

Alternative Connections for Public EV Charging Points

Using existing Municipal Grid Connections and Objects
for the installation of Public EV Charging Points

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Date

June 2016



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Definitions

Electric vehicle (EV): passenger car which has an electric motor as propulsion and a battery with electricity as energy carrier. The battery can be charged externally using a plug.

Public charging station: freestanding object in the public space with one or more charging points, which solely has the function to provide electricity to EVs. The charging point is publicly accessible and can be used by anyone having an EV.

Charging point: socket on a charging station which can be used to charge an EV by connection the EV with a charging cable.

Grid connection: splitting of the electricity grid which is used to connected one or more objects to the electricity grid. In this way the objects are provided with electricity.

Municipal connection: grid connection of which the electricity contract is concluded by the municipality. By doing so the municipality is responsible for paying the electricity bill.

Combined connection: charging station which is connected to an already existing grid connection. In this way a connection arises which is used to power multiple objects.

Combined object: charging point which is physically integrated in another object. In this way an object arises with a combined function.

Alternative connection: the collective name for both combined connections and combined objects. Since using combined connections or combined objects is not the conventional way of connecting a charging station, both are called alternative connections for charging stations.

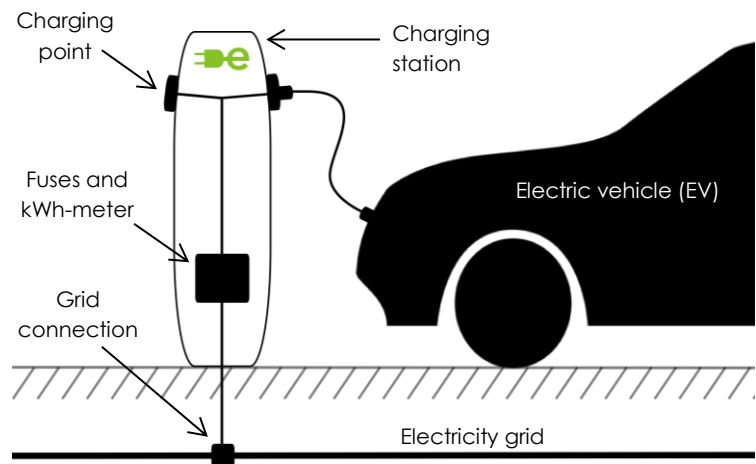


Figure 1: Existing charging infrastructure.

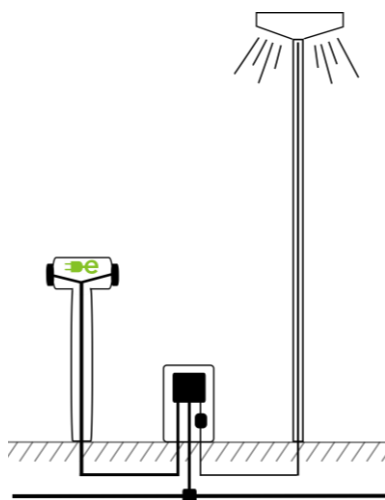


Figure 2a: Combined connection.

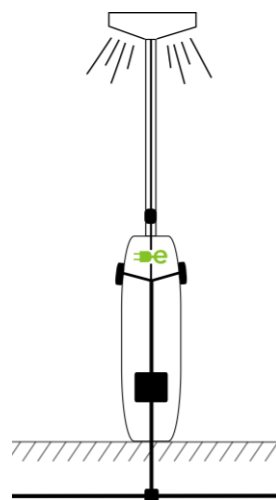


Figure 2b: Combined object.

1. Introduction

Electrifying transportation is a promising approach to alleviate the climate change issue. Electric Vehicles (EVs) could protect the environment by minimizing tailpipe emissions. Besides that they can improve energy security by diversifying energy sources and foster economic growth by creating new advanced industries (Yong et al., 2015). The use of electric vehicles is growing rapidly. Different kinds of EVs exist, like full electric vehicles (FEVs), extended range electric vehicles (E-REVs) and plug-in hybrid electric vehicles (PHEVs). All these technologies need to be externally charged (Yong et al., 2015). The number of EVs on the Dutch roads is currently more than twice the number of January 2015. By April 2016 there were over 10.000 FEVs and over 80.000 E-REV and PHEV registered in the Netherlands (RVO, 2016). It is expected that this rise will continue in the coming decades and the ambition of the Dutch government is to have 2 million EVs in 2030 (Formule E-team, 2015).

An important prerequisite for a continuous increase of electric transportation is the availability of enough charging stations. Especially at home, EV users must be able to charge their vehicle (Steinilber, 2013). Therefore, many municipalities have the policy that they help installing a public charging station for each EV user who does not have private parking ground available. The current procedure for placing a charging station is that the station is installed as a freestanding object and connected to the electricity grid by making a new grid connection. The parking lot next to the object is available only for EV users and the charging station in most cases is exploited by a commercial party. With the increasing adaptation of EVs a large number of new charging stations will be necessary in the near future. If the ambitions of the government will be achieved, about 720.000 charging points are necessary in 2030 (Formule E-team, 2015). However, the current procedures and technologies for placing charging stations might be inappropriate to keep on providing each EV user with a required station.

There are two issues related to the installation and exploitation of public charging stations, which might become problematic when many extra stations are installed. The first problem is that the installation requires relatively large investment costs for municipalities since the business case of charging stations is not profitable yet. The exact costs differ per location, but the contribution of municipalities is around 3000 euro per public charging station. A recent report of Natuur & Milieu (2014) showed that 75% of the Dutch municipalities have problems with financing all requested charging stations. The second problem is that the placement of charging stations puts pressure on the public space. In city centers public space is already loaded with objects like street lights, traffic lights, road signs, parking meters and billboards. Municipalities try to minimize the addition of even more public objects, making them hesitant about adding many more charging stations. Because of these issues it seems to be interesting to look at new ways of installing and exploiting charging stations so that municipalities are able to provide all charging stations that are required in the near future.

A promising new idea for installing public charging stations is to combine them with already existing municipal grid connections. This can be done in two ways. The first option is to connect a charging station to an already existing municipal grid connection. This means that two objects are connected to the same grid connection, instead of having an individual grid connection for a charging station. In this way a combined connection arises which might save money since only one grid connection has to be made and maintained and electricity consumption can be charged together. The second option

is to physically integrate a charging point in an object that is already connected to a municipal grid connection. By doing so public space becomes less crowded, since less different public objects have to be installed, and money can be saved if also the same connection is used. In this research both options are called alternative connections, since both are alternative ways of connecting charging stations. Because of the potential advantages of alternative connections, many ideas are in development for making combined connections or combined objects. BWM and Lightwell, for example, both developed a streetlight with an integrated charging point (BMW, 2015; Lightwell, 2015). Other possibilities might be to combine charging points with parking meters, sewage pumps or public buildings.

2. Problem definition

Using alternative connections is a very promising idea to deal with the increasing demand for charging stations. However, there is still a lot uncertainty about how alternative connections must be installed and used in practice. The uncertainty is based on locational, technical, legal/organizational and financial aspects. From a locational point of view it is still unclear which type of connections are often present in cities and are located on a suitable location for being used as an alternative connection. From a technical point of view there are questions about how existing grid connections can be used for installing a charging station and which municipal connections are suitable for doing this. From a legal/organizational point of view it is still unclear how to deal with ownership and exploitation when a charging station is connected to an existing grid connection. Finally, from a financial point of view there are no indications yet what the costs are for installing, exploiting and maintaining alternative connections. Because of these uncertainties it is still unclear how suitable and beneficial it is to make use of alternative connections, resulting in no large scale implementation yet. Since using alternative connections seems to be a promising solution for the problems related to public charging, this paper tries to take away the uncertainties by answering the following research question:

Which existing municipal grid connections are from a technical, locational, legal/organizational and financial point of view suitable and beneficial to be used as an alternative connection, and how can alternative connections be implemented in practice?

By answering this research question it is explained how alternative connections can be implemented in practice. Both making combined connections and making combined objects are investigated. It is explained under what preconditions the implementation of alternative connections is possible and what the consequences are of doing this. In this way the uncertainties regarding alternative connections are eliminated, so that all stakeholders can make a well-founded decision whether or not to invest in combined connections and/or combined objects.

This report starts with providing the relevant background information, which is given in chapter 3. After that, in chapter 4 the methods used for answering the research question are explained. Chapter 5 discusses the results of the evaluations, first for combined connections, than for combined objects. Finally, in chapter 6 and 7 the discussion and conclusion are given.

3. Background information

To do a profound evaluation of alternative connections some basic knowledge about the electricity supply system in the Netherlands and charging infrastructure is required. In this chapter the relevant background information is provided by discussing both topics.

3.1 Electricity supply system

3.1.1 Electricity grid

In the Netherlands electricity is mainly generated in power plants at large scale. It is produced as alternating current (AC), since this has the characteristic that it can be transformed easily to different voltages. Directly after production the electricity is transformed to high voltage to limit transport losses (RVO, 2006). Using the aboveground high voltage (HV) electricity grid the electricity is transported throughout the Netherlands. Long distance transport in the Netherlands is mainly performed at 380kV. More regionally the voltage is lowered in transformer stations to 150 or 50kV. Near urban areas the voltage is reduced even more to 10 kV, which makes it medium voltage (MV). MV cables feed local transformer boxes which can be found throughout urban areas. These boxes reduce the voltage to lower voltage (LV) of 230V. The HV and MV grid is called the transport grid, the LV grid the distribution grid. This means that the LV grid is designed to provide electricity directly to users and that grid connections can be made without using any extra transformers. Only large electricity customers, like heavy industries, are provided directly with medium voltage (TenneT, 2016).

Ownership of the electricity grid in the Netherlands is described in the electricity law ('Electriciteitswet', 1998). The law splits ownership of the grid in a national owner of the HV grid and regional owners of the MV and LV grid. TenneT is the owner of the complete high voltage grid. The company is responsible for maintaining the high voltage grid and balancing supply and demand at any time (TenneT, 2016). Ownership of the MV and LV grid is divided into zones and is assigned to regional grid operators (RGOs). In each zone only one RNB is active. The division is visualized in figure 3. The electricity law describes that RGOs have the duty to maintain the MV and LV grid in their region and that they are the only one allowed making connections to these grids.



Figure 3: RGO zones in the Netherlands (Microwatt, 2016).

In the Netherlands the HV, MV and LV grid is in very good condition, which means that there are barely blackouts or overloads (Movares, 2013). However, due to the rise of electric transportation and local electricity production the pattern of supply and demand is changing. This can put pressure on the capacity of the various grids, especially the LV grid (Movares, 2016). If overload of the LV grid is an urgent problem differs per location and detecting this requires specialized technical research by the RNBs. Since this research tries to describe general conditions for using alternative connections, these very location specific

differences are not relevant. Therefore, for this research, it is assumed that the capacity of the HV, MV and LV grid is not an obstacle for implementing alternative connections.

3.1.2 Grid connection

To extract power from the LV grid a grid connection has to be made. A grid connection is defined as a connection between a real property and the distribution grid which is used to provide electricity to a consumer ('Wet belasting op milieutoeslag', 1994, hoofdstuk 4, afdeling 1, artikel 47f). Each grid connection has an EAN code which is used as an identification number of the connection for RGOs and energy suppliers. RGOs are obliged to connect each customer with a connection up to 10 MVA, comparable to about 7MW, to the nearest point in the distribution grid with sufficient capacity (ACM, 2016a). In general only one object is connected to a grid connection, like a building, sewage pump or public charging point. In some cases, though, multiple objects are connected to the same grid connections. This is especially customary when low power objects are connected, like streetlights or electrical billboards.

