

## Deploying charging infrastructure for electric vehicles; viability analyses for municipal and private car parking facility operators

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A lot of research has been done on the adoption of electric vehicles and on the deployment of the infrastructure for charging the batteries of these vehicles. Currently the total number of installed charging points keeps growing due to both public and private investments. Often charging services are offered as free service extensions. Maintaining this free business model will be difficult on the long term because of the investments needed. Therefore, the long term business viability and durability is not always clear from an investor point of view. This work presents a techno-economic model that describes the expected cost and revenue evolution resulting from different deployment strategies for a municipal or private parking facility operator. For charging service providers, charging pole exploiters and infrastructure owners for electric vehicle charging, the model allows to project the expected profitability. The main findings from this research indicate that business cases for public charging infrastructure can be viable, durable and could be competitive with the costs for charging the electric vehicle at home. Also, in a multi-actor market model all actors involved could benefit from deploying electric vehicle charging infrastructure. Although the business cases will be positive, significant investments are needed.

*Keywords:* actor analysis, deployment strategy, economic viability analysis, electric vehicle charging infrastructure, techno-economic modelling.

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### 1. Introduction

The increasing pressure on the fossil fuel sources, the more difficult extraction of these energy resources and its overall negative impact on the global environment resulted in a reviving interest in electric vehicles as a 'green' alternative over the last decade. National and international efforts led to an extensive list of research on the technology for electric vehicles (EVs, both Plug-in electric vehicles (PHEV) and battery powered electric vehicles (BEV)), the adoption of EVs, the charging infrastructure and the deployment of it. Also most of the developed countries formulated goals towards the adoption of EVs and the stimulation of it by 2020 (Belga/TV, 2012) (Electric Vehicle Initiative (EVI), 2013), whether or not based on targets formulated by the European Commission (European Commission, 2011). In the quest to reach these ambitious goals, numerous EV-introduction pilots and test projects were set up.

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Due to the limited driving range of current EV models, range anxiety (the fear of not being able to reach the destination because of the limited driving range (Lundström et al., 2012)) and charge anxiety (the fear of not being able to recharge the battery at the destination point and therefore not being able to return from the destination (Lundström et al., 2012)) are seen as two major issues that need to be addressed before a general adoption of EVs will take place (Wiederer and Philip, 2010) (Peterson et al., 2010). Research indicates that from a socio-economical viewpoint it would be more optimal to invest in additional battery capacity if all users had the same battery capacity smaller than 25kWh and the investments for additional infrastructure would be borne by people who need the extra infrastructure. But since many deployment projects for charging infrastructure are subsidized by governments and costs are borne by all EV drivers, investing in additional charging infrastructure is more economic than investments in additional battery capacity (Gnann et al., 2012). Due to the importance of a widely available network of charging infrastructure for EVs (Kearney, 2011) (and for alternative fuels in general (Flynn, 2002)), whether or not funded by the government or private investors, this research focuses on and aims to answer the following questions: In the role of parking facility operator, being a municipal or private actor, how much charging infrastructure is needed and when? What will be the investment and could a viable business case be obtained?

#### *Literature overview*

Several publications can be found that describe the geographical implementation of charging infrastructure based on geographic information system (GIS) (Liu, 2012) (Dashora et al., 2010). Other researchers modelled the implementation as clustering problems (Ip et al., 2010) or as (mixed) integer linear programs (ILPs) (Kim and Kuby, 2012). The current paper aims to answer how many charging points and at what fee charging services can be offered from a parking provider's perspective. It assumes that there is no freedom in geographical deployment, because the available parking lots are already clustered in parking buildings or dedicated areas. Therefore geographical implementation is not treated in this paper.

On the temporal character of the EV charging infrastructure deployment, a lot of literature is available. The adoption of EVs over time is often the key driver for this type of research. Numerous reports and literature describe the adoption and diffusion models of EVs (International Consultancy Group, 2010) (Lieven et al., 2011) (Graham-Rowe et al., 2012). In their work, (Al-Alawi and Bradley, 2013) give an extensive overview of previous studies on EV market penetration rates and their results. Three main methods for market adoption projections can be recognized and are based on 1) agent-based modelling, 2) consumer choice modelling, 3) diffusion rate and time series modelling (Al-Alawi and Bradley, 2013). Although there exists a significant variation between the available EV diffusion models (Hacker et al., 2009), the forecasted diffusion rate of EVs in Belgium, used in this research, results from user research conducted in a Flemish study on smart plug-in automobile renewable charging services (SPARC) (iMinds vzw., 2012). The input describes a Bass model (Bass, 1969) for determining the EV share in Belgium for the near future. But based on the findings of Lamberson (Lamberson, 2009), the numerical model also allows formulation of the adoption via a Gompertz diffusion model (Gompertz, 1825).

In their research, Stuben and Sterman (Struben and Sterman, 2008) present a model that incorporates various socio-, techno- and economical parameters in order to determine the adoption model for alternative vehicles. The authors show the importance of the word of mouth to internal combustion engine (ICE) drivers and indicate the need for subsidies for alternative vehicles in order to foresee a sustainable adoption of it. It has been modified and applied to the temporal evolution of the EV market share in the UK in particular by Shepherd et al. (Shepherd et al., 2012). In their work the authors show the importance of policy measures and incentives for the emerging market to be sustainable. On the other hand they conclude that although subsidies are needed, they do not have a significant impact on the sales of EVs.

In (Wiederer and Philip, 2010), Wiederer et al. formulate a set of policy recommendations on the deployment of charging infrastructure. Key recommendations vary from providing subsidies in the form of waiving parking fees to subsidizing private investors to deal with the uncertainty of the premature technology. In their work (Lutsey and Sperling, 2012), Lutsey and Sperling sum up some stimulating initiatives in the US and the authors formulate new policies regarding the inclusion of upstream greenhouse gas emissions. In addition, various local and national governments provide development plans or guidelines on the deployment on EV charging infrastructure (e.g. California (US) (Governor, 2013) and the collaborative effort between the International Energy Agency (IEA) and the Electric Vehicles Initiative of the Clean Energy Ministerial (EVI) (Electric Vehicle Initiative (EVI), 2013)).

Together with the growing market of EVs, the market for charging services is growing as well. Currently many of the large scale deployments of EV charging infrastructure are directly or indirectly subsidized by local or federal government (Chang et al., 2012). At present, charging services are often offered for free (e.g. as service extension) resulting in acceptable costs, but a non-durable and long term viable situation, for the charging service providers. New markets, with new actors and new business models are arising. In (San Román et al., 2011) and (Kempton et al., 2013), the authors describe several charging scenarios e.g. charging stations on private property with public access, public street charging, etc. and EV charging service offers as well. In (Chang et al., 2012), the authors clarify current revenue models of various stakeholders such as the charging point owner and the electric network operator. The authors foresee also a discounted cash flow analysis in order to investigate the durability of certain revenue models. (Kley et al., 2011), (Chang et al., 2012), (Accenture, 2010) and (San Román et al., 2011) describe new market roles, new actors, new market models and their characteristics. The market models used in this research are based on and are elaborations of these previous findings. In addition with previous studies on EV charging, this research aims to quantify and investigate whether or not certain business models are durable and viable for the actors involved.

In this research we rely on the IEC 61851 standard as the technical reference. This European/ Chinese standard is derived from the J1772 SAE-standard from the US auto industry. Both standards describe the technical requirements for EV charging infrastructure, ranging from the power levels to the physical connection with the vehicle (IEC 62196). The IEC 61851 standard distinguishes four charging modes based on the charging power and communication between the charging infrastructure and the EV. Table 1 gives an overview of the several modes according to the IEC 61851 standard (International Electro technical Commission, 2010).

**Table 1. Overview of the IEC 61851 charging modes**

Charging mode	Max. current	AC/DC	Max. charging power (single-phase)	Max. charging power (three-phase)
Mode 1	16 A	AC	3,7 kW	11 kW
Mode 2	32 A	AC	7,4 kW	22 kW
Mode 3	63 A	AC	14,5 kW	43,5 kW
Mode 4	400 A	DC	50 kW	-

As said in the beginning of this section, there is already a lot of research available on the adoption of EVs, the used technology and the emerging markets for charging services. The goal of this paper is to complement this research by focussing on potential costs, benefits and sustainability of EV charging infrastructure deployment by a private parking facility operator or in a municipal multi-actor scenario. Therefore the focus is on specific market actors such as parking providers and municipalities instead of local or national city developers or planners.

