenario for the EVSE Operator is when it is compared with diesel vehicles, as the charging price is lower price (see section 3.2.5.1):

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.077997\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.077997\ €/km = 6.49975\ €/session$$

Therefore, by adding 19% VAT, the maximum daytime EV charging prices for EV customers to have a competitive mileage cost with diesel is 7.73 € per charging session.

The TCO for EV customers who use the public charging spot for street side parking very frequently must consider that they are not the EVSE Operators in this charging service (so $EVSE_{Inv}$ and $EVSE_{O\&M}$ are not considered here), as well as the equivalent TCOs for ICE vehicles, are calculated as (see section 5.2.4.1):

$$TCO_{Gasoline} = 1656 + 0.121816 * K = 1656 + 0.121816 * 15000 = 3483.24\ €/year$$

$$TCO_{Diesel} = 1958 + 0.103816 * K = 1958 + 0.103816 * 15000 = 3515.19\ €/year$$

$$TCO_{EV} = 3161 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + EV\ charging\ cost$$
$$= 3161 + 0.011 * 15000 + 0 + 0 + EV\ charging\ cost = 3326 + EV\ charging\ cost$$

As in the private home charging service, EV customers charge 180 times in this charging service, so the mileage that EV customers can drive by overnight charging is the same as the assumed annual mileage. Therefore, the cost of EV charging overnight can be up to 157.24 €/year (3483.24 €/year - 3326 €/year), or 132.13 €/year without VAT, i.e. 0.734 €/session.

According to the prices for overnight (0.734 €/session) and daytime charging (6.49975 €/session, to be competitive against diesel vehicles), reminding that there are the same number of charging sessions in each period and assuming that there are no additional sources of income, the incomes for the EVSE Operator are:

$$Annual\ EVSE\ Operator's\ incomes = (CP * C * N) + OS = \left(6.49975 * \frac{C}{2} * 124\right) + \left(0.734 * \frac{C}{2} * 124\right) + 0$$
$$= 448.50 * C$$

The costs for the EVSE Operator in Germany are calculated by using equation (2) and the values in Table 6, but considering that the EVSE Operator must pay MP_{EVSEO} = 2000 € for accessing the marketplace:

$$Annual\ EVSE\ Operator's\ costs\ in\ Germany$$
$$= \left\{ \left[\left((Te * E * C) + (M * 12) \right) * (1 + VAT) \right] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} \right\} * N$$
$$+ MP_{EVSEO}$$
$$= \left\{ \left[\left((0.25 * 10 * C) + (8.60 * 12) \right) * (1 + 0\%) \right] + \frac{10\,500}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + 1725 \right\} * 124 + 2000$$
$$= 457712.40 + 310 * C$$

EVSE Operator's incomes equal costs when:

$$448.50 * C = 457712.40 + 310 * C \Leftrightarrow C = 3304.78\ sessions/year \sim 9.05\ sessions/day$$

This EVSE usage rate means that each of the outlets in the EVSE must be used every day for more than 2 overnight charging sessions and another 2 daytime charging sessions, which is too high. However, if an additional income from advertising of 4000 €/EVSE per year is considered (totalling 496 000 €/year for the 124 EVSE), this income is enough to pay all the fixed costs, so the EVSE Operator would make a profit even if the EVSE were not used at all.

6.2.4.2 The Netherlands

As in the other countries analysed, the process in **Figure 3** is followed in the Netherlands too. The parameters for the analysis are presented in Table 17.

As in the Highway charging service, public charging spots for street side parking cannot be considered as having a living or working function, so there is no reduction in the electricity bill.

Parameter	Value	Unit	Reference
E	10	kWh	Scenario description
EF	120	Wh/km	
N	124	EVSE	
K	19 000	km/year	[51]
VAT_{EVSEO}	0	%	EVSE Operator is not the final customer
$VAT_{EV\ Customer}$	21	%	EV Customers are final customers
MP_{EVSEO}	2000	€/year	See section 2.5.1
F	54	€/year	Prices for a three-phase, 80 A, connection[52]
Te	0.1874	€/kWh	
R	0	€/year	
P	1614.2855	€/year	Grid fees for a 3 x 80 A connection[53]
$EVSE_{Inv}$	10 500	€/EVSE	[NPE 2014]
$EVSE_{O\&M}$	1 725	€/EVSE/year	

Table 17: Values for the parameters in the Public charging spot for street side parking service (The Netherlands)

The daytime charging price is calculated so that sporadic EV customers have a mileage cost comparable to diesel vehicles (see section 3.2.5.2):

$$For\ diesel: CP_i \leq \frac{Ei}{EFi} * 0.078692\ €/km = \frac{10\ kWh}{120\ Wh/km} * 0.078692\ €/km = 6.55767\ €/session$$

By adding 21% VAT, this price gets 7.93 €/session for EV customers.