In most regions in the Netherlands the LV grid is built up out of three phases. This means that an LV cable is made out of a neutral wire and three wires of each 230V (Enexis, n.d.). A three phase system provides 230V between the neutral hub and one of the phases, also called the phase voltage, and 400V across any two phases, also called the line voltage. When making a grid connection it can be decided to connect all three phases for the same user, or only one phase. Due to the growing number of electrical devices used in a household, most houses nowadays are connected with three phase voltage. The three phases are split in the meter cupboard making three groups of each 230V. It can also be decided to connect all three phases to the same group. In this way one high voltage group is created which makes use of the line voltage of 400V. A high voltage group is necessary when appliances with high power demand are connected, like a heat pump, sauna or Jacuzzi.

The power that can be delivered by a grid connection is, besides the voltage over the grid, also determined by the size of the connection. The size of the connection is defined by the thickness of the connection cable and the size of the fuse (Liander, 2016). The connection wire is the cable between the LV grid and the object, the fuse is a security against the effects of overloads and short circuits. For each phase that is separately connected in an object first a main fuse owned by the RNB is installed. The main fuses are sealed and only RNBs may open the seals for doing maintenance work. In this way the RNBs always keep in control over the main securities of the electricity grid and its connections. After the main fuse a group fuse is installed as an extra security. The group fuse must be smaller than the main fuse to make sure only the group fuse blows when the system is overloaded or when there is short circuit. This is called the selectivity of the installation. The rule of thumb is that the group fuse must be 1.6 times smaller than the main fuse to ensure the installations selectivity. The group fuses are not sealed and may be changed and maintained by individual customers (Gaslicht, 2016).

When a grid connection is made it must be decided if the consumer is a small or a large consumer. Till a maximum size of 3x80A the connection is called a small user connection, which means that all three phases of the LV grid are connected and each phase has a main fuse of 80A. A small user can choose out of several default sizes of the connection. The sizes vary from 1x6A to 3x80A and come along with default thicknesses of the connection wire, default sizes of the fuse, and is charged with fixed costs for the RGOs (Liander, 2015). The costs for making a new grid connection are presented in

table 1. Nowadays households and charging stations are generally equipped with a 3x25A connection. With a 3x25A connection the grid operator first equips each phase with a main fuse of 25A and then with a group phase of 16A. With a standard voltage of 230V this results in a maximum power capacity of 3,7kW per group and 11kW for all groups combined.

Connection size	Price excl. VAT (€)	Price incl. VAT (€)
1x6A	370,50	448,31
3x25A + alle overige 1-fase aansluitingen	654,55	792,01
3x35A	937,00	1.133,77
3x50A	937,00	1.133,77
3x63A	1.139,00	1.378,19
3x80A	1.139,00	1.378,19

Tabel 1: Price for making a new small consumer grid connection (Liander, 2015).

When more power is required the connection can be enlarged. The costs for doing this, presented in table 2, depend on the fact if the connection cable which is already present is thick enough to provide the power of the desired larger connection. When this is the case only the fuse has to be replaced. This requires only some small changes in the fuse box so can be implemented for only small fees. However, when the thickness of the connection cable is not sufficient also this needs to be replaced. Replacing the connection cable requires excavation and installation work comparable to making a new grid connection. Therefore the costs are also exactly similar to making a new grid connection. When the existing connection size is only 1x6A the connection cables are so thin that a replacement of the cable is always required. The costs for enlarging a 1x6A connection are therefore not included in table 2 since they are always similar to making a new connection (Liander, 2016).

Connection size	Price for replacing fuse excl. VAT (€)	Price for replacing fuse incl. VAT (€)	Price for replacing fuse & cable excl. VAT (€)	Price for replacing fuse & cable incl. VAT (€)
1x25A to 1x35A	free	free	free	free
1x25A/1x35/40A to 3x25A	166,55	201,53	654,55	792,01
1x25/1x35/40A to 3x35/50A	166,55	201,53	937,00	1.133,77
1x25A/1x35/40A to 3x63/80A	166,55	201,53	1.139,00	1.378,19
3x25A to 3x35/50A	110,55	133,77	937,00	1.133,77
3x25A to 3x63/80A	110,55	133,77	1.139,00	1.378,19
3x35A to 3x50A	110,55	133,77	937,00	1.133,77
3x35/50A to 3x63/80A	110,55	133,77	1.139,00	1.378,19
3x63A to 3x80A	110,55	133,77	1.139,00	1.378,19

Table 2: Costs for enlarging different types of small user connections (Liander, 2016).

When a connection is larger than 3x80A it is called a large consumer connection. Till a size of 3x125A the size of the connection is expressed in Amperages. When the connection is even larger the capacity is expressed in Volt-Ampere (VA). This unit is used to indicate the apparent power (Energieconsultant, 2016). The apparent power is the load on an installation with a certain active power. With direct current (DC) these values are equal; however, with AC the value of the apparent power is higher than the value of the active power. The more power used by a connection, the larger the difference between the apparent and the active power. The apparent power is in general about 1.2 to 1.5 times more than the active power. Therefore, with large connections, the RGOs use the apparent power for their calculations to prevent overloads.

The connection of a large consumer is custom made so can have every connection size till a maximum of 10MVA. The costs for making the new connection are dependent on the size and are presented in table 3. The costs for enlarging large consumer grid connections are calculated per individual situation because many different combinations are possible. When an enlargement is necessary the costs have to be defined in consultation with the RGO (Stedin, 2016).

Connection size	Price excl. VAT (€)	Price incl. VAT (€)
> 3x80A up to 3 x 125A	3.059,93	3.702,52
> 3x125A up to 175kVA	3.844,76	4.652,16
> 175kVA up to 630kVA	34.391,08	41.613,21
> 630kVA up to 1MVA	36.432,70	44.083,57
> 1MVA up to 1,75 MVA	43.891,84	53.109,13
> 1,75MVA up to 3MVA	189.449,99	229.234,50
> 3MVA up to 10MVA	258.814,87	313.166,00

Table 3: Price for making a new large consumer grid connection (Stedin, 2016).

3.1.3 Electricity supply

With the liberalization of the electricity market each consumer has a free choice for its energy supplier, for both electricity and gas. Besides that, everyone is free to start producing and selling energy. (Energiegids, 2015). Delivering energy to consumers is only allowed with a license which is only issued under strict conditions by the Market & Consumer Authority (in Dutch; Autoriteit Consument & Markt, ACM). A supply license is mandatory when a party supplies power to a consumer with a connection up to 3x80A (Electriciteitswet, 1998, hoofdstuk 8, § 1a, artikel 95a). The most important requirement that must be met before receiving the license is that a party must be able to provide each small consumer within the Netherlands with energy if it wants to. The supplier must show that they have the resources and means to meet this supply obligation (ACM, 2016a). In general only large suppliers can meet this requirement. In the Netherlands about 53 companies have an energy supplier license (ACM, 2016b).

With the rise of sustainable energy sources, like solar panels and wind turbines, more and more small parties enter the market who can supply electricity. These parties do often not have the ability and resources to meet the supply obligation and are therefore not eligible for receiving the supplier license. An alternative for them is to start collaborating with a party who does have a supplier license. In this way the party without license becomes a local reseller of electricity and in this way still gets the permit to produce and sell electricity at small scale. The small party is not the legal seller of the electricity, but only the reseller. The licensed company remains the legal seller (ACM, 2016c).

3.1.4 Measuring electricity consumption

To charge consumers for the electricity they have used it is necessary to calculate how much electricity is consumed. This can be done in two ways. The first method is that the electricity consumption is estimated. This method is only allowed when your connection is up to 3x25A and when the installation has a predictable consumption, which is for example the case for street lights. In the case of estimation the owner of the objects corresponds to the RNB how many objects are installed, how much power these objects use and how often the objects were activated. The RNB then calculates how much power must have been consumed, based on the data provided by the owner. By doing so no electricity measuring equipment has to be installed, but variations in electricity consumption are also not visible.

The second method is that the power consumption is measured using an electricity meter. This is mandatory for all connections with more than 3x25A or when consumption is unpredictable (Energieleveranciers, 2016). The latter is the case for, for example, households and charging stations. It is not allowed to use an own electricity meter for calculating the power that has to be charged by the RGO, since the RGO does not accept own meters as accountable measuring equipment. For small consumer connections it is mandatory to use the electricity meter of the RGO, which is always installed together with making the grid connection. For large consumers it is mandatory to appoint a certified measurement company for doing the electricity measurements (Energieleveranciers, 2016). For most kWh-meters the measurement values are recorded yearly by the RGO or user. However, more and more smart meters are installed which have an internet connection and can send their measurement values continuously to the RGO. RGOs may charge users for installing, maintaining and recording the kWh-meter. The costs for this are yearly defined by the ACM (Liander, 2016).

3.1.5 Payment

After the electricity is delivered and measured, the owner of the connection must be charged for the consumed electricity. The electricity price is built up out of three components; grid operator fees, electricity consumption and governmental levies. All three components are charged with 21% VAT (Nuon, 2016). Grid operator fees are periodic costs that have to be paid to the RGO. For small consumers these costs do not depend on the amount of electricity consumed, but only on the size of the connection and whether or not a kWh-meter is installed (Liander, 2015). The grid operator costs must not be confused with the one-off costs for making or enlarging a grid connection. The grid operator costs are built up out of different components and are used for maintaining, the distribution and transport grid, the connection and the kWh-meter. The total yearly grid operator costs for small consumers are presented in table 4.

Connection type	Tariff excl. VAT (€/year)	Tariff incl. VAT (€/year)
1x6A without kWh meter	10,7238	12,9757
1x6A	27,7062	33,5245
3x25A without kWh meter	173,6670	210,1370
3x25A	190,6494	230,6857
3x35A	743,1264	899,1829
3x50A	1.083,1404	1.310,5998
3x63A	1.429,2300	1.729,3683
3x80A	1.769,2440	2.140,7852

Table 4: Total yearly grid operator costs for different small consumer connections (Liander, 2015).

For large consumers more variables determine the height of the periodic grid operator costs. The costs are determined by the size of the connection, the contract power, the peak consumption and the absolute consumption (Stedin, 2016). The contract power is the capacity that is reserved in the grid by the RGO for the consumer and is determined by the expected peak power in a given year. At the beginning of each year the contract power is defined and throughout the year there is one possibility to adjust it when consumption changes significantly due to unforeseen circumstances. Since the periodic grid operator costs are unique for each situation, they are not further discussed.

The costs for the electricity consumption and government levies are charged per kWh and are therefore directly dependent on the electricity consumption. Energy suppliers can decide on their own electricity price. In the Netherlands the average electricity price without levies and VAT is around €0,06 per kWh (Milieucentraal, 2016). Government levies depend on how much electricity is consumed. The more electricity is consumed, the lower tax per kWh. The energy tax is displayed in table 5.

Tax cat.	Consumption category	Tax/kWh excl. VAT (€)	Tax /kWh incl. VAT (€)
1	< 10.000 kWh/year	0,1007	0,12185
2	10.001 – 50.000 kWh/year	0,04996	0,06045
3	50.001 – 10 million kWh/year	0,01331	0,01611
4	> 10 million kWh/ year (private)	0,00107	0,00129
5	> 10 million kWh/ year (business)	0,00053	0,00064

Table 5: Energy tax for different tax categories (Belastingdienst, 2016a).