## 2. Electric vehicle charging service market model

It took many years before the market was ready for today's traditional car with an internal combustion engine (ICE). There was already a widespread availability of gasoline fuel before the first Ford Model T vehicles made their entrance in 1908. Fuel was sold in cans at general stores, at automobile repair garages, etc. Because of that widespread availability of fuel, vehicle sales were not slowed down and boomed because of cost reductions due to the mass production. In 1920 first service stations aroused like we know them today (Melaina, 2007).

In contrast with the early days of the traditional ICE vehicles, availability of an adequate network of charging points for electric vehicles (EVs) is not in place yet. Therefore EVs are facing a chicken or egg problem (Struben and Sterman, 2008). What will come first? An overall available charging network which would lower range anxiety significantly for many potential EV drivers or clients that will drive EVs and use the charging services?

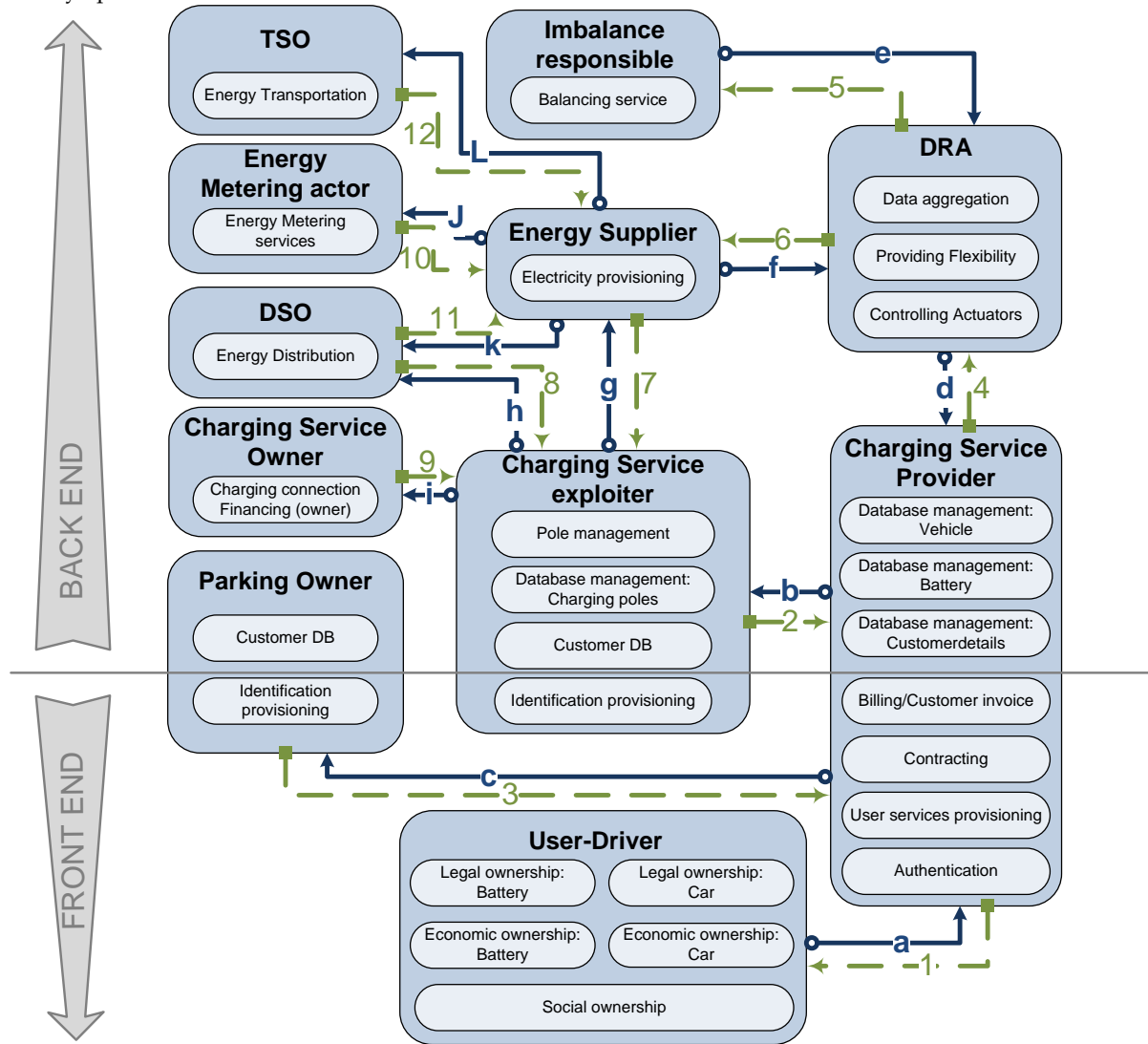
This time, policymakers realise that without governmental interference the market for EVs will take too much time and effort to develop because of the well-established oil and car industry. In current societal context where pressure on the climate and oil price variance are two of the main concerns for providing durable transport, governments/policymakers believe that providing incentives and adjusting regulations is the way to go and many national and local governments took up their responsible role and defined a number of public investment projects to deploy electric vehicle charging infrastructure (Kearney, 2011) (Wiederer and Philip, 2010) (Lutsey and Sperling, 2012) (Electric Vehicle Initiative (EVI), 2013). Indeed, research indicates that extra effort of politics is needed to provide a sustainable market landscape (Chang et al., 2012), (Momber et al., 2011). Efforts of policymakers will not be limited to providing financial incentives towards potential EV drivers, but will extend to the formulation of a legal framework for the involved actors to operate in. Also guidelines and specific incentives must be foreseen (for specific actors like distribution system operators, etc.) to ensure a durable integration of EVs in the current grid (Momber et al., 2011).

Also more and more private investors like large shopping malls, parking providers, etc. have been showing interest in the deployment of charging infrastructure (e.g. IKEA, Wal-Mart, Walgreen, etc. (Green Retail Decisions, 2013)). Energy providers see potential in provisioning charging services for EVs as well. The strong growth of the amount of wind turbines requires some buffer and flexible switching capacity (Veldman et al., 2013). Accumulated battery capacity could play a significant role in the future smart grid story.

Managing all these different market players requires a clear market model for offering electric vehicle charging services (Kley et al., 2011) (San Román et al., 2011). Based on a market model formulated by (Accenture, 2010) a more elaborated market model for provisioning charging services for EVs is defined in this research (Figure 1). The model allows indicating not only the financial and service flows; also the energy flow could be highlighted. It needs to be stressed that the proposed market model is consistent with the structure and regulations of the current European energy market. Using the model outside these boundaries could require making adjustments to the model. Important roles and actors in the market model are described in Table 2. A role is the minimum task set that needs to be fulfilled in order to provide added value for an actor. An actor (institution, person or firm) can be responsible for one or more roles.

**Table 2. Overview of actors and their roles in the market model (Accenture, 2010) (Kley et al., 2011) (San Román et al., 2011) (Bolczek et al., 2011)**