The TCO in the Netherlands is (see section 5.2.4.2):

$$TCO_{Gasoline} = 2033 + 0.131168 * K = 2033 + 0.131168 * 19000 = 4525.19\ €/year$$

$$TCO_{Diesel} = 2335 + 0.106217 * K = 2335 + 0.106217 * 19000 = 4353.12\ €/year$$

$$TCO_{EV} = 3538 + 0.011 * K + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5} - 1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M} + EV\ charging\ cost$$

$$= 3538 + 0.011 * 19000 + 0 + 0 + EV\ charging\ cost = 3747 + EV\ charging\ cost$$

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[51] Average mileage in the Netherlands is about 9200 km/year [OECD 2014], which is very close to the Spanish average. Hence, the same 19 000 km/year as in Spain are assumed for EV customers.

[52] http://www.nuon.nl/mkb/lightbox/tarieven-flexibel.jsp [access in February 2015].

[53] https://www.enexis.nl/consument/diensten-en-tarieven/tarieven/elektriciteit/periodieke-netwerktarieven-e?pageid=44 [access in February 2015].

Hence, EV charging cost for EV customers cannot exceed 606.12 €/year, or 500.93 €/year excluding 21% VAT.

Assuming 180 charging sessions per year, 15 000 km/year can be driven out of public charging spots for street side parking, but another 4000 km/year must be charged by using other charging services. The cost of those other charging services in the worst case (if their price is set to compete against gasoline) is:

$$EV\ charging\ cost\ in\ other\ services = 0.099312\ €/km * 4000\ km/year = 397.25\ €/year$$

As a result, the maximum EV charging cost for EV customers in public charging spots for street side parking is 103.68 €/year (500.93 €/year - 397.25 €/year), which, for 180 sessions/year result in an overnight charging price of 0.576 €/session. Consequently, EVSE Operator's incomes are:

$$Annual\ EVSE\ Operator's\ incomes = (CP * C * N) + OS = \left(6.55767 * \frac{C}{2} * 124\right) + \left(0.576 * \frac{C}{2} * 124\right) + 0 = 442.29 * C$$

The costs for the EVSE Operator in the Netherlands are calculated by using equation (3):

$$Annual\ EVSE\ Operator's\ costs\ in\ the\ Netherlands = \left\{[(F + P + (Te * E * C) - R) * (1 + VAT)] + \frac{EVSE_{Inv}}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + EVSE_{O\&M}\right\} * N + MP_{EVSEO}$$

$$= \left\{[(54 + 1852.56 + (0.1868 * 10 * C) - 98.86) * (1 + 0\%)] + \frac{10\,500}{\frac{(1+7\%)^{7.5}-1}{7\% * (1+7\%)^{7.5}}} + 1725\right\} * 124 + 2000 = 669070.40 + 231.63 * C$$

EVSE Operator's incomes equal costs when the EVSE are used about 8.70 times per day:

$$442.29 * C = 669070.40 + 231.63 * C \Leftrightarrow C = 3176.07\ sessions/year \sim 8.70\ sessions/day$$

This EVSE usage rate is too high, so additional incomes are required by the EVSE Operator to have a profitable business. By considering an advertisement income of 4000 €/EVSE per year (496 000 €/year for the 124 EVSE), the required EVSE usage can be reduced to:

$$442.29 * C + 496000 = 669070.40 + 231.63 * C \Leftrightarrow C = 821.56\ sessions/year \sim 2.25\ sessions/day$$

This usage rate is very similar to the one required in Spain if incomes from advertisement can be obtained. As discussed in the base case, this usage rate can be obtained when there are enough EVs on the road and in the EVSE located in places where overnight charging will take place every day and the location is also attractive for daytime charging.

7 Summary and discussion

Electric mobility is a very complex ecosystem, where a network of actors interrelate with each other and where regulatory and market structures still need to be defined. However, despite the advances in the last couple of years, EV market is still incipient, so it is difficult to have profitable business models under present conditions. Therefore, the analysis presented here looks more into the future (medium term), where the assumed number of EVs on the road is enough to create a considerable demand of public charging infrastructure.

Four charging services are presented to describe different charging alternatives for EV customers. In each of them, the required EVSE usage for all the involved stakeholders to have a positive business case is calculated.