3.1.6 Clustering regulation

The energy tax is calculated per connection (Belastingdienst, 2016b). As mentioned in section 3.1.2 a connection is defined as a connection between a real property and the Dutch distribution grid which is used to deliver electricity to the consumer. For the implementation of the energy tax the definition of the term real property is important as described in the law ‘Real Property Valuation’ (in Dutch: Waardering Onroerende Zaken, WOZ). According to the definition a combination of built or unbuilt real properties – or parts of these - can be seen as a single real property when they are in use by the same legal entity and they, assessing the circumstances, belong together. (‘Wet waardering onroerende zaken’, 1994, hoofdstuk 3, artikel 16). This means that, for example, a residence with garden and barn or a factory complex consisting of office buildings, factory buildings and a storage yard can be seen as one real property. When these properties have multiple grid connections they can be seen as one connection for calculating the energy consumption. This ‘clustering’ of connections can be profitable when due to the clustering the total energy consumption increases and less energy tax has to be paid per kWh.

In some cases it is possible to use the cluster regulation also for objects which, based on the WOZ, cannot be treated as one real property. An additional conclusion defines to which objects this is applicable (Belastingdienst, 2016b). One category of objects to which it is applicable is to objects that are part of the public infrastructure and for which one legal entity is charged for the electricity consumption. This is, for example, the case for streetlights and pumping stations of which the municipality pays the electricity bill for all connections combined. The electricity consumption of those objects can be clustered which results in a significant lower energy tax per kWh. However, in the additional conclusion it is mentioned specifically that the regulation is not applicable to public charging stations since they are not part of the public infrastructure. The electricity consumed by means of a charging point is, namely, used for charging individual vehicles and is therefore not for benefit of the public space. Therefore, the electricity consumption of public charging points cannot be clustered. (Belastingdienst, 2016b).

However, at the beginning of 2016 an extra policy measure is announced for charging infrastructure to stimulate electric transportation. (Energeia, 2016). The policy measure is only applicable to public charging stations and not to semi-public and private stations (definitions are specified in chapter 3.2.2). Besides that, the measure only applies when the public charging station has an own

connection to the LV grid. The policy measure describes a tax reduction of electricity consumed by a charging station from the first category (€0,1007 per kWh) to the second category (€0,4997). Since most charging stations nowadays consume less than 10.000 kWh per year this results in a significant tax benefit. A special tax measure for charging stations is chosen instead of using the cluster regulation, since the tax measure is less complex and burdensome for the tax authorities and charging point operators. Besides that the tax measure is only valid till 2020 since it is expected that afterwards no government support is necessary anymore for the public charging sector.

3.2 Charging infrastructure

4.2.1 Types of EV's

Different types of EV's are currently available on the market. This investigation focusses only on those of which the battery can be charged externally by using a plug. Full hybrid electric cars, like the Toyota Prius, are left aside since these cars do not require any type of charging infrastructure. There are currently three types of vehicles available that can be charged externally. These are the full electric vehicle, the electric vehicle with range extender and the plug-in hybrid electric vehicle. A short description of the three types is given below.

- Full electric vehicle (FEV): an FEV only uses an electromotor to drive its shaft. The electromotor gets its power from a battery which can be externally charged by means of a plug. Mostly the battery is provided with extra power during driving by using a regenerative braking (RB) system. An RB system converts kinetic energy into chemical energy during braking which can be stored in the battery. The capacity of the battery differs per model and determines the range and charging requirements of the car. The battery of the Nissan Leaf, as an example, has a capacity of 30 kWh, which results in a range of between 125 and 200 km, depending on weather, road and driving characteristics (Nissan, n.d.). The battery of the Tesla model S is significantly larger with a capacity of 70 to 90 kWh, resulting in a range of over 500 km (Tesla, n.d.).
- Electric vehicle with range extender (E-REV): also the shaft of an E-REV is only driven by an electromotor which is provided with electricity from a battery. Also this battery can be charged externally and by means of an RB system. However, the battery of an E-REV can also be charged by means of an on board electricity generator; the range extender. The range extender is usually powered by a conventional combustion engine, whereby the battery can be charged while driving. This significantly extends the range of the car, but also results in considerably more emissions of greenhouse gasses (Idtechex, 2015). An example of an E-REV is the BMW i3 REX, of which is also a full electric model available. The full electric model has a battery of 19 kWh, resulting in a range up to 160km. Due to the range extender the range of the BMW i3 REX is almost double (BMW, n.d.).
- Plug-in hybrid electric vehicle (PHEV): the shaft of a PHEV can be driven by both an electromotor as an internal combustion engine. The part of the electromotor is comparable to the system of an FEV. However, the propulsion of a PHEV can switch completely to a combustion engine when the battery runs out of electricity (Yong et al., 2015). The capacity of the battery in a PHEV is often significantly smaller than an FEV due to the possibility to switch over to the combustion engine. The capacity of the battery of a Chevrolet Volt, as an example, is only 18.4kWh, resulting in a range of only about 85km. When including the combustion engine, however, the range increases up to about 675km (Chevrolet, 2016).

4.2.2 Types of charging stations

Charging stations that are currently installed can differ on several aspects. First of all, the location and accessibility of charging stations differ. A distinction can be made between private, semi-public and public charging stations. Private charging stations are located at private ground of an EV owner and can be used only by the owner of the station. Installing a private charging station is therefore only a possibility when the EV owner has access to private parking ground. Also charging stations which are installed at private parking ground of companies are classified as private stations. Private charging stations are often connected to the existing grid connection of the house or office building. The consumed electricity is therefore automatically charged to the owner of the grid connection (AgentschapNL, 2010).

Semi-public charging stations are also located at private ground but are publicly accessible. This type includes, for example, charging stations located at parking grounds of supermarkets. Semi-public charging stations can be connected to the existing grid connection of the adjacent building or can have an individual grid connection. Since each EV user can charge its vehicle at a semi-public charging station, the object is often operated by a charging point operator. The operator is owner of the charging station and charges each EV user for the consumed electricity. Besides that, the operator is responsible for maintaining the charging station. Finally, public charging stations are located at municipal ground and also publicly accessible. Public charging stations always have an individual grid connection and are always operated by a charging point operator (AgentschapNL, 2010). This research only focusses on alternative connections for public charging stations.

Secondly, charging stations differ in the maximum charging speed that they can deliver. A distinction can be made between AC and DC chargers. Most charging stations deliver AC current to EVs since the Dutch power grid supply is AC. However, for charging car batteries DC current is required, which makes a conversion process necessary. Therefore all EVs are equipped with a rectifier which converts AC into DC power. To reduce weight the rectifier is often designed in small size and only limited amount of power can be handled. Therefore, an AC charger can only be used for 'slow' charging of at maximum 22kW. To enable fast charging of more than 50kW a DC charger is necessary. A DC charger has a rectifier inside the charging station and therefore delivers DC current to the EV. Since the rectifier in the DC charging station is larger than the rectifier in EVs, much higher charging powers can be reached (Yong et al., 2015). A major disadvantage of DC chargers, however, is that they are approximately eight times as expensive as AC chargers (ABB, 2012).

Finally, charging stations differ in the type plug that is used. A distinction can be made between the type and the mode of plug that is used. For this research the exact specifications of all possibilities are not relevant, however, it is important to notice that the Dutch EV market has accepted the type 2 mode 3 plug as the standard for public charging. This plug allows for single or three phase charging up to 44kW. Besides that the plug allows for communication between the charging station and the EV so that power can be delivered in a safe and controlled way.

4.2.3 Charging behavior of the EV user

Clear patterns can be seen in the charging behavior of EV users, which are important to take into account when installing new charging stations. The energy demand of EVs has its peaks in the morning when EV users plug in their vehicle at work, and in the early evening when EV users come back home. This is visualized in figure 4. In the early morning the energy demand of EVs reaches its lowest point (ElaadNL, 2013). More than 50% of the charging sessions are less than five hours (RVO, 2014). This means that a significant amount of power must be available to transfer a useful amount of power to the battery. For this research it is assumed that at least 3,7 kW (1x16A, 230V) must be available per charging point for a practical usage of charging stations.

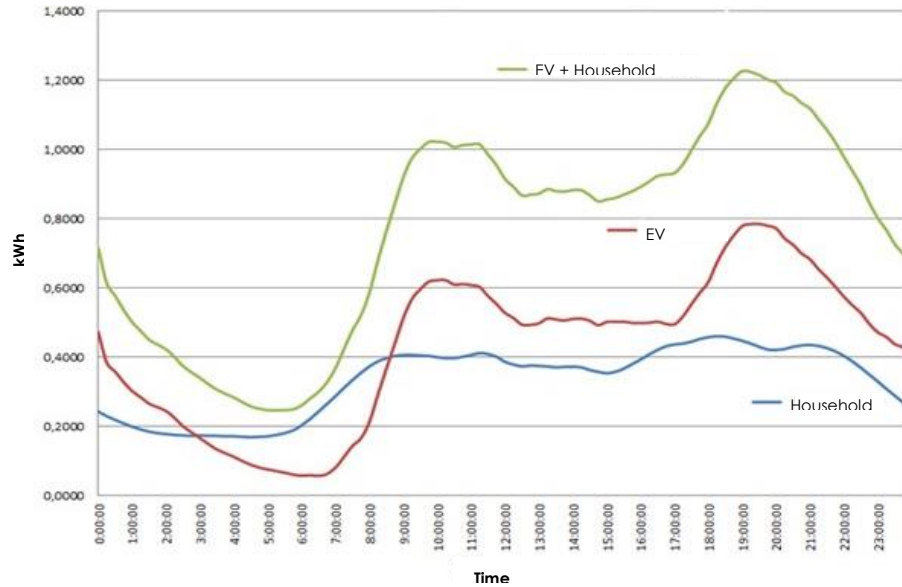


Figure 4: Average load profile of EVs and households over the day in June 2012 in the Netherlands (ElaadNL, 2013).

4. Methodology

To answer the research question this research will be dealt with in two parts. In part 1 the possibility of connecting a charging station to an already existing municipal grid connection, resulting in a combined connection, is investigated. Part 2 focusses on the possibility of integrating a charging point in an object connected to an already existing municipal grid connection, resulting in a combined object. For both parts the Strategic Technology Evaluation Program (STEP model) is used, which is described in chapter 3.1. The research design that flows out of the STEP model, and is used for both parts of this research, is explained in chapter 3.2. Chapter 3.3 gives the criteria per evaluation for both parts of the research. Finally, in chapter 3.4, it is described how the required data is collected for both parts.

4.1 STEP model

A solid framework is required to evaluate the potential of a new technological idea, and to define the important aspects for a successful practical implementation of a technology. A useful framework provides a clear overview of all important aspects that determine the success of a new technology. Therefore this research makes use of the STEP model. The STEP model is a method to evaluate the commercial potential of emerging technologies (Chifos and Jain, 1997). It is originally developed by the University of Cincinnati and describes six aspects by which a new technology effectively can be assessed. Evaluating a technology using these six aspects reveals if a technology has any potential and what the obstacles might be for implementing the new technology (Bandarian, 2007). Therefore, the STEP model can be used in this research as a framework for evaluating the potential of combined connections and objects, and for finding the obstacles when implementing them in practice. The six evaluations are displayed in figure 2.