Actor	Roles
Energy supplier	Electricity provisioning
Distribution system operator (DSO)	Responsible for the electrical connections and the distribution of energy
Transport system operator (TSO)	Responsible for the transport of energy
Energy metering actor	Monitoring and validating the energy consumption
Balance responsible	Adjusting electrical supply and demand in order to balance the network load. So there are no shortages, blackouts or excesses of electrical power.
Demand response aggregator (DRA)	<ul style="list-style-type: none"> <li>- Aggregation of consumer data</li> <li>- Providing flexibility to energy suppliers and imbalance responsible actors.</li> </ul>
Charging infrastructure owner	Providing the financial assets to deploy charging poles (e.g. current oil companies, but also advertisement service operators do pilot deployments (e.g. (LastMileSolutions, 2012))
Charging infrastructure exploiter	<ul style="list-style-type: none"> <li>- Managing, exploiting and maintaining the poles and control infrastructure (e.g. logging and error databases, etc.).</li> <li>- Customer identification interface provisioning at the charging points</li> </ul> <p>This actor needs to check whether there is an agreement with the charging service provider of the EV driver to use the charging infrastructure. This actor can exploit charging poles which are owned by another actor. For instance a general store can exploit poles owned by advertisement service operators.</p>
Charging service provider	<ul style="list-style-type: none"> <li>- Offering charging services, pole access, authentication and billing services, based on the contractual agreements.</li> <li>- Maintaining all the user, battery and vehicle databases.</li> </ul> <p>This actor provides a network of charging infrastructure to its customers by buying access rights from different charging infrastructure exploiters. Ideally EV drivers have one contractual relationship (subscription, fee per usage, post/pre-paid, etc.) with the charging service provider to have charging rights and access to a wide network of charging points regardless different charging point exploiters.</p>
Parking owner	Parking place and/or facility ownership
User- driver	<p>The driver is the service user, but the battery can be owned by another actor (e.g. the car manufacturer can remain the owner of the battery and lease it to its customers. In that case, the owner of the battery can decide which charging speed is allowed for instance)</p> <ul style="list-style-type: none"> <li>- Legal ownership: being the legal owner of the asset. This actor bought the battery or EV. (e.g. car leasing company)</li> <li>- Economic ownership: being the operational owner of the asset but not per se the legal owner. (e.g. the company which leases vehicles from a car leasing company)</li> <li>- Social ownership: being the end user of vehicle (e.g. employee of a company that leases their vehicles from a car leasing company)</li> </ul> <p><i>Note:</i> in some cases the different types of ownership can assigned to three different actors.</p>



**Money streams**

- a service subscription or pre/post-paid service fees (cf. telecom contracts)
- b fee for charging facilities and energy
- c fee for parking facilities
- d fee for power flexibility aggregated over all customers of a charging service provider
- e fee for flexible power availability and switching possibilities
- f fee for flexible electrical power, distribution costs and grid use included
- g fee for electricity consumption
- h fee for electrical connection
- i fee for leasing the charging poles
- j fee for energy metering
- k fee for electricity distribution
- l fee for electricity transport

**Service streams**

- 1 providing a network of charging and parking services (cf. telecom provider)
- 2 access to charging infrastructure
- 3 access to parking infrastructure
- 4 offering flexibility aggregated over all customers (e.g. a charging service provider could offer a cheaper service offer to its clients if they allow active switching flexibility on their battery)
- 5 offering flexible power availability and switching possibilities
- 6 offering electrical power by flexible switching on customers
- 7 Energy provisioning
- 8 Providing or upgrading the electrical connection
- 9 Leasing charging infrastructure
- 10 Providing energy monitoring data
- 11 Energy distribution
- 12 Energy transport

Figure 1. Market model for offering charging services for EVs

Depending on the location of the charging infrastructure, different user scenarios with each different market models are expected (e.g. home charging scenario versus charging at a municipal charging point). This market model provides a generic market structure, but depending on the local regulations different actors can be responsible for different roles. For instance in Europe, TSO's are often also responsible for the grid balance and DSO act as energy metering actors as well sometimes. Because of the similar core roles, another possible role aggregation is for instance the energy supplier who also provides the charging services.

The charging location also determines the type of equipment that needs to be installed. A simple home charger unit will not suffice when installed at a public parking spot and a medium-speed charging system for charging the EV overnight is an overshoot as well (Schroeder and Traber, 2012) (Wiederer and Philip, 2010) (Wirges et al., 2012). Table 3 describes the four main charging location categories together with the needed charging infrastructure and capital.

**Table 3. Overview of EV charging infrastructure**

Charging scenario	Charging characteristics	Charging infrastructure according to the IEC 61851 norm (International Electrotechnical Commission, 2010)	Charging power [kW]	Time needed for charging a complete depleted 25kWh battery [h] (simplification: $\cos\phi = 1$ ) (Schroeder and Traber, 2012)	Magnitude of the investment (including costs for grid reinforcement and transformer cost) [euro] (Schroeder and Traber, 2012) (Liander, 2012) (de Koninklijke Nederlandse Toeristenbond ANWB, 2013)
A: Home	Overnight charging	Mode 3 slow charging infrastructure*	3.7 kW	6.75h	1000-3000€
B: Work	Charging during working hours	Mode 3 slow charging infrastructure	3.7 kW	6.75h	1000-3000€
C: Private owned parking facility	Charging during short visits (shopping malls, city visits, etc.)	Mode 3 slow + medium charging infrastructure	3.7/11 kW	6.75/2.3h	10000-15000€
D: Municipal parking facility	Idem previous scenario + charging overnight when no access to a private charging installation	Mode 3 slow + medium charging infrastructure	3.7/11 kW	6.75/2.3h	10000-15000€

\* Mode 3 slow charging infrastructure indicates that charging speed is fixed at 3.7kW. The internal safeties and communication provisioning meet the Mode 3 standards. Medium charging speed is used for charging power around 11kW.

Because not all EV owners will have the possibility to charge the EV in their own garage, in front of their house or at work, low barrier alternative solutions must be available for this category of EV owners. A wide availability of public charging infrastructure, or having charging infrastructure available at the private parking lot they rent would be worthy alternatives for home charging or charging at work. Installing charging infrastructure at home when driving an EV and providing infrastructure for employees with electric company cars is believed to become obvious and does not require a viable multi-actor market model. But for the deployment of charging infrastructure in the scenario of a private (scen. C) or municipal parking facility

operator (scen. D), the market model (fig.1) must be viable for all actors involved. This implies that all actors must at least have a positive cost/benefit balance as a result of fulfilling market roles. In this research, focus is on the business viability and durability of the business models of the private parking facility operator, charging service provider, charging pole exploiter and infrastructure owner.

Note that a charging scenario does not demand a particular contractual relationship with the EV driver. Several contractual relationships can exist (e.g. fee per usage, subscription model, pre-paid cards, etc.)

### 3. Methodology: Techno-economic assignment and investment model

Although policy measurements could significantly accelerate the adoption of EVs (Wiederer and Philip, 2010), this research focuses on the business viability of a large scale deployment of infrastructure. A techno-economic model has been developed in order to determine the amount of charging poles needed to provide a sufficient service level to maintain and attract future EV-drivers. Via a net present value (NPV) analysis, a viable charging fee proposal could be made.

Since the desired availability ratio of the installed charging poles (the chance that an EV-driver cannot charge his vehicle because all charging points are in use) impacts the amount of installed poles, the complete techno-economic model is a waterfall model with strategic requirements as starting point. Figure 2 gives a schematic overview of the model structure.

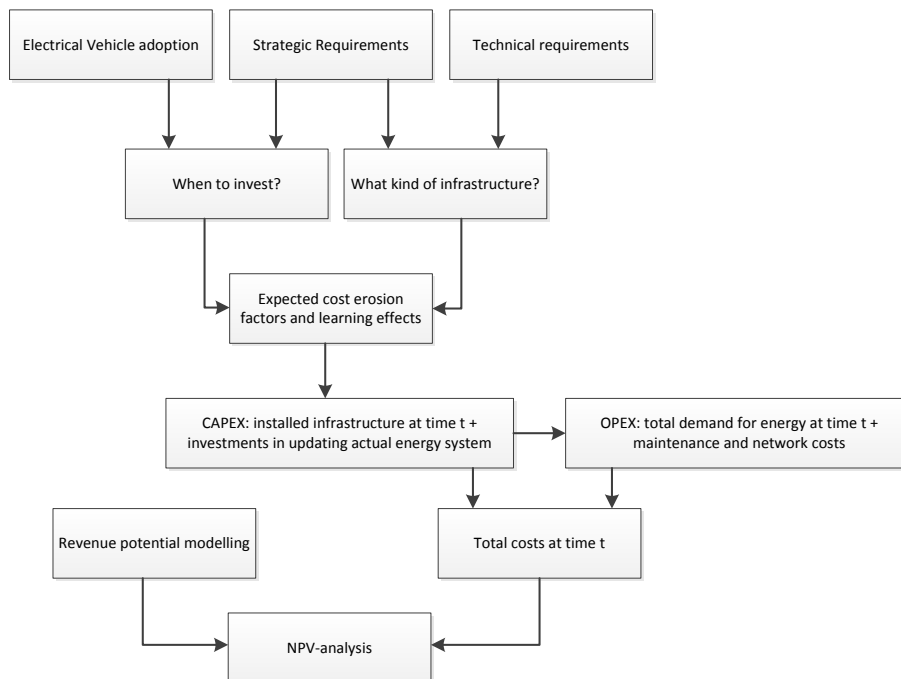


Figure 2. Schematic structure of the model



### 1. Electric Vehicle adoption:

Although the availability of charging infrastructure is a critical success factor for the adoption of electric vehicles, the number of installed charging poles will be driven by the expected adoption of EVs. Based on user research and previous studies (Elektrische voertuigen in Actie, 2012) (International Consultancy Group, 2010), an expected adoption curve has been created, but the user of the model can also formulate an own adoption curve. This can be done by adjusting the input parameters of a Gompertz diffusion model (Gompertz, 1825). See Figure 4 for the expected adoption curve for EVs in Belgium.