In the traffic hotspot and highway charging services, the EVSE Operator aims at establishing an EV charging price which is enough to recover all its costs, while, at the same time, allows EV customers to have a cost per kilometre lower than diesel or gasoline vehicles for an equivalent trip. For that purpose, EVSE usage is of paramount importance: as EVSE usage increases, the required EV charging price to cover all EVSE Operator's cost decreases, which allows EV customers to have a lower cost per kilometre, until it becomes competitive against ICE vehicles.

The traffic hotspot charging service can be profitable if 3-4 charging sessions per EVSE and day are achieved, which, taking into account that each EVSE has two outlets, may be feasible if there are enough EVs on the road, thanks to the hotspot nature of the location. In general, the electricity bill design is an important parameter, with better conditions if fixed costs are low in comparison with variable costs. As an additional source of value to increase EVSE profitability and improve the performance of the business model at lower usage rates, advertising can be a good option. The effect of EV technological development (either by increasing battery size or improving EV efficiency) is difficult to predict, as it may encourage customers either to charge more or less often at this type of EVSE.

In the highway charging service it seems more difficult to make a profit in the short-term, because, if the EVSE Operator aims at offering an EV charging price that makes EV customers have the same cost as an ICE vehicle for an equivalent trip, it needs to have 7-8 charging sessions per EVSE and per day to cover its costs. The main reasons for the worse performance of this service is the high EVSE investment and O&M costs, together with a lower EV driving efficiency resulting from the higher driving speeds in highways. Moreover, the range of existing EVs is not suitable for long-distance trips, which is the main driver for EV customers to use highway charging. Although advertising does not seem as attractive as in traffic hotspots, it could be a complementary option to increase EVSE incomes. The incomes for the EVSE Operator can be further increased if there is a shop or a restaurant attached to the EVSE, as EV customers must wait until the charging process finishes and, thus, they are likely to spend more money while charging. An additional way to improve business performance is to install an EVSE with dual charging (DC+AC) capabilities, since, although it increases the required EVSE usage rate to about 8-9 sessions per day, it allows to charge two EVs at the same time and enlarge the portfolio of potential users of the EVSE, making it easier to reach the required number of charging sessions.

However, the expected increase in battery size (which can result in double the battery size as early as in 2016, see footnote 20) will have a positive effect on the economic performance of highway charging. On the one hand, EV customers will gain confidence and will opt to make more long-distance trips, which will increase the number of potential users of the highway charging service. On the other hand, they will charge more energy each time they use the service, so a lower EVSE usage rate will be enough to cover all the costs, as many of them are fixed costs. Moreover, charging more energy means spending more time while charging, which will result in an increasing income from additional sources of revenue, as discussed above. Therefore, the required EVSE usage rate can be reduced to 2-3 charging sessions per day (up to 4 if there are no incomes from advertising), which is quite likely to be reached in the future, when there are enough EVs on the road and they are able to drive longer distances in the highway, thanks to the increased battery size.

Private home charging service is the preferred option by EV customers who can charge at home, because it is the low-cost option for them when time-of-use tariffs are available, even if the investment in the EVSE is taken into account. In general, these EV customers are expected to charge their EVs at home regularly, so that they normally start their trips with a full battery, and only use the other charging services when they have specific, unusual needs to extend their daily range. For EV customers with high annual mileages and who use it intensively (more than about two thirds of the kilometres are driven by charging at home), it offers a better TCO than ICE vehicles even today, if subsidies for EV purchase are considered. It is also important that regulation does not impose too strict technical requirements for private home EVSE, as they may increase cost so much that the TCO is not competitive any more.

The public charging spot for street side parking is the most complex service, as it is the one in which more actors are involved as two different usage patterns are considered for EV customers. On the one hand, it is used by EV customers who do not have access to private home charging for overnight charging, while, on the other, it is used by other EV customers to charge their EVs during the day. The price to be requested to each type of customer is different, as the costs for the charging sessions and the value provided to them also differ.

EV customers who use this charging service sporadically (EV customers with access to private home charging and use public charging spots for street side parking just to increase their range during the day, as in the traffic hotspot charging service) must have a cost per kilometre which is competitive against ICE vehicles, so the EV charging price for daytime charging has to be carefully selected. Likewise, EV customers who use it as their preferred charging alternative (EV customers without access to private home charging who use this charging service overnight) must have an ownership cost which is comparable or lower than the cost of owning an ICE vehicle, so, again, the overnight EV charging price that EV customers would accept to pay is limited. By considering these pricing limitations, the only way for the EVSE Operator to recover all its costs is if the EVSE usage rate is increased. In the public charging spot for street side parking, almost 5 sessions per EVSE and per day are needed for the EVSE Operator to make a profit while offering competitive prices to EV customers. Once more, advertising appears to be a good option.