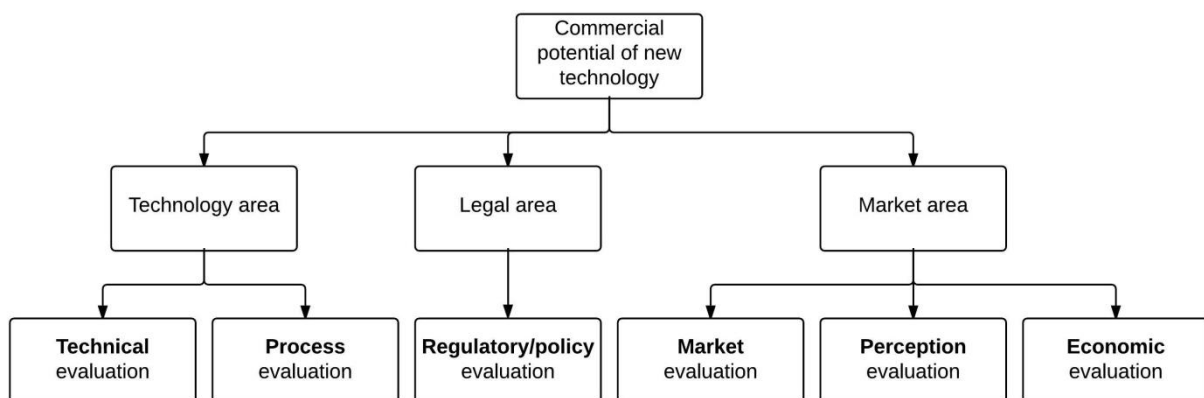


Figure 5: the STEP model describing six evaluations to assess new technologies (Bandarian, 2007).

The six aspects that must be evaluated according to the STEP model are the technology, process, regulation/policy, market, public perception and finances (Bandarian, 2007). Firstly, the purpose of the technical evaluation is to determine how the technology works and if it is capable of accomplishing its goal. The technology must at least be capable of achieving the desired result to have any commercial potential. Secondly, the process aspects of the evaluation address the adoptability and adaptability of a new technology into existing methods of utilization. If large changes to the current system are required the technology might experience difficulties when implementing it in the current technological system. The third evaluation focuses on the regulations and policies concerning the technology in the region where the technology is implemented. When

policies or regulations are in place which counteract the technology, changes to the technology might be necessary to introduce it. However, when policies and regulations support a certain technology they might stimulate its implementation. Fourthly, the evaluation of market aspects is based on the identification and assessment of a market demand for the technology. Fifthly, the evaluation of the public perception must reveal how end-users feel about the technology and its potential to be an attractive product or technique for their utilization. Finally, the economic evaluation assesses if it is financially possible and beneficial to introduce the technology.

In this paper the STEP model is used to evaluate the potential of combining charging points with existing municipal grid connections and to determine what aspects to focus on for a successful implementation. The model is chosen because it gives a complete overview of all aspects when assessing the potential of a technology. However, not each of the six evaluations might be relevant since the framework is not designed for one specific case. Therefore each evaluation must be checked if it is useful for assessing the potential of combined connections and objects. Two evaluations are certainly relevant for this paper; the technical evaluation and the economic evaluation. The technical evaluation is important since it is very relevant to know if grid connections are capable of providing the technical specifications that are required when installing a charging station. The economic evaluation is relevant for all stakeholders who are financially involved to see if it is beneficial to use combined connections and objects.

Besides that, there are two more evaluations which are relevant, but are more useful when they are formulated in a slightly different way. These are the process evaluation and the regulatory/policy evaluation. The process evaluation focusses on all aspects concerning the adoptability and adaptability of a new technology into existing methods of utilization. For combined objects this mainly includes locational aspects and organizational aspects. Locational aspects include aspects like the possibility to install combined object at similar locations of regular charging stations. Organizational aspects include aspects like who is going to be the owner and operator of the combined object. The organizational aspects, however, are closely related to the regulatory/policy evaluation since it includes many legal questions. Therefore it is useful to rename the process evaluation into a locational evaluation, and the regulatory/policy evaluation into a legal/organizational evaluation.

Finally the market evaluation and the perception evaluation are not relevant to include in this paper. This is irrelevant because the incentive for this paper is that municipalities and producers of charging points have expressed their interest in combining charging points with existing municipal grid connections. Therefore it can be assumed that there will be a market for any kind of combined connection or object if it turns out to be suitable and beneficial. The perception evaluation is irrelevant because the only noticeable differences for consumers between normal charging points and combined charging points might be some technical specifications and the location. However, already in the technical and locational evaluation it is assessed if these aspects of a combined connection meet customer demands. Therefore it is redundant to include a separate evaluation of the public perception.

This leaves four evaluations which will be performed in this research to assess the potential of combining charging stations with existing municipal grid connections. These are a technical, locational, legal/organizational and economic evaluation.

4.2 Research design

For both part 1 and part 2 of this research the four evaluations that flow out of the STEP model will be performed in subsequent steps, as is visualized in figure 6.

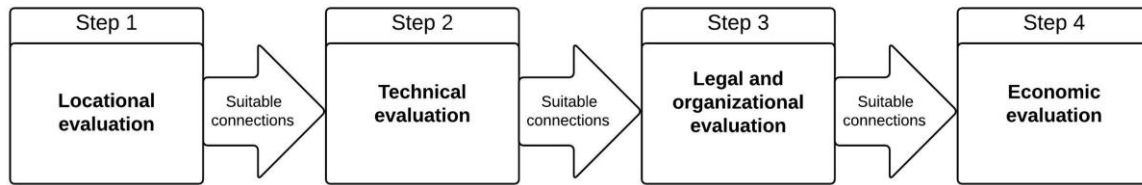


Figure 6: The four steps that are performed in both parts of the research.

In each evaluation a set of criteria is used to assess the potential of making combined connections or combined objects. The criteria are discussed in detail in section 3.3. A criterion is rated as positive when the technology meets the criteria, or when the criteria can be met by making only minor changes to the technology or environment. When all criteria have a positive result it can be concluded that making combined connections or combined objects has great commercial potential. When one or more criteria have a negative result which cannot be changed into positive ones by making changes to the technology or environment, it must be concluded that making combined connections or objects has no great commercial potential.

There are, however, different ways in which a combined connection or combined object can be made. The difference is based on which type of existing municipal grid connection is used for making the combined connection or combined object. The results of the evaluations may be different for different types of existing municipal grid connections. This might especially be the case for the locational and technical evaluation. The grid connection of a municipal building, for example, might turn out to have great technical potential for being used as a combined connection, while the grid connection of a parking meter might not have. Therefore, the locational and technical evaluations are performed per type of municipal grid connection. In this way a distinction can be made between the potential of different types of connections. Since many different types of municipal grid connections exist, a categorization is made of grid connections with comparable characteristics. The categorization of the types of grid connections is shown in table 6.












Icon	Category	Includes connections of	Icon	Category	Includes connections of
	Streetlights	Street lights ABRIs (e.g. bus shelters) MUPIs (e.g. billboards)		Public area	Markets Gardens Parks Child farms Cemeteries
	Public lightning boxes	Public lightning boxes		Sports accommodations	Sports grounds Sports accommodations
	Parking meters	Parking meters		Swimming pools	Swimming pools
	Traffic lights	Traffic lights		Buildings	Municipal offices Schools Gyms Churches Car parks Community centers
	Bridges	Bridges Bridge operator houses		Pumping stations	Pumps Sewage pumps
	Fountains	Fountains			

Table 6: Categorization of municipal grid connections.

Each connection category that turns out to have no potential for being used as a combined connection or combined object according to the locational or technical evaluation, is excluded in the further evaluations. This exclusion is possible since the different evaluations are not interrelated. This means that a negative result for the locational or technical evaluation cannot be compensated by a positive result for one of the other evaluations. When, for example, a certain type of connection turns out to have an unsuitable location for being used as a combined object, it can be concluded that this type of connection has no potential for being used as a combined object, irrespective of the result of the technical, legal/organizational and economic evaluation.

The locational and technical evaluation will be performed for combined connections and combined objects in general. Since for these evaluations the results are similar for all connection categories, no distinction is made between the different connection categories. In the end it can be concluded which existing municipal grid connections are suitable for making alternative connections and how they can be implemented in practice.

4.3 Criteria per evaluation

The STEP model provides some general criteria per evaluation (Chifos and Jain, 1997). These criteria, however, must be specified to be useful for the evaluation of a specific technology. The specification of the criteria for this research is based on interviews with experts in the EV sector. The experts have most experience with assessing which aspects determine the success of combined connections and objects. For both parts the same set of criteria is relevant. Only for the second criterion of step 1 the operationalization is slightly different. The criteria are presented in table 7 and explained below.

Analysis	Criteria	Operationalization
Step 1: Locational evaluation	1. Presence in cities	Existing municipal connection/objects must be present in urban areas
	2. Location relative to parking lot	Combined connection: Existing municipal grid connections must be located within 5 meters of a parking lot Combined object: Objects must be located directly next to a parking lot
Step 2: Technical evaluation	3. Grid/connection capacity	At least 7,4 kW must be available for the charging station (3,7 kW per charging point)
	4. Grid/connection activation	The grid to which the connection is made must be active 24 hours a day
	5. Presence of power measuring equipment	kWh-meter authorized by the regional grid operator must be installed
	6. Safety	The combined connection/object must comply to safety standards of both the existing connection/object and charging stations
Step 3: legal and organizational evaluation	7. Legality to sell power	It must be legal to sell electricity to EV users by using a combined connection/object
	8. Legality to use cluster regulation	It must be legal to use the cluster regulation for the purchase of electricity
	9. No conflicting interests between involved parties	No conflicting interests between public and private parties
	10. No conflicting interests within municipality	No conflicting interests between different departments of the municipality
Step 4: Economic evaluation	11. Favorable business model	Business model of combined connections/objects must be more favorable than the current business model of charging stations

Table 7: criteria for the evaluation of combined connections and combined objects.

4.4 Data collection

To evaluate all the criteria both qualitative and quantitative research is done and four types of data sources are used; desktop research, expert interviews, two municipal data sets and internal communication. The results of all evaluations are combined to give an answer on the research question. First of all desktop research is performed, in which existing literature, documents and projects focused on alternative connections are inventoried. However, there is a substantial lack of literature on this topic since using alternative connections is still a very immature technology. Only in some cases information from literature or documents is used to conclude the results.

Most information was derived from expert interviews. Since using alternative connections is such an undeveloped technology, experts in the sector can give most reliable information about the possibilities of implementing combined connections and objects. All interviews were conducted using semi structured interviews. The interviewees were questioned in their field of expertise, which was useful for specific parts of the results. Which experts are interviewed, when the interview was conducted, what the function of the interviewee was and for what part of the results the interview was used, is presented in table 8.

Person	Date interview	Function	Interview used for
Harry van der Wal	24/02/2016	Municipality of Groningen, department Public Lightning	Part 1: technical evaluation
Gerald Meijegaarden	12/04/2016	Municipality of Nijmegen, department Public Lightning	Part 1: technical evaluation
Jan van de Ven	01/03/2016	Eneco, manager smart outdoor	Part 1: technical evaluation
Peter Holswilder	17/02/2016	Municipality of Rotterdam, department Public Lightning	Part 1: technical evaluation
Martin Huisman	23/03/2016	Municipality of Rotterdam, energy operator	Part 1: technical and legal/organizational evaluation
Capser Vogelaar	25/04/2016	Alliander, accountmanager	Part 1: technical and legal/organizational evaluation
Arthur Klink	15/04/2016	Municipality of Utrecht, department City Engineering	Part 1 & 2: legal/organizational evaluation
Florian Mesch	22/04/2016	Lightwell, product designer	Part 2: technical and legal/organizational evaluation

Table 8: Information about the conducted interviews. All interviewees have agreed upon the fact that their name was mentioned in this research and that their information is used in the results.