### 2. Strategic and technical requirements:

Both building blocks allow the formulation of constraints imposed by managerial decisions or through technical aspects. For example, the management wants to maintain a certain availability ratio of the charging infrastructure so whenever that condition could not be met any longer additional charging infrastructure needs to be installed. Or at least one quick charging unit needs to be foreseen per car park, etc. Also management needs to determine the type of infrastructure. This imposes technical constraints (See Table 3) and influences the magnitude of the investments as well.

### 3. When to invest and what kind of infrastructure to install?

Based on the expected share of EVs and the strategic demands (the maximum allowable rejection rate because all charging poles are occupied) an M/M/s/s queuing model (Laragan, 2000) (Kharoufeh, 2013) presents a time-dependent deployment strategy for the appropriate charging infrastructure. The number of charging poles, required to satisfy the desired rejection rate, is projected until 2030. An M/M/s/s queuing model is the Kendall's notation for an Erlang Loss or Erlang Formula B queuing model with exponential distribution for the average arrival ( $\lambda$ ) and average service times ( $\mu$ ). The arrival rate is determined as an average amount of arriving vehicles per hour. But since the proportion of EVs will grow in the future, the arrival rate of EVs will change over time. The complete process buffer is equal to the number of servers, being parking spots in this case (see Figure 3). The model is often used to determine the size of parking facilities (Laragan, 2000).

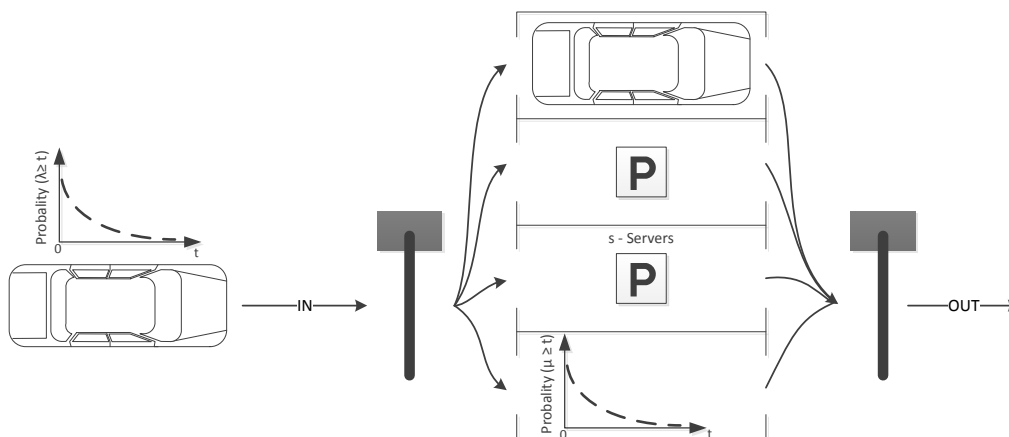


Figure 3. Principle of M/M/s/s queuing system

4. Expected cost erosion and learning effects

Our calculation model allows modelling the impact of learning effects, cost/price erosion and economy of scale effects. Price erosion effects simulate the decrease in price of the hardware because of the maturing technology. The increase in efficiency for the installation of the charging poles leads to a lower installation costs over time, this is modelled by an extended learning curve (Olsen and Stordahl, 2004) (see figure 5) (K-value: 0.97 for the components and 0.99 for the decreasing installation cost. According to (Olsen and Stordahl, 2004), the used K-values are in both case conservative). At last, economies of scale mean that when buying/producing hardware in bigger quantities, lower prices can be expected. These effects can also be modelled via step functions (evolution of price decrease modelled a.f.o. number of charging points: 1-50 points: 100%, 51-100: 97%, 101-300: 95%, 300-600: 85%, >600: 80%)

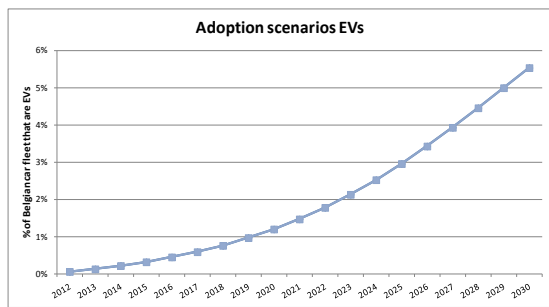


Figure 4. Modelled adoption curve for EVs in Belgium

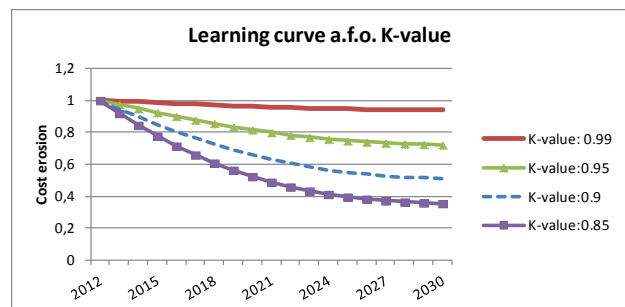


Figure 5. Effect of k-value on extend learning curve

5. Capital and Operational expenditure (CAPEX & OPEX)

CAPEX or capital expenditures are the sum of all the investments in physical assets (installation of the infrastructure). Most significant CAPEX and their cost drivers are presented in figure 6. OPEX or operational expenditures are the sum of all the costs that result from delivering and maintaining the charging services.

Because of the earlier described cost erosion, learning effects and economies of scales, the evolution of CAPEX and OPEX is time dependent.

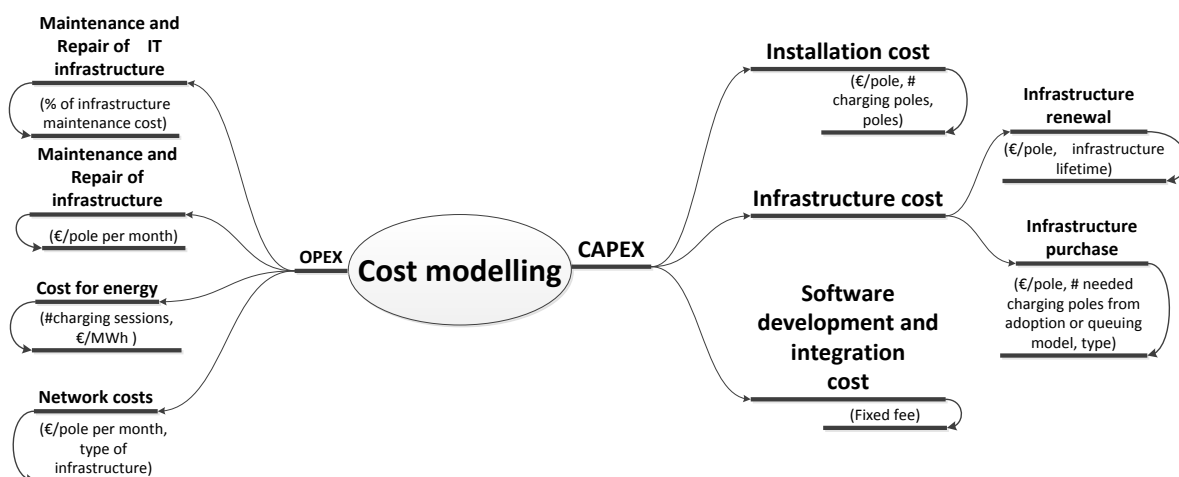


Figure 6. CAPEX and OPEX breakdown

To model the yearly cost for electricity, the amount of expected loading sessions per year is calculated by (1). Since the total amount of loading sessions drives the revenue potential, it is

worthwhile to focus on the formulation of this number. The number of loading sessions per year is derived from the pole occupancy rate. This last number is a result from the M/M/s/s Erlang Loss queuing model.