Figure 4 below presents the required EVSE usage rate so that the EVSE Operator can recover all its costs and request a charging service price which allow EV customers have a mileage cost which is comparable to the mileage cost of an equivalent trip with a diesel vehicle.

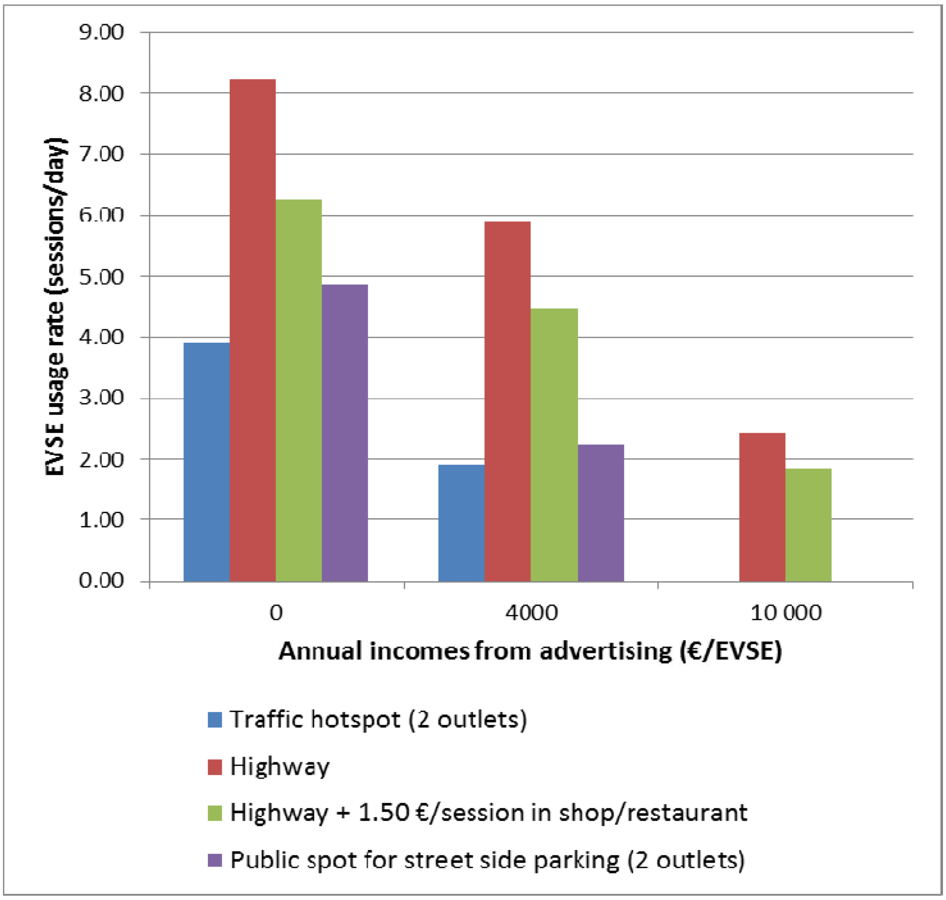

Figure 4: Required EVSE usage rate for EV mileage cost to compete against diesel vehicles

On the grounds of these findings, it seems that EV customers with private home charging availability will be the early adopters of electric mobility, as long as they need to use their EVs regularly and there are subsidies for EV purchase. Then, as EV market grows, publicly accessible EVSE with semi-fast charging capabilities are likely to appear in cities and traffic hotspots. In the meantime, technology development is expected to increase driving ranges while reducing costs, so that highway charging can also be profitable in the medium-term.

Until these technological developments materialise, electric mobility should be supported by a favourable regulatory framework. By comparing the electricity bill structures in the countries analysed, giving more weight to the consumption component (variable part vs. fixed part) and allowing price differences within a day (time of use tariffs) to create better conditions for electric mobility. This effect is further strengthened if higher fuel excise taxes are applied to gasoline and diesel prices. Direct subsidies for EV purchase are also important to improve EV customers' TCO and, thus, they are especially relevant to enhance the performance of private home charging and public charging for street side parking. However, these subsidies should be phased out as the market conditions and technological development improve the economics of EV ownership. In any case, rigorous cost-benefit analyses must be performed, also including the social component, before any subsidy scheme is considered, in order to be efficient, i.e. to reach the objective of promoting electric mobility without unnecessary public spending. Moreover, the regulatory framework should also provide additional incentives for infrastructure deployment, as public charging beyond traffic hotspot does not seem to be profitable at the current trends of EV market penetration rate.

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