Next to the interviews, part of the results is based on the two data sets with all municipal grid connections in Rotterdam and Utrecht. The data sets were necessary since for part of the criteria quantitative data is required, like for criteria 1, 2 and 3. The data sets of Rotterdam and Utrecht are used because most problems with EV charging occur in large cities where EV users do not have any private parking space available. Utrecht and Rotterdam are both large cities in the Netherlands so their municipal grid connections can be seen as representative for other large cities where EV charging problems occur. The data set of Rotterdam contains both locational and technical data of all municipal grid connections, so is used for both evaluations. The data set of Utrecht only contains locational data so is only used for the locational evaluation.

Finally, part of the results is collected by means of internal communication with employees of EVConsult. Since EVConsult has much experience in the EV sector this can be seen as a very reliable source. Especially for the financial evaluation internal knowledge about charging stations is used to define the parameters for calculating the business cases.

5. Results

In chapter 5 the results of both parts of this research are presented. Chapter 5.1 discusses the evaluation of combined connections, chapter 5.2 the evaluation of combined objects.

5.1 Evaluation of combined connections

5.1.1 Locational evaluation

In the locational evaluation it is evaluated if existing municipal grid connections are present in urban areas and what their location is relative to parking lots. Without streetlights, there are about 2300 municipal grid connections in Rotterdam, and 1700 in Utrecht. The number of connections per connection category in both cities is presented in table 9. It can be seen that all connection categories are present in both cities, although the number of connections per category differs strongly. By far most municipal grid connections are made for streetlights, with about 100,000 connections in both cities. Connections for parking meters, traffic lights, buildings and pumping stations are most commonly present in both cities. Connections for bridges, fountains, public areas, sports terrains and swimming pools are less prominent. The presence of public lightning (PL) boxes is only large in Utrecht, which is a result of the technology used for connecting lightning objects in both cities. This discussed in more detail in the technological evaluation of combined connections (section 5.1.2).












											
Rotterdam	±100k	12	466	262	47	51	107	24	7	266	476
Utrecht	±100k	583	789	235	24	5	21	55	6	188	383

Table 9: Number of connections per connection category in Rotterdam and Utrecht. All data is derived from the data sets with municipal grid connections of both cities, except of the number of lightning objects in both cities and the number of parking meters in Utrecht. The number of lightning objects in both cities is estimated by Peter Holswilder (Rotterdam) and Arthur Klink (Utrecht). The number of parking meters in Utrecht is derived from a data set with all parking meters in Utrecht.

The distribution of the municipal grid connections over the city of Utrecht is visualized in figure 7 and 8. For fountains and swimming pools the locations of all existing connections are included, for the other connection categories the locations of eight randomly selected connections are included. It can be seen that the connections of PL-boxes, traffic lights, bridges, fountains, buildings and pumping stations are distributed evenly all over the city. The connections of public grounds, sports accomodations and swimming pools are located more in the outskirts of the city. Streetlights and parking meters are not included in the figures since these connection categories are not included in the data set with municipal grid connections of Utecht, so no exact locational information is available. It can be assumed that streetlights are distributed evenly all over the city and parking meters are mostly located in city centers since only there paid parking areas are located.



Figure 7: Locations of connections which are distributed evenly over the city of Utrecht. Of fountains all connections are included, of the other five categories eight connections are randomly selected out of the data set of municipal grid connections in Utrecht.

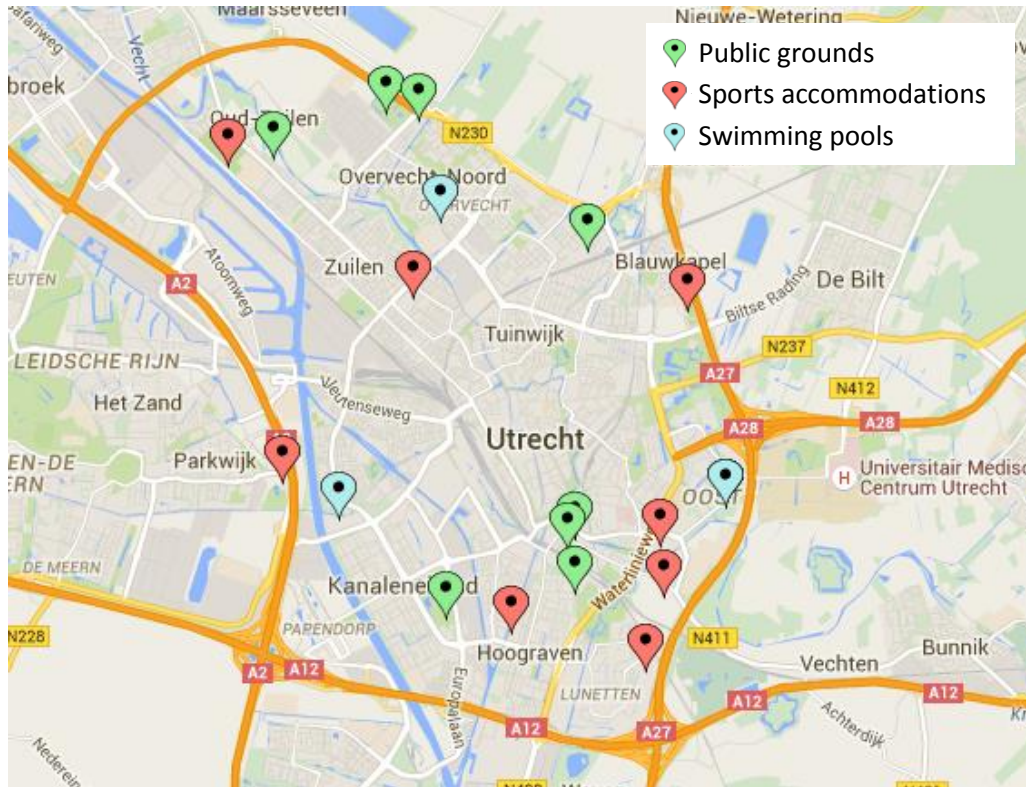


Figure 8: Locations of connections which are located only in the outskirts of Utrecht. Of swimming pools all connections are included, of the other two categories eight connections are randomly selected out of the data set of municipal grid connections in Utrecht.

The location of a municipal grid connection relative to parking lots differs per situation. It is, however, interesting to see if there is a significant difference between the percentages of the connections of each category that are located within 5 meters of a parking lot. Table 10 shows this result for the grid connections in four districts of Rotterdam. Only connection sizes between 3x25A and 3x80A are included, which excluded all connections of streetlights and parking meters. Besides that there is no swimming pool located in one of the four districts. Since of some connection categories only few locations are included, no firm conclusions can be drawn based on table 10. However, it can be seen that for all connection categories at least in some cases the connection is within five meters of a parking lot. Of all investigated connections in total 35% is located within a distance of 5 meter of a parking lot.












											
N° of conn. investigated	-	3	-	14	5	12	2	6	-	58	92
% within 5 meter of lot	-	100%	-	7%	20%	42%	100%	50%	-	41%	32%

Table 10: Number of connections per connection type within 5 meters of a parking lot. All connections in the Rotterdam districts Kralingen, Noord, Charlois and Delfshaven with a connection size between 3x25A and 3x80A are included. Connection type, size and address are derived from the data set with municipal grid connections of Rotterdam. The location of each connection relative to parking lots is estimated using Google Maps.

From the locational evaluation it can be concluded that the connections of all categories have the potential for being used as a combined connection. Despite of the fact that there are strong differences between the connection categories, at least several connections of all eleven categories are present in both Rotterdam and Utrecht. By far most connections are for streetlights, followed by connections for parking meters, sewage pumps, traffic lights, municipal buildings and in some municipalities PL boxes. The location of the connections relative to parking lots differs per situation, but also in this case of each category at least several connections are located within five meters of a parking lot.

5.1.2 Technical evaluation

In the second step the technical aspects of combining objects are evaluated. It is investigated on which type of connections there is enough capacity available, if connections are always activated, if there is measuring equipment installed and if it is safe to make combined connections. The technical situation of streetlights is significantly different than the technical situation of all other connection categories. Therefore first the technical evaluation of only streetlights is discussed, thereafter all other connection categories will be discussed together.

Streetlights

The technical situation of streetlights is different than those of the other objects because there is no single way in which streetlights are always connected to the electricity grid. Each municipality has its own ideas about connecting streetlights, which largely influences the possibility to make combined connections. Three main options can be distinguished, of which the first one is visualized in figure 9.

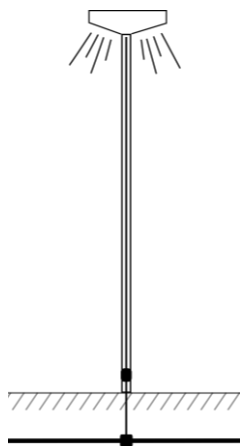


Figure 9: Streetlight with direct connect. to the LV grid.

In option 1 a streetlight has a direct connection to the LV grid, comparable to most other municipal grid connections. The connection is only 1x6A since streetlights consume only small amounts of power. The power consumption of an average lightbulb in streetlights is about 50W. With the introduction of LED light this consumption has reduced to about 35W. In the casing of the streetlight a switch is installed which turns off the power by day. No electricity meter is installed since the power consumption is very predictable and can be estimated. This way of connecting streetlights, however, cannot be found on many locations in the Netherlands anymore. Since the object is connected directly to the LV grid large amounts of power can be released in case of an accident, for example in case of a collision by a car. This forms a significant risk since many streetlights are located next to roads. Therefore on only limited locations these kinds of connections for streetlights can still be found, for example in the cities of Rotterdam and Amsterdam.

The safety issue, however, might not be a barrier for using this type of streetlights for making combined connections. Charging stations are usually only located at the sides of streets or parking areas where cars drive only slowly, which lowers the chance of heavy collisions. Therefore, regular charging stations comply with all safety standards, while also having a direct connection to the LV grid. The connection size of this type of streetlight, on the other hand, is too small for making a combined connection. With a connection of only 1x6A at maximum 1.38A is available. An increase of the connection size is required for a practical used of the charging station. This increase, however, can be made quite easily due to the assumption that there is always enough capacity available at the LV grid. Besides that the LV grid is always activated so there is always power available. Finally, measuring equipment must be installed which can be placed in the casing of the charging station.

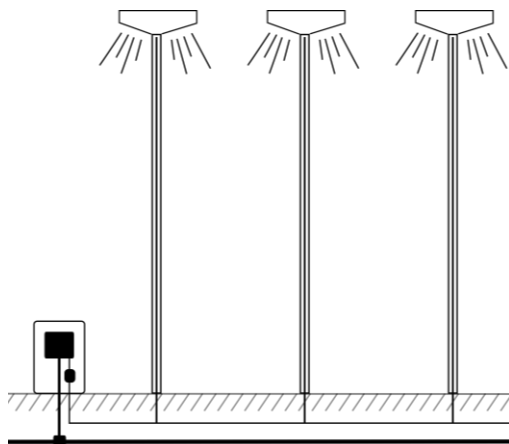


Figure 10: Streetlights connected to a PL grid.