$$\begin{aligned} \text{charging sessions}_t = & \text{charging poles}_t \times \frac{\text{sockets}}{\text{pole}} \times \frac{\text{available charging hours}}{\text{day} \times \text{sockets}} \\ & \times \frac{365 \text{ days}}{\text{year}} \times \frac{\text{sessions}}{\text{hour}} \times \text{pole occupancy rate}_t \end{aligned} \quad (1)$$

With:

charging session<sub>t</sub> = Total amount of charging sessions in year t

charging poles<sub>t</sub> = Total amount of charging poles in

To model the yearly demand for electricity, we multiply the total amount of charging sessions with the average demand of energy derived from the State of Charge (SOC) model that indicates the average state of charge of an EV battery over a day. The model was developed in the research project (based on (Van Roy et al., 2011)). This SOC-model indicates that arriving average EV-drivers that can charge their vehicle overnight at home are expected to have a minimum SOC of 81%. Or in other words, the expected demand for energy of an average EV-driver that can charge his vehicle at home is about 4.75 kWh (battery size of 25 kWh). 4.75kWh used for transportation at a current average driving efficiency of 0.14 kWh/km results in a daily average trip length of 34 km, which is a bit less than the Belgian average trip length per day per person, which is 42 km (Kwanten, 2013). This demand for electricity multiplied with the expected evolution of the electricity cost as given in (European Commission, 2009) (van den Bulk, 2009) leads to a total yearly cost for electricity (incl. grid access costs, transport cost) . Adding the CAPEX and OPEX results in the total expected costs in year t.

## 6. Revenue potential modelling

Direct revenues stem from fees for the charging activity, modelled as fee/hour or fee/ amount of transferred energy. Complementary sources for revenue streams are for instance subscription models for the EV drivers. When an EV driver would allow demand response aggregating parties to control the charging sessions in order to balance the load on the electrical grid, the EV driver would be financially compensated for that. Providing flexibility indeed will result in uncertainty about the state of charge of the battery. Load balancing is not in the scope of this research, so it does not result in complementary revenues.

Next to the direct revenues, deploying and providing charging services for EVs will lead to indirect effects as well. City marketing, the green image and the service level increase are often important aspects for municipalities and early charging service providers. This work takes only into account the direct, quantifiable revenues only.

## 7. Net present value & discounted cash flow analysis

Because this model is a projection of future investments and future cash flows we have to take into account the time value of money. Therefore the cash flows are discounted in each year, in other words future investments are corrected to actual value. Adding all the discounted cash flows for each year, the Net Present Value (NPV) of the project can be calculated (formula given by (2)). The project is profitable as the NPV of the total project period is >0. We refer to (Verbrugge et al., 2008) for more information on investment analysis.

$$NPV = \sum_{i=0}^n \frac{CF_i}{(1+r)^i} \quad (2)$$

With:

$CF_i$  = Cash flow at year  $i$

$n$  = Total time period of the project

$r$  = Discount rate

$i$  = Time of the cash flow

## 8. Sensitivity- analysis

Since management decisions such as the deployment of charging infrastructure rely heavily on this kind of investment analysis which represents projections of future investments and revenues, it is clear that most relevant sources of uncertainties should be investigated. Therefore a sensitivity analysis is provided which reveals the impact of all the input parameters and gives us a confidence interval for the NPV when the model is subjected to uncertainty.

## 9. Model summary

Based on many different inputs, the model calculates the expected discounted cash flow. The model formalisation is given by Figure 7.

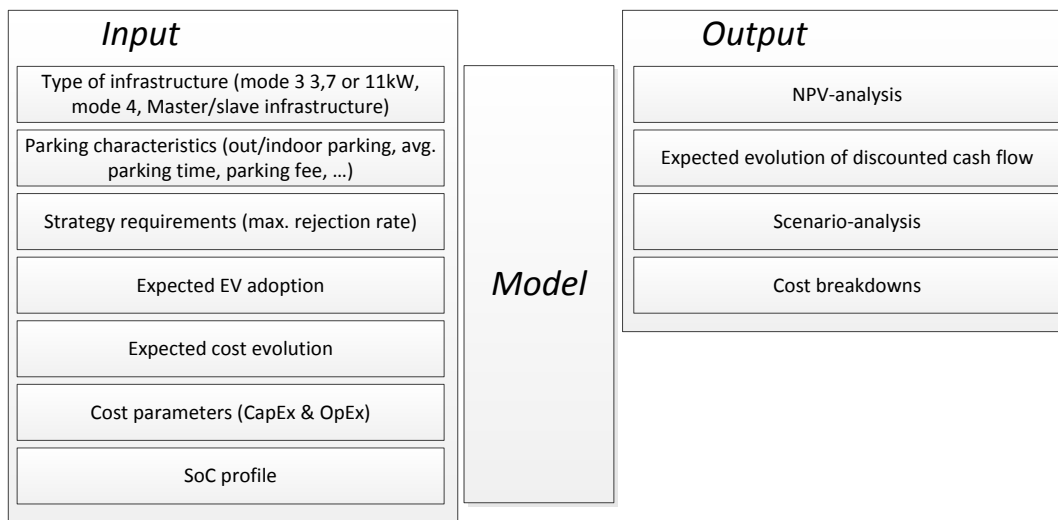


Figure 7. Model Formalization

## 4. Viability of charging infrastructure provisioning

In general four different charging scenarios can be distinguished. They differentiate on both place and infrastructure for the charging process. In Table 3, the four scenarios are lined up together with the type of infrastructure and the investment needed. In this research only the charging scenarios at private parking lots [scenario C] and at municipal parking spots [scenario D] are investigated (installation of charging infrastructure at home or at work will be typically of a much smaller scale and will also have a more simple market and financial model). It is important to keep in mind that integrating extra battery capacity is an alternative of installing a network of charging infrastructure. According to (Gnann et al., 2012), it would be more economical to invest in additional battery size for EV drivers when they all have a battery smaller than 25 kWh and

the couple of individual EV drivers with a higher need for energy have to bear the investments on their own. This is on the condition that every EV driver has the opportunity to charge the EV at home. But on average 30% of the Belgian residents do not have access to a private parking spot (Belgian Federal Government, 2012). Since it can be expected that most EV drivers will charge their vehicle at home during the night, charging facilities located at other places than their homes and public available charging infrastructure will be needed to allow this significant portion of the Belgian resident to charge their vehicle. In more urbanised areas where on average people have even less front door space available (apartment buildings, streets without parking facility, etc.) the need for public infrastructure will even be much higher.

Input for both scenarios comes from national and international actors involved in the SPARC project. The Smart Plug-in Automobile Renewable Charging Services (SPARC) is a Flemish project that focused on how to optimize the charging process in favour of renewable, fluctuating energy sources (iMinds vzw., 2012).

Focus of the first scenario analysis is on the business viability of large scale deployment of charging infrastructure and services from a private car parking facility operator. The second scenario presents the results of deploying and operating charging infrastructure in a Belgian city. Main difference between the two scenarios can be found in the market model. In the first scenario, the parking facility operator is responsible for buying, maintaining, operating the infrastructure and providing charging services, whilst in the latter scenario these roles are divided over several individual market actors.

#### *4.1 Deployment of charging infrastructure by private car parking facility operators (the case for a Belgian parking service provider) [Scenario C]*

From the perspective of a private parking service provider, it is valuable to know how many charging poles (and financial resources) to foresee per parking lot and what a viable charging fee will be. Interparking, a Belgian car parking facility operator, owns 67 parking buildings in Belgium which results in a total of more than 41 500 parking places (Interparking, 2012).

The parking provider wants to install Mode 3 slow speed (3.7kW, see table 1) charging infrastructure supported by Mode 3 medium speed (11kW) master-slave infrastructure for clients with a higher energy demand (e.g. EV drivers that cannot charge their vehicle at home or at work). For parking spots in an outdoor environment, the management wants to install only the Master-Slave Mode 3 (11kW) charging infrastructure. For both types of infrastructure, the life time is set at 15 years. After that period new infrastructure needs to be installed.