The second option is most common and is presented in figure 10. This option is used in Utrecht for nearly all streetlights and in Rotterdam for a limited amount of streetlights. In this option a connection to the LV grid is made of at least 1x25A. In most cases in Utrecht the connection is 3x25A. The main fuse and group fuses of the connection are installed in a box which is located outside near a place where streetlights are installed. This box is called the public lightning (PL) box. From the PL box thin PL cables are laid underground to which individual streetlights are connected. The PL cables are thin since only small amounts of power are consumed by streetlights. Each streetlight has an individual fuse which

is mostly 6A, but can also be smaller with only 4A or 2A. This is done so that in the case of short circuit only a single streetlight is shut down and not a complete PL cable. Usually a few of tens to at maximum about hundred streetlights are connected to one PL box. In the PL box a switch is installed which switches off all PL cables by day, so that all streetlights are shut down by day. Besides the switch, it is also possible to install an electricity meter in the PL box which measures the consumption of the complete box. In Utrecht most PL boxes are equipped with an electricity meter. In most other municipalities, however, when the size of the connection of a PL box is 3x25A or less, its power

consumption is estimated. A PL box including all its PL cables is called a PL grid. Multiply PL grids are necessary to connect all streetlights in a municipality to the electricity grid. In Utrecht, for example, 583 PL grids are installed.

When making a combined connection of this type of streetlights, a charging station can be connected to the PL cable. This is different than connecting a streetlight directly to a PL box, which is discussed later in this section. When connection a charging station to a PL cable, however, the same capacity problems occur as in option 1. In this option, however, increasing the connection is much more difficult. PL cables are designed only for 1x6A connections, which has the consequence that a complete PL cable must be replaced before a charging station can be connected to it. Besides that, PL cables are deactivated by daylight. For a practical usage of the charging station the PL cable must be activated permanently which has the consequence that each streetlight must be equipped with an individual switch. When no measuring equipment is present this must be added, in the casing of the charging station or in the PL box.

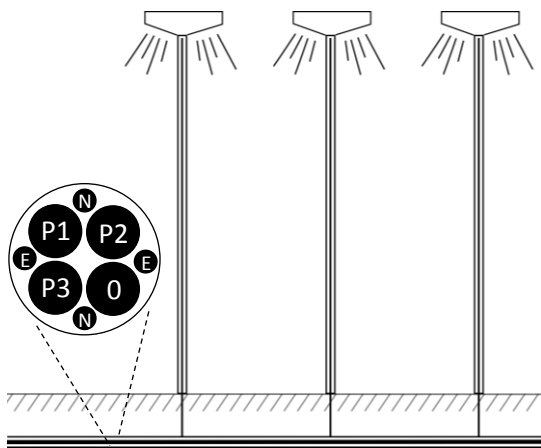


Figure 11: Streetlights connected to a combined grid.

The final option is visualized in figure 11. In this option the LV grid in a city does not consist out of four wires (a wire for each of the three phases and a neutral wire), but out of eight wires. The four extra wires are thin PL wires, of which two are evening wires and two are night wires. The evening wires are activated only in the evening, the night wires are activated all night. In this option streetlights are directly connected to the PL wires. When a streetlight is equipped with one lightbulb it is connected to the night wire, so that the streetlight is burning all night. When a streetlight is equipped with two lightbulbs, one is connected to the evening wire and one to the night wire. In that case

the illuminance is decreased at midnight. The connection size of each streetlight is only 1x6A and the energy consumption is estimated, so no measuring equipment is installed.

Also in option 3, the connection of a charging station to the PL wires results in a capacity problem. Comparable to option 2, also in this situation the PL wires are designed for handling at maximum 1x6A connections. This is too low for a practical usage of charging stations. The PL wires must be replaced completely before larger connections are possible. Besides that, also in this situation the PL wires are switched off by day. For a practical usage of the charging station the PL wires must also be activated by day, which results in the necessity of a switch in each individual streetlight. Also in this case measuring equipment must be installed in the casing of the charging station.

All other connection categories

The connections of all other categories are from a technical point of view relatively similar. They can possibly be used for making combined connections as visualized in figure 2a. The connections of all remaining categories are directly connected to the LV grid, which means that they are activated 24 hours a day. Besides that, they almost all have an electricity meter installed. Only the connections of parking meters and some connections of traffic lights do not have. However, a kWh-meter can be installed quite easily. Finally, also for all other connections no safety issues occur when making a

combined connection, since the charging station of a combined connection is installed on a comparable location to current charging stations. This means that the only barrier for making a combined connection is the available capacity on the connection.

The capacity that is available on an existing connection depends on the size of the connection and the current load on the connection. The latter is the effect of the power consumption of objects already connected to the existing connections. The size of a connection is in most cases not the same for all connections of a certain category. The main fuses of grid connections for bridges in Rotterdam, for example, have a size which ranges from 1x35A to 347kVA. It is, however, interesting to see which sizes are most common per connection category, so which connection categories have the largest technical potential for making a combined connection without increasing the connection size. The distribution of the sizes of connections per category is displayed in table 11.












											
1x6A	100%		100%								
1x25A		9%									
1x35A		18%		80%	2%	8%	10%	4%		7%	2%
3x25A		36%		19%	11%	50%	5%			7%	35%
3x35A		9%			16%	31%	56%	17%	14%	45%	43%
3x50A		9%				6%	8%			2%	2%
3x63A					13%		8%	29%		10%	6%
3x80A		9%			18%	2%	7%		14%	6%	2%
>3x80A		9%			40%	2%	6%	50%	71%	24%	11%

Table 11: Distribution of the sizes of connections per connection category. All data is derived from the data set with municipal grid connections in Rotterdam, except of the sizes of the connections for streetlights. The size of the connections for streetlights is based in the interview with Peter Holswilder.

In table 11 it can be seen that only for the streetlights and parking meters all connections of the category have the same size. For both objects this is only 1x6A. Therefore, for parking meters, the situation is similar to the first option of connecting streetlights; only when the connection of a parking meter is replaced by a larger one there is a possibility of making a combined connection. Also the connections of traffic lights are on average relatively low, with only 1x35A. In Rotterdam only 19% of the connections are 3x25A. Based on the interview with Arthur Klink, about the similar situation applies to the connections of traffic lights in Utrecht. This means that only a limited amount of connections for traffic lights can be used for making a combined connection without increasing the connection. For all other connection categories the connection sizes are on average 3x25A or more. The connections of PL boxes and fountains are on average 3x25A. The connections of public areas, buildings and pumping stations are on average a bit larger; 3x35A. The connections of bridges, sports accommodations and swimming pools are the largest with on average a connection of more than 3x80A. The larger the connection size, the larger the chance that enough capacity is available for making a combined connection. The average load on the different connections is displayed in table 12.











											
Average load	4%	42%	8%	13%	4%	8%	5%	16%	25%	15%	5%

Table 12: Average load of connections in Rotterdam. All data is derived from the data set with municipal grid connections in Rotterdam, except of the energy consumption of streetlights. For streetlights it is assumed that they have a power consumption of 50W. For the other connection categories it is assumed that the maximum possible amperage on a connection of small users is two 'steps' lower than the size of the main fuse, due to the required selectivity of an installation. For large users it is assumed that the maximum possible amperage on a connection is 75% of the size of the main fuse, due to the difference between the active and the apparent power. The average load of streetlights and PL boxes applies to the time that the streetlights are activated, which is assumed to be on average 10 hours a day. By day the load of streetlights and PL boxes is zero.

In table 12 it can be seen that none of the connections on average has a load which is near the maximum capacity of the connection. This means that a large part of the existing connection is available for a potential charging station. Especially for bridges and pumping stations the average load is remarkably low. This is a result of the fact that these connections are only used occasionally; when a bridge is opened or closed and when water is pumped away. All time in between the complete capacity of the connection is available. For PL boxes it is important to notice that by daylight load is zero since streetlights are switched off then. Due to the relatively low loads, there seems to be a significant chance that at least 7,4kW is available on an existing connection when the size of the connection is 3x25A or more.

From the technical evaluation it can be concluded that all connection categories have potential for being used as a combined connection, except of streetlights which are connected to a PL grid (option 2 and 3). For all other categories the size of the connection is large enough, or can be increased easily. Since the current load on almost all connection categories is remarkably low, there is a significant chance that enough capacity is available for making a combined connection, without increasing the connection. The larger the connection is, the higher the chance that enough capacity is available. Therefore especially the connections of bridges, sports accommodations and swimming pools have high potential for being used as a combined connection.

5.1.3 Legal and organizational evaluation

In this chapter the legal and organizational aspects of making combined connections are evaluated. The legal evaluation focusses on the legitimacy of selling power to EV users and the legitimacy to use the cluster regulation for calculating the energy tax when using a combined connection. In the organizational evaluation it is investigated how the municipality and the charging point operator can collaborate in an efficient way and what conflicts of interest might arise between different departments of the municipality. The results of this evaluation are comparable for all connection categories and are therefore discussed for all categories together.

Legal aspects

The first legal issue that is investigated is the legitimacy to sell power to EV users when using a combined connection. Due to the involved obligations and bureaucracy it is not favorable for the municipality and charging point operators to apply for an energy supply license or to become an official reseller of electricity. However, two energy transfers take place when using a combined connection; from the grid connection to the charging station and from the charging station to the EV.

For both transfers it is important to investigate if it is allowed to transfer the electricity without having an official license.

The energy law states that it is mandatory to have a supply license when electricity is supplied to a consumer with a grid connection up to 3x80A (Electriciteitswet, 1998, hoofdstuk 8, § 1a, artikel 95a). For this situation the exact definition of the term grid connection is important. A grid connection is defined as a connection between a grid and a real property ('Wet belasting op milieutoeslag', 1994, hoofdstuk 4, afdeling 1, artikel 47f). This means that a license is only required when a grid and a real property are involved. For the first energy transfer no license is required since the connection between the existing connection and the charging station is not classified as a grid, but as part of the installation. This is the case when the existing connection and the charging station have the same legal owner (Baljon, 2016). The Dutch civil law describes that a landowner becomes the legal owner of all real properties built at his or her ground (Burgerlijk wet boek 3, 2015, titeldeel 1, afdeling 1, artikel 4). Since public charging stations are always installed at municipal grounds the municipality becomes the legal owner of the object. Since the municipality is also the owner of the grid connection, the connection cables are not classified as a grid but as part of the installation. For the second energy transfer also no license is required since the EV is not classified as a real property. This is the case because an EV is not permanently fixed to the ground (Movares, 2014). Therefore for both energy transfers no official energy supply licenses are required.

The second legal issue that is investigated is if it is allowed to use the cluster regulation when selling power via a combined connection. It is clearly stated in an extra conclusion of the tax authorities that regular public charging stations cannot be clustered for calculating the energy tax (Belastingdienst, 2016b)). However, it is not clear which regulations apply when a charging station is connected to a grid connection that is used by an object that can be clustered. When, for example, a charging station is connected to the grid connection of a pumping station, it is unclear if the energy consumption of the charging station can be clustered with the energy consumption of pumping stations. After all, the energy consumption of pumping stations can be clustered and it is not 'visible' for the grid operator which part of the electricity is consumed by the charging station and which part by the pumping station.

Since there are no practical examples of this situation yet, it cannot be concluded with certainty whether or not it is allowed to use the cluster regulation for the charging station. However, based on the existing regulations it can be expected that it will not be accepted. Municipalities can decide by themselves how to implement the law WOZ, including the clustering regulation. However, they are kept under strict surveillance by the national 'valuation authority' (in Dutch: *waarderingskamer*) (Waarderingskamer, n.d.). In official documents it is stated that all changes to the situation that can affect the implementation of the clustering regulation must be reported immediately (GDF Suez, 2014). Due to the clear statement that charging stations cannot be clustered, and due to the obligation to report adjustments to the situation immediately, it is assumed that it is not possible to use the cluster regulation for charging stations which are connected with combined connection.