The model distinguishes two types of parking lots; outdoor and indoor parking lots. That is because there are different characteristics of the parking usage. Other distinctions are possible as well (e.g. long term airport parking versus park and shop parking lots in city centres), but therefore we refer to future work.

Next to that, the maximum allowed chance that all charging sockets are occupied is 5%. The queuing model assumes, based on interviews with parking facility operators, an average arrival rate of 90 vehicles per hour and an average parking stay of two hours (iMinds vzw., 2012) (Nieuwborg, 2013). These numbers are overall averages and result into a magnitude of investment. For an optimal deployment strategy, each parking should be modelled with its own arrival rate and average parking stay. Based on these parameters, and the expected adoption of EVs (see Figure 4), which determines the share of arriving EVs, the Erlang Loss queuing deployment model suggest following deployment evolution in order to satisfy the rejection constraint, see Figure 8.

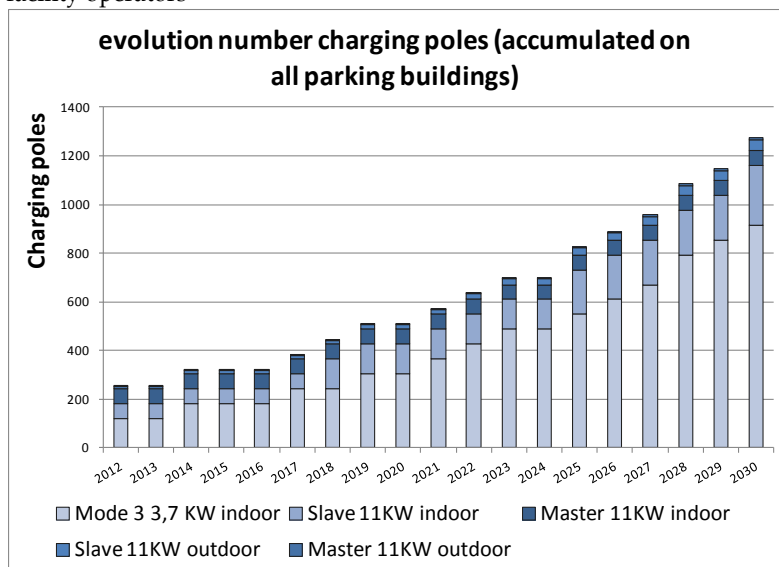


Figure 8. Evolution of the number of charging poles accumulated over all parking areas (scen. C)

The average expected electrical demand per arriving EV is based on the SOC-model and parking availability analysis per type of house in Belgium (Belgian Federal Government, 2012) (approximately 70% of all residents have the access to a private parking spot). People who can charge at home will have a lower average demand for energy than people who cannot charge their vehicle at home. The latter people will not have the capability to charge their vehicle at home during the night and will have therefore a higher demand for external energy. Table 4 gives an overview of the desired installation. In this model, the initial charging fee is set at 32c€/kWh. This means a mark-up of 13c€/kWh is added on top of the average consumer price for electricity (incl. grid access and transport costs) (Commissie voor de Regulering van de Elektriciteit en het Gas (CREG), 2013). According to (Kley et al., 2010) and (Wiederer and Philip, 2010) realistic mark-ups range from 0.01 to 0.20€/kWh.

Table 4. Type of charging infrastructure a.f.o. place of installation

Place of installation	Type of infrastructure	Average demand for energy per charging session (SOC-model ((iMinds vzw., 2012)) & (Wiederer and Philip, 2010)) (depending on the availability of a charging point at home, the average SOC will be influenced)	Expected % of arriving EVs (derived from (Belgian Federal Government, 2012))
61 parking buildings	Mode 3 (3.7kW)	4.75 kWh	70%
61 parking buildings	Mode 3 (11kW) Master + 4 Slaves(2 sockets) configuration per parking	22 kWh	30%
6 outdoor parking lots	Mode 3 (11kW) Master + 8 Slaves(2 charging sockets) configuration	11.65 kWh (40% of outdoor parking lot users need 22kWh, the other 60% only need 4.75kWh)	100%

Adding the CAPEX, OPEX and the modelled revenues and discounting this sum per year results in a net present value. The evolution of the cumulative discounted cash flows is presented by Figure 9.

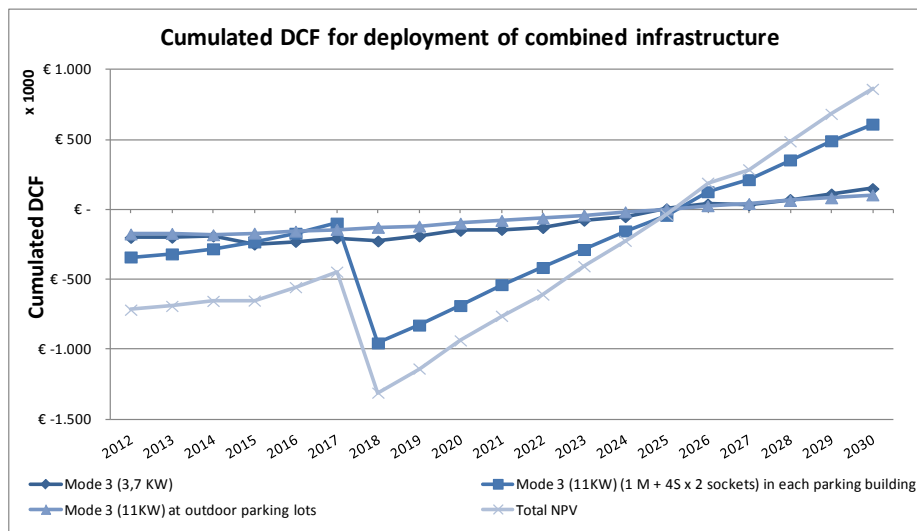


Figure 9. Evolution of the cumulated DCF for the private parking facility provider (scen. C)

From the analysis above, a steady growth in Discounted Cash Flows (DCF) can be noticed, except for 2018. At that point in time, an upgrade of the electrical installation will be needed. The model assumes that currently 30KVA per parking lot is still available (e.g. power foreseen for ventilation etc.) without further upgrade only a couple of charging poles could be installed (11kW per socket per slave pole and 3.7 kW per Mode 3 slow charging speed infrastructure). Upgrading the electrical installation requires a significant investment of approximately 25K euro per parking lot (Liander, 2012).

A scenario analysis shows that, based on the modelled demand for energy, a uniform fee per kWh of 29.1 eurocent is the minimum price for obtaining a positive NPV by 2030 (see figure 10). Careful price setting is at place. If all charging services (mode 3 slow speed (3.7kW) and mode 3 medium speed(11kW) would have the same charging fee, why should a user then use the slower charging infrastructure? It can be expected that without price differentiation, the mode 3 medium speed will always be in use even if the demand for energy would allow charging at a slower speed.

Also setting fees per hour would encourage the EV driver for not parking longer than needed on a charging spot. And if they would do so, the parking provider would have no opportunity cost (e.g. per hour charging at slow speed could cost 1 euro/hour, etc.). Allowing demand response aggregating parties to use the connected EVs as energy buffer could lead to further decreases of the charging fee as well. This issue will be discussed later.

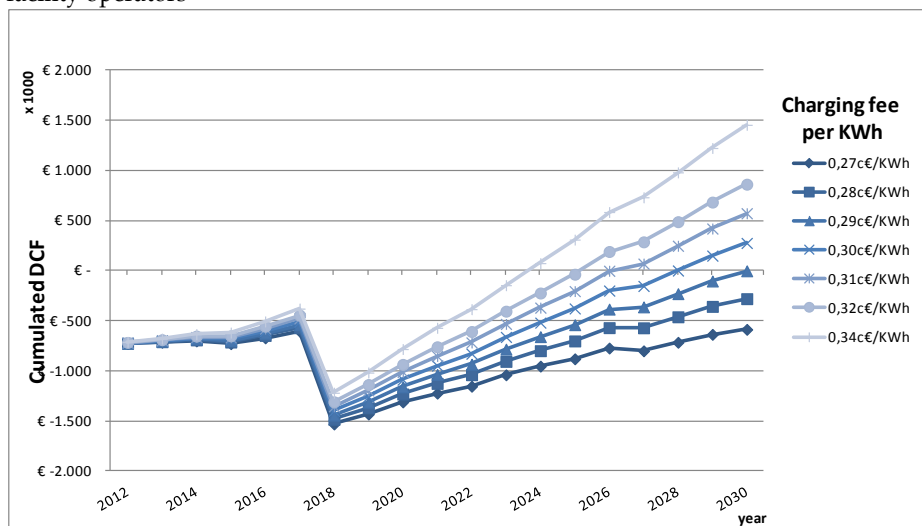


Figure 10. Evolution of the cumulated DCF for the private parking facility provider for various charging fees (scen. C)

#### 4.2 Deployment of charging infrastructure in municipal parking lots (City of Bruges) [Scenario D]

Local governments already show great interest in deploying charging facilities. In the first place they can then carry out a green and environmentally friendly image and secondly they can provide charging facilities and services for those citizens that do not have the opportunity to charge their vehicle in front of their homes.

Today many local and national deployment initiatives can be noticed, but installing just a few charging poles is not enough to build a strong basis for a durable adoption to electric vehicles. Municipalities will play a very important role in order to satisfy the demand for parking places with charging facilities for EVs.

Bruges, a historic city in the north-west of Belgium also carries out a green image and already does some efforts for being EV-friendly. A couple of charging poles are installed already. The next step is to gain insights in the needed investments and time line for deploying a complete network of charging facilities. The role of Bruges in this case is providing the financial resources and the right of way to install the charging poles. Compared to the previous scenario, it can be expected that each market role will be fulfilled by a dedicated actor (Figure 1 and table 2 for an overview of the market roles and actors). In this scenario, focus is on the business case of the charging pole exploitant, the charging pole owner and the charging service provider.

Table 5 presents several characteristics of the parking situation in Bruges. Based on this input the model is able to determine the evolution of the required charging infrastructure.

**Table 5. Parking characteristics for the inner city of Bruges**

Characteristic	Data (source (Mobiliteitscel Stad Brugge, 2011))
Average parking times	1hr. < x < 2hrs. Max. 2-4 hours.
Number of parking places in the inner city	5859 places
Average parking occupancy rate day	76%
Average parking occupancy rate night	70% (assumption)
Parking type	unguarded outdoor parking lots

Because of these parking characteristics, Mode 3 with adjustable charging speed (11kW or 3.7 kW) charging infrastructure in master-slave setup seems to be the most appropriate choice as charging infrastructure. In this way, EV drivers who only have limited time to charge their vehicle can be satisfied, but also citizens who do not have access to own charging infrastructure



at their homes can use this public infrastructure at a lower charging speed and fee during the night. So the municipal charging infrastructure serves two purposes; short medium power charging sessions during the day for citizens and tourists, and longer low power charging sessions during the night for citizens who do not have the ability to charge the vehicle in front of their homes. Because the queuing model does not take into account the geographical area of the parking lot, it would suggest a suboptimal amount of charging facilities. In this case the model would suggest deploying 31 charging points by 2030 to cover demand for the whole city centre of Bruges. In reality, this is not practical since it would require driving to the other side of the city to check whereas there is a charging point available over there. Therefore this deployment model is based on the expected adoption of EVs (see Figure 4) as a driver for the total number of charging points (see figure 11).

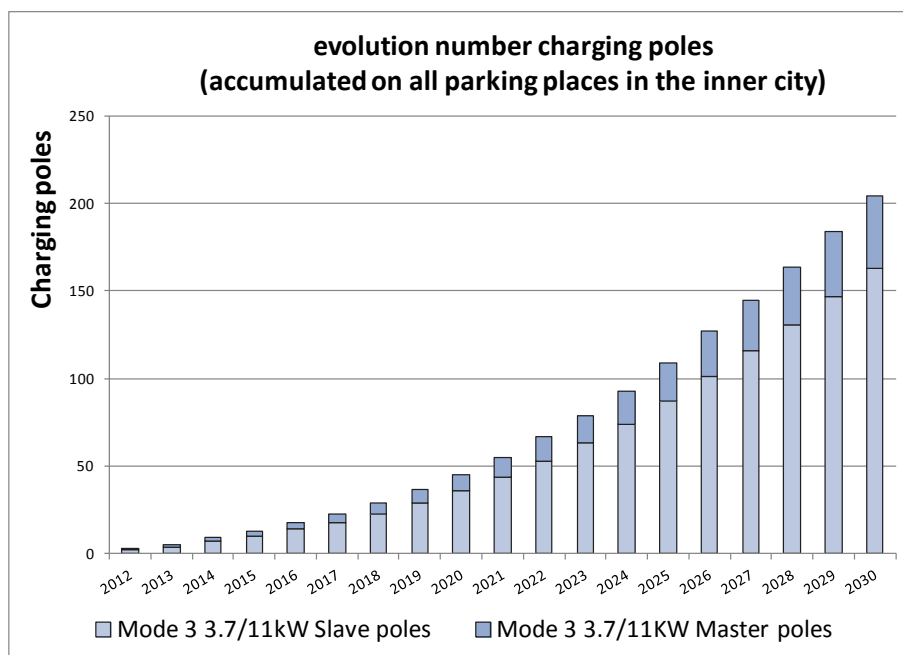


Figure 11. Evolution of the number of charging Poles in the inner city of Bruges (scen. D)

A master pole, joined by four slave poles can be treated as a single charging isle. A total of 41 charging isles, spread over the total inner city centre of Bruges (ca. 4km<sup>2</sup>) means a maximum walking distance of 200 metres to the nearest charging isle when equally spread. In reality, distances will be somewhat longer since the geographical places of the parking lots are already fixed and not uniformly spread. The total revenues and costs result from two separate models; a day model and a night model. Both models have different characteristics. Most important model characteristics are presented in Table 6.

Table 6. Modelled inputs for the municipal parking scenario

Input parameter	Charging during day	Charging during night
Average energy demand per arriving EV (Wiederer and Philip, 2010)	8.75 kWh	17.5 kWh
Average parking duration	1.2 hours	7 hours
Expected chosen charging speed	11 kW	3.7kW
Modelled charging fee	0.42c€/kWh +1.8 euro/hr parking	0.24c€/kWh

A significant difference between the hourly fees for charging services in both models can be noticed. This is due to the modelled policy requirements (according to (Wiederer and Philip, 2010)) that demand that the charging fee for citizens who do not have access to own charging

infrastructure should be about the same for people who do have their own charging infrastructure. This measure could stimulate the overall adoption of EVs. In this model it would cost about 6 euro (25 kWh \* 0.24c€/kWh) to charge a completely depleted battery of 25kWh at a municipal charging station versus 5,5 euro (25 kWh \* 0.22c€/kWh (Commissie voor de Regulering van de Elektriciteit en het Gas (CREG), 2013)) to charge it at home.

The modelling approach for determining the amount of needed infrastructure and the charging fee is the same for both scenarios. But scenario 2 is a multi-actor model, so the several costs and revenues streams belong to different market actors. In Table 7 most relevant costs and revenue sources integrated in the model are presented. Data stems from actor input in the iMinds SPARC-project. In what follows the business viability for each relevant actor is presented.

**Table 7. Most important costs and revenue sources listed per actor**

<b>Charging Service Provider (CSP)</b>		
Revenues	Costs	[Value]
Revenues from EV charging sessions during day and night	CAPEX costs: service start-up cost	[40 000€]
	OPEX costs during day time:	
	- parking costs	[1,8 euro/hour]
	- transaction costs for billing and user management	[0,36 euro/transaction]
	- charging infrastructure access and usage costs	[Turnover-profit rate]
	OPEX costs during night time: transaction costs, charging infrastructure access and usage costs	
<b>Charging pole exploiter (CPE)</b>		
Revenues	Costs	[Value]
Revenues from access and usage charging services during day and night	CAPEX costs: IT integration -platform development	[40 000€]
	OPEX costs during day time:	
	- communication network costs	[5 euro/pole per month]
	- Infrastructure and IT maintenance costs	[>20euro/pole per month]
	- energy cost	
	- infrastructure leasing costs	
	OPEX costs during day time: network costs, infrastructure and IT maintenance costs, energy cost, infrastructure leasing costs	
<b>Charging pole owner (CPO)</b>		
Revenues	Costs	
Revenues from infrastructure leasing activities	CAPEX costs: infrastructure deployment costs	

Discounting (discount rate 10%) all the costs and revenues for each relevant actor being CSP, CPE and CPO leads to following evolution of the discounted cash flows (DCF) and NPV's. (See figures 12, 13 and 14).