Organizational aspects

The first relevant organizational aspect is the collaboration between the municipality and the charging point operator when using a combined connection. The collaboration can be arranged in two ways:

- The most common way for public charging stations is that the municipality grants a concession to a charging point operator to install and operate charging stations in a certain area and for a certain time period. The municipality becomes the legal owner of the charging station, the operator the economic owner. This means that the operator is responsible for all costs and benefits in the period of the concession, including the costs for placing the charging station. The business model of charging stations, however, is not favorable yet. Therefore, the municipality provides a financial support to cover the expected financial gap. The height of the financial support is defined at the beginning of the contract period. Thereafter the operator carries the economic risk of the charging station.
- The second option is that a municipality buys a charging station and becomes both the legal and the economic owner. The municipality receives all incomes of providing the charging services. The municipality only hires a private party for doing the administration work and maintaining the charging station. The municipality carries the economic risk of the charging station. This option is most common when municipalities install charging stations at their own connections, for example in car parks.

For combined connections both options are possible, however, one might be more suitable than the other. Since with combined connections charging stations are connected to municipal grid connections, the second option seems to be logical. In this way a municipality can control its own connections and all objects connected to it. However, the business model of combined connections, as described in section 5.1.4, still contains a lot of uncertainties. Since municipalities are generally unwilling to make risky investments, it seems to be more favorable to use the second option. In that case a private party carries the risk of the charging station. When doing so, however, clear arrangements must be made about load control and payment of the consumed electricity since the private party makes use of a municipal connection.

The second relevant organizational aspect is the cooperation between different departments of the municipality when using a combined connection. When a combined connection is implemented there is a high probability that different departments of the municipality are responsible for the different objects connected to the grid connection. It is experienced that this might lead to serious conflicts. To describe the complex organizational issues that might arise when implementing combined connections, the organizational structure of the municipality of Utrecht is used as an example.

In Utrecht there are six councilors who are responsible for 14 main programs, which are divided in multiple sub programs (Gemeente Utrecht, 2016a). Each program focusses on a specific topic within the municipality, for example education, safety, public health, accessibility and sustainability (Gemeente Utrecht, 2015). The yearly municipal budgetary is defined per program and sub program. Besides that, there are 9 departments responsible for development and policy making, 4 departments responsible for the practical implementation of projects, and 1 department responsible for the daily operation and maintenance of all objects and activities within the municipality (Gemeente Utrecht, 2016b). All departments have their own focus, but they can work on projects of

different programs. The department responsible for the daily operation and maintenance, called ‘stadsbedrijf’ (SB), is divided into 7 different sub departments. Each sub department focusses on the daily operation and maintenance of other objects and activities (Gemeente Utrecht, 2016c).

When combined connections are implemented it is important to investigate for which processes the interests and responsibilities of different departments get intertwined. The less processes get intertwined, the smaller the chance of internal conflicts of interest. When implementing combined connections, the tender process for charging stations can still be performed by the same department, but now with some charging stations at combined connections included. In Utrecht the Environment & Mobility department is responsible for this, which is one of the nine development & policy making departments. Maintenance work of the charging station can still be performed by the charging point operator. However, when making a combined connection, one of the sub departments of SB is responsible for maintaining the other connected object. This department is also responsible for paying the electricity bill of the complete connection. Which sub department of SB is responsible for which connection category is displayed in table 13.












											
Responsible department	SB-SB	SB-SB	SB-VB	SB-SB	SB-SB	SB-SB	SB-SB	SB-VE	SB-VE	SB-VE	SB-SB

Table 13: Departments responsible for maintenance work and payment of the electricity bill of the different connection categories in the municipality of Utrecht. Data derived from the dataset with municipal grid connections in Utrecht. SB-SB = Stadsbedrijf – Stedelijk Beheer, SB-VB = Stadsbedrijf – Vastgoed Beheer, SB-VE = Stadsbedrijf – Vastgoed Exploitatie.

In table 13 it can be seen that only three departments are responsible for maintenance work and payment of the electricity bill of the different connection categories. However, almost all connection categories are part of different programs, and the budget that is used to pay the electricity bill is part of the concerned program. No connection type is part of the same program as charging stations, which is part of a sub program of the accessibility program. Therefore, the program that pays for the electricity consumption of the complete connection must reclaim the part of the electricity costs that can be allocated to the charging station from the charging point operator. There are two ways in which this can be done. The first option is that the concerned program directly charges the charging point operator for the consumed electricity. The second option is that the concerned program reclaims part of the budget of the accessibility program, which in its turn passes the costs on to the charging point operator. The second option minimizes the amount of payments that are necessary and therefore seems to be most favorable. However, since it can be expected that the concerned program has no expertise in contract management with a charging point operator, the accessibility program might advise in this.

The processes mentioned above indicate that there are possibilities to structure the municipal organization in such a way that combined connections can be implemented. However, it can also be seen that the internal structure of municipalities is very complex and that in some cases significantly different structures are required for the implementation of combined connections. It is experienced that there is much resistance among the employees of the municipality of Utrecht to switch any new structures. Most employees are accustomed to the current processes and are unwilling to adapt to new ones. Therefore, there seem to be suitable organizational structures for combined connections, but it will require significant efforts to implement these new structures.

5.1.4 Financial evaluation

In the final evaluation the business case of making combined connections is investigated. The result of the business case depends on the characteristics of the existing connection, like whether or not the size of the connection must be increased, whether or not an electricity meter must be installed, whether or not the clustering regulation can be used and what the total electricity consumption of a combined connection is. No combination of characteristics is unique for a connection category; however, some combinations of characteristics are more likely to occur than others. Therefore different scenarios are described which are likely to occur for certain types of connections. For each scenario the business case is calculated for a situation in which one charging station is connected to an existing municipal grid connection, and is exploited for 8 years. For the calculation of the business case data provided in the background information is used, together with the parameters given in table 14. All prices are excl. VAT.

Category	Parameter	Value
General	Average usage of a charging station with two charging points	3500 kWh/year
	Interest rate	2 %
	Distance between charging station and existing connection	5 meter
Incomes	Sales price of electricity	0,28 euro/kWh
Costs	Hardware of a charging station (incl. electricity meter)	2000 euro/pole
	Hardware of a charging station (excl. electricity meter)	1000 euro/pole
	WIOR (building license)	10 euro/pole
	Construction costs (charging station incl. electricity meter)	900 euro/pole
	Construction costs (charging station excl. electricity meter)	700 euro/pole
	Increasing cable size/extend cable length	45 euro/meter
	Maintenance	400 euro/pole
	Back office	60 euro

Table 14: Parameters used for the calculation of the business cases. All data is based on internal communication.

In total eight business cases are investigated; two reference scenarios and six scenarios for combined connections. The two reference scenarios represent the situations of how charging stations are installed nowadays. By doing so a comparison can be made between the reference situation and the situation in which combined connections are made. In each business case of combined connections only the extra costs that have to be made for making, increasing or maintaining a grid connection, are allocated to the business case of the charging station. When the costs for the grid connection remain similar, no costs are allocated to the charging station.

It must be noted that all scenarios turn out a bit more negative than they are in reality, since each business case is calculated for only a single charging station. In practice a company would install multiple charging stations which lead to economies of scale. However, since also the reference scenario is calculated for only one charging station, a valid comparison can be made between the different scenarios. The scenarios are explained in table 15, the results of the business cases are presented in table 16.

Scenario		Realistic for	Description
Reference	a	Current charging stations	Reference scenario in which a new grid connection of 3x25A is made for a charging station. Energy tax level 1 must be paid.
	b	Current charging stations	Reference scenario in which a new grid connection of 3x25A is made for a charging station. Due to the tax reduction tax level 2 can be paid from 2017-2020, after that level 1 must be paid.
Increase of connection necessary	1a	Streetlights, parking meters	A connection must be increased from 1x6A to 3x25A. Tax level 1 must be paid.
	1b	Traffic lights	A connection must be increased from 1x35A to 3x25A. Due to the large consumption of the combined connection, tax level 2 can be paid for the consumption of the charging station.
	1c	PL boxes	A connection must be increased from 3x25A to 3x35A. Due to the large consumption of the combined connection, tax level 2 can be paid for the consumption of the charging station.
	1d	pumping stations	A connection must be increased from 3x25A to 3x35A. Due to the very large consumption of the combined connection, only tax level 3 has to be paid for the consumption of the station.
No increase of connection necessary	2a	PL boxes, fountains, pumping stations	Enough capacity is available so the connection does not have to be increased. Due to the large consumption of the combined connection, tax level 2 can be paid for the consumption of the charging station.
	2b	Bridges, sports accommodations, pools, buildings	Enough capacity is available so the connection does not have to be increased. Due to the very large consumption of the combined connection, only tax level 3 has to be paid for the consumption of the charging station.

Table 15: 8 scenarios for which the business case is calculated; 2 reference scenarios, 6 scenarios for combined connections.

Scenario	Increase of connection	Tax category	NPV (€)	Difference with reference scenario a (€)	Difference with reference scenario b (€)
Ref a	0 > 3x25A	1	-5.202,22	0,00	0,00
Ref b	0 > 3x25A	1 and 2	-4.526,01	676,21	0,00
1a	1x6A > 3x25A	1	-5.344,25	-142,03	-818,25
1b	1x35A > 3x25A	2	-2.246,85	2.955,37	2.279,16
1c	3x25A > 3x35A	2	-5.062,64	139,59	-536,63
1d	3x25A > 3x35A	3	-4.122,96	1.079,26	403,05
2a	No	2	-907,09	4.295,13	3.618,91
2b	No	3	32,58	5.234,81	4.558,59

Table 16: results of the business cases of combined connections per scenario.

It can be seen in table 16 that only in specific cases a combined connection is significantly more favorable than the reference scenarios. When the connection must be increased, only the increase of a 1x35A connection to a 3x25A can lead to significant benefits. This is the result of the fact that the periodic grid operator costs for a connection of 1x35A and 3x25A are equal. Therefore no periodic grid operator costs are allocated to the charging station. The periodic grid operator costs of a 3x35A connection, on the other hand, are about four times as much as the costs of a 3x25A. Therefore, there are no significant benefits when increasing a 3x25A to a 3x35A connection for making a combined connection. It is clearly most favorable when an existing connection does not have to be increased. Especially when a large connection is used and only tax level 3 has to be paid, savings of about 5000 euro per charging station can be achieved compared to the reference scenarios.

5.2 Evaluation of combined objects

5.2.1 Locational evaluation

In the first evaluation of combined objects the presence of objects in cities and the location of objects relative to parking lots are investigated. The presence of objects in cities is directly related to the presence of their grid connection, which is already evaluated in the locational evaluation of combined connections. It could be seen that all objects were present in both Rotterdam and Utrecht. For the location relative to parking lots it is important that the object is located directly next to the parking lot. This means that when a charging point is integrated, a car can be connected without crossing the pavement with a cable. The location of connections is unique for each situation; however, some similarities can be seen between connections of the same category. To reduce the amount of objects in public space, the municipality endeavors to place the boxes of grid connections against walls. Examples of this can be seen in figure 12 and 13.



Figure 12: Example of a PL box in Utrecht.

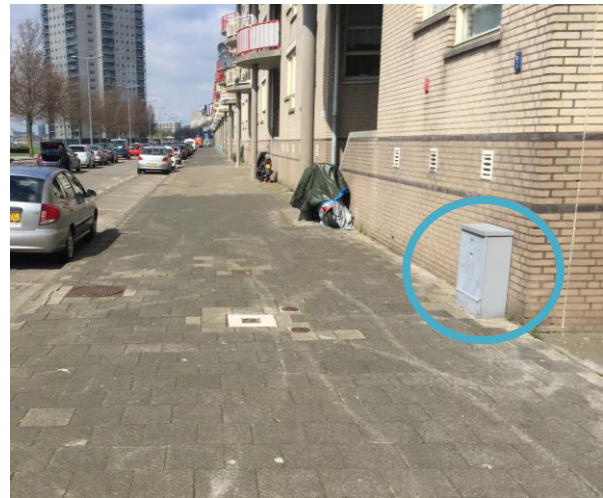


Figure 13: Example of the connection for a pumping station in Rotterdam.

This has the result that in almost no cases a charging point can be integrated in these objects. Only streetlights and parking meters are often located directly next to a parking lot, as can be seen in figure 14 and 15. Therefore only streetlights and parking meters have potential for being used as combined objects and only those objects will be included in the following evaluations.



Figure 14: Example of a parking meter in Utrecht.



Figure 15: Example of streetlight in Utrecht.

5.2.2 Technical evaluation

The technical evaluation focusses on the available capacity, the activation of the grid, the presence of measuring equipment and the safety of making combined objects. As could be seen in the technical evaluation of combined connections, both the connections of streetlights and parking meters have a capacity which is too low for making a combined connection. For streetlights which were connected by means of a PL grid or combined grid, the connection was even deactivated by day. Therefore it is impossible to make a combined object of streetlights and parking meters without improving the connection. There are four options to make the improved connection, visualized in figure 16 till 19.

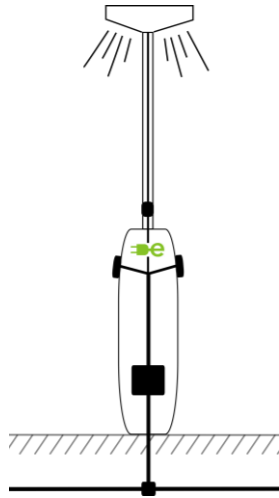


Figure 16: Combined object with a grid connection to the LV grid to power both the charging points and the streetlight.

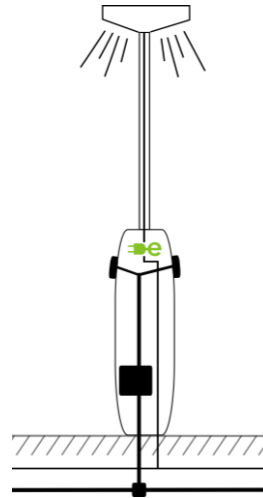


Figure 17: Combined object with a connection to the LV grid for the charging points and a connection to the PL grid for the streetlight.

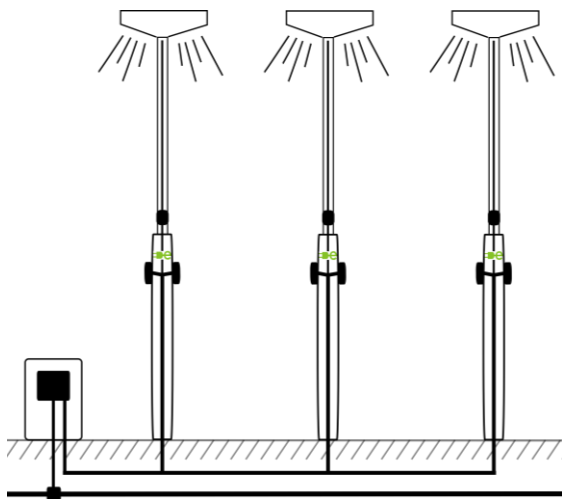


Figure 18: Multiple combined objects connected to a PL box.

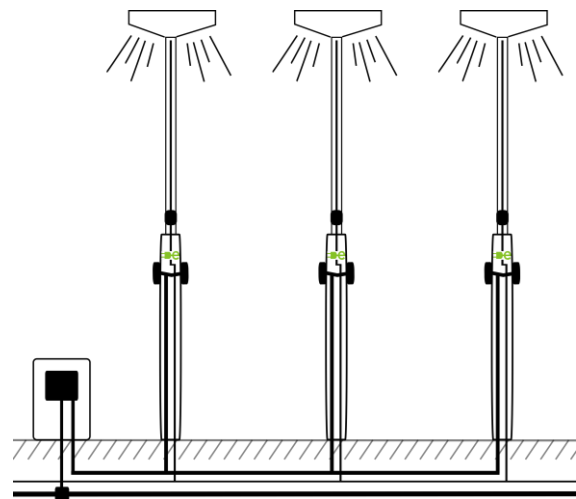


Figure 19: Multiple combined objects connected to a PL box and the PL grid.

In the first option a 3x25A connection is made to the LV grid. With this connection both the charging station and the streetlight or parking meter are powered. A switch must be installed to switch off the streetlight by day. Since the connection, in contrast to regular streetlights, has no predictable consumption, it is not allowed to estimate the power consumption. Therefore a kWh-meter of the RGO must be installed. This kWh-meter has a size of 30x18x12cm (HxWxD), which is more than the thickness of a default streetlight. Besides that the RGO requires 2 cm free space at both sides, 5 cm

at the top and bottom side and 1 cm at the front side. This space is called the RGO compartment and is necessary because the RGO uses a device for calibrating the kWh-meter which has to be placed over the kWh-meter. Previously, also smaller ABB meters were approved by the RGOs. However, since RGOs want to step over to smart meters which have about the same size as the big kWh meter, the small ABB meters are not allowed anymore for new connections. Therefore a charging point cannot be integrated in a conventional streetlight, but a streetlight with an enlarged bottom part must be used.

In the second option two grid connections are made for the same object. Not only a 3x25A connection to the LV grid is made to power the charging points, but also an existing 1x6A connection to the PL grid is used to power the lightbulb. This option is comparable to the previous option, except of two aspects. The first difference is that no switch is required because the power of the PL grid is automatically switched off by daytime. Secondly, since two grid connections are made in the same object, the object needs two compartments to physically separate the different connections. The NEN 1010 standard requires the possibility of maintenance work at both of the connections without seeing the other connection. This might require an even larger casing of the streetlight, however, with smart installation it can be fit in the same object as option 1.

In the third option a PL box is installed with a large connection of about 3x63A to the LV grid. Multiple streetlights with integrated charging points are connected to this PL box, which all get an individual switch for the lightbulb. The PL box contains a load controller so that the combined load of the objects does not exceed the maximum available capacity of the connection. The cables used for connecting the streetlights to the PL box are significantly thicker than PL cables of a conventional PL grid. The cables can only be 60 meters long, otherwise the communication signal between the charging point and the load controller gets distorted. The kWh-meter can be installed inside the PL box, which allows for a much slimmer casing of the individual streetlights. There are also ideas to place the PL box underground, however, RGOs are unwilling to accept underground installations since this complicates their calibration and recording activities.

In the fourth option a PL box comparable to the third option is used to connect the streetlights, with the only difference that in this option each streetlight also has a connection to the PL grid. Therefore no switch has to be installed but different compartments for the two connections must be made within the casing of the streetlight. This separation, however, is less difficult than in option three since no measuring equipment has to be installed inside the casing of the streetlight.

5.2.3 Legal and organizational evaluation

In the third evaluation it is evaluated if it is legitimate to sell power to EV users and if it is allowed to use the clustering regulation when using combined objects. Besides that, it is investigated how the municipality and the charging point operators can collaborate in a most efficient way, and if any internal conflicts within the municipality might arise when implementing combined objects.

Legal aspects

In the legal evaluation of combined connections it could be seen that it is legal to sell power to EV users when using a combined connection. This same result applies to combined objects, so this aspect will not be further discussed in this section. The legitimacy to use the cluster regulation, however, might differ from the result of combined connections. For combined connections it was concluded that the cluster regulation may not be used, mainly because the tax authorities have

stated clearly that the regulation does not apply to charging stations. However, when integrating a charging point in a streetlight, it is questionable if the resulting object will be classified as a charging station or as a streetlight. When the object is classified as charging station, the same result as for combined connections is applicable. However, when the object is classified as streetlight, the regulations of regular streetlights might be applicable. In that case it might be allowed to use the cluster regulation also for the electricity consumption of the charging point. Also in this situation the 'waarderingskamer' must determine what classification the object will receive. For this research it is assumed that both classifications are realistic, so both scenarios are included in the business case. It must be noted, however, that using the cluster regulation is only a possibility when the charging points and the lightning objects make use of the same grid connection. This is only the case for option 1 and 3 of the technical evaluation, so only for those options the possibility to use the cluster regulation is included in the business case.

Organizational aspects

The organizational aspects of implementing combined objects are comparable to those of combined connections. However, there is one aspect that requires extra attention when implementing combined objects, which is the installation of the object. Since two objects are physically integrated they have to be installed at the same time, which was not the case for combined connections. Therefore the tender processes of both objects get intertwined. There are three ways in which the tender process of combined objects can be arranged, which all have their pros and cons:

- The first option is that a normal tender for lightning objects is held however, now included with some combined objects. In this case the party that wins the tender must replace part of their streetlights by combined objects at specific locations. The benefit of this type of tender is that the combined objects perfectly fit in the lightning plan of the other streetlights. However, it can be expected that the company installing streetlights does not have any experience with operating charging points. Therefore they will have to cooperate with a charging point operator which gets responsible for maintaining and operating the charging points. This type of tender seems to be favorable when only a few streetlights distributed over a certain area have to be installed as combined object.
- The second option is that a normal tender for charging stations is held however, now included with some combined objects. In this case the party that wins the tender must install part of their charging stations as combined object. The benefit of this type of tender is that the combined objects can be operated in a similar way to all other charging stations. However, the company installing the combined objects must work together closely with the party responsible for public lighting to fit the combined objects in the existing lightning plan. Also the exterior of the combined object must be comparable to the existing streetlights. Also this type of tender seems to be a possibility when only a few combined objects distributed over a certain area have to be installed.
- The final option is that a tender is held specifically for a certain number of combined objects. The benefit of this type of tender is that it can be held at locations where there are already existing concessions for streetlights and charging stations. In this situation, however, the company installing the combined objects will enter the work field of both the company maintaining the existing streetlights and the company operating the regular charging stations. Therefore, this option seems to be most favorable when multiple combined objects

have to be installed in only a small area, for example in only one street. In that case the work fields of all involved parties remain most separated.

Which type of tender is most favorable depends on the situation and must be decided by the municipality. However, also in this case it must be noticed that the required processes differ significantly from the current procedures and it must be investigated if all involved people are willing to switch to new processes. It can be expected that policymakers will face strong resistance among employees of the municipality when implementing the required organizational changes.

5.2.4 Financial evaluation

In the final evaluation the business cases of combined objects are evaluated. The result of the evaluation depends on which of the four technical options for installing the combined objects is used, and whether or not it is allowed to use the cluster regulation. For this evaluation the same parameters as in the financial evaluation of combined connections are used. Only two parameters are added, which are presented in table 17. Table 18 shows a description of the different scenarios and table 19 the results of the business cases. Also this business case is calculated for a situation in which the combined objects are exploited for 8 years.

Category	Parameter	Value
General	Average distance between streetlight	30 meter (24 meter when 5 streetlights are placed ideally relative to PL box)
Costs	Hardware allocated to charging function (incl. electricity meter)	2000 euro/pole

Table 17: Extra