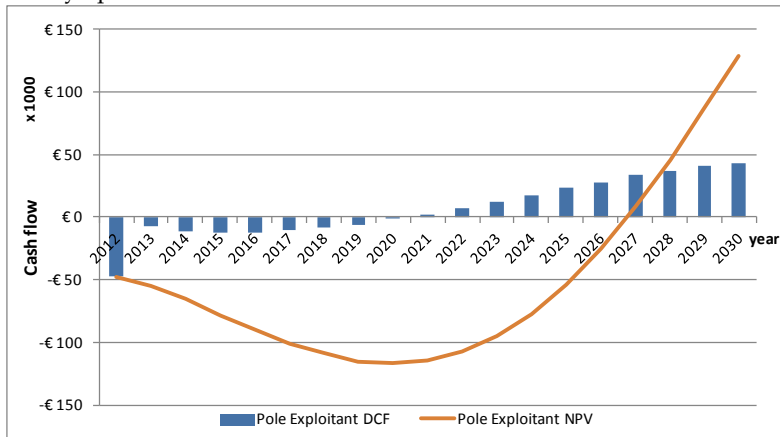


Figure 12. Evolution of the NPV for the charging pole exploitant (scen. D)

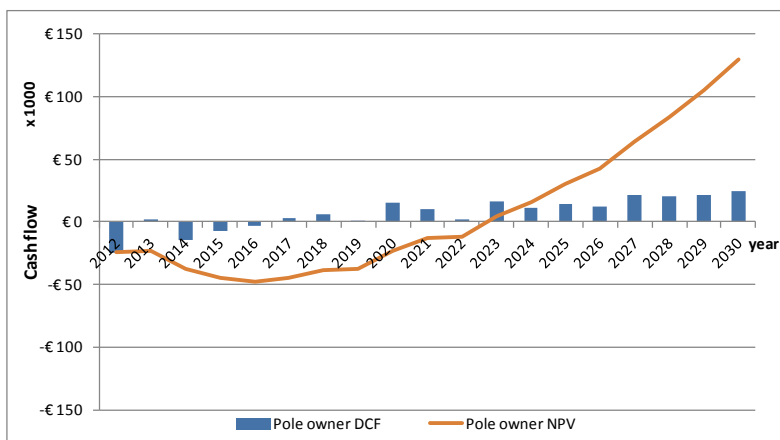


Figure 13. Evolution of the NPV for the charging pole owner (scen. D)

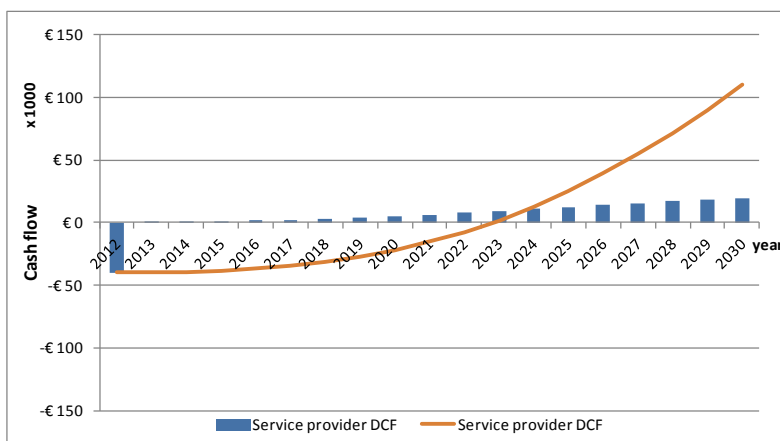


Figure 14. Evolution of the NPV for the charging service provider (scen. D)

Based on the input values mentioned above, these results indicate a viable and sustainable value network. Although the different actors face a different evolution of the DCF, each relevant actor has a positive NPV by 2026. The differences are a result of the dissimilar revenue and cost models. For instance, the charging pole owner will receive a leasing fee based on the amount and lifespan of the deployed poles. The charging service provider on the other hand only faces a platform development cost and OPEX. As revenue, this actor will take a margin of the charging

fees so practically this actor faces little risk. In contrast, the charging pole exploiter has to pay a leasing fee to the CPO, but is not sure whether he will be able to generate the needed turnover in order to pay the leasing fees. This actor takes most risk in this scenario. The results of the model indicate that the deployment of charging infrastructure in a mid-sized city centre would be a valuable project not only for the providing actors, but also for citizens who do not have access to own charging infrastructure.

## 5. Conclusions

Under increasing pressure from the European Commission, the general interest in the electrification of vehicles has been growing. Although the car manufacturers already launched several models of hybrid, plug-in or pure battery powered electric vehicles, a significant adoption of EVs has not been noticed yet. Next to the adoption barrier of the higher investment costs for electric vehicles, also range anxiety and charge anxiety are named as very important obstacles. Since the average actual electrical driving range is about 120-150 kilometres and depends heavily on the temperature and driving attitude, the fear of stranding with a depleted battery is not that unlikely. In order to address this fear of future EV-drivers, universal accessible charging infrastructure need to be deployed.

This demand leads to a chicken or egg paradox. Will the deployment of charging infrastructure result in a higher adoption of EVs or will the adoption of EVs be a driver for the installation of charging infrastructure? Many local, national and international governmental driven initiatives prove that policymakers believe that a minimal installed base of charging infrastructure is a minimum requirement to give electric vehicles a real chance on success.

This paper focuses on the investments and deployment strategy for charging infrastructure from a private and public parking provider perspective. After clarifying the various roles and actors of the market model for the provisioning of charging infrastructure for EVs, a techno-economic model was set up for two relevant business cases; 1) the deployment of EV charging structure on privately owned city parking lots and 2) the deployment of infrastructure on parking spaces owned by municipalities and governments. Other scenarios are charging the vehicle at home or at work. But these are not in the scope of this research.

The model suggests the number of required charging points needed to be installed over time based on the expected adoption rate of EVs, the utility degree of the parking spaces, arrival rate and maximum allowable rejection rate. Capital and operational expenditures as the infrastructure purchase price, lifetime, maintenance, network costs and energy costs were adjusted to the expected market trends and economies of scale.

The model indicates that depending on the scenario (day/night, municipal or private public parking lots) a charging fee of 24 - 42eurocent per kWh is realistic. This means a mark-up of 5-24 eurocent on top of the average energy price is needed for covering the CAPEX and OPEX costs and to achieve a viable business case for the involved actors. These mark-ups are in line with international pilot projects. If EV-owners would allow load balancing on the charging operations of their vehicles, this could lead to a significant impact on the business case. In exchange for the load flexibility EV-drivers offer towards the load balancer, a significant financial compensation could improve the business case for the EV-drivers and the charging infrastructure providers.

National and local governments and policymakers will play an important role in the provisioning of universal accessible charging infrastructure. For instance the public parking spaces are owned by the local government, which means that this actor has a direct role in the market model for the deployment and provisioning of charging infrastructure. Next to that, citizens who cannot charge their vehicle at their own houses need a low barrier alternative to charge their EVs. Public charging infrastructure could bridge that gap. Also supporting and facilitating the laws and policies on the provisioning of charging services will be a key future task of the government.

## 6. Future Work

Next to a fee per kWh, other revenue models as service subscription models (all-in-one models) will arise as well. Minor adjustments of the model are needed to provide these insights as well.

The model takes into account sufficient parameters in order to do a complete viability analyses for deploying EV charging infrastructure.

Next to the direct benefits and revenues that could result of the deployment of charging infrastructure, indirect effects like 'green city image', 'future proof parking facility operator', etc. are believed to be significant investment drivers. Being able to translate those indirect revenues into quantifiable results could have a serious impact on the viability analyses for charging infrastructure.

Aggregating all the simultaneously charging EVs into one pool of flexibility that can be used by DRAs would be a valuable extension. As said before, allowing grid balancing actions of DRAs will be compensated and could impact the cost for charging EVs in a positive way.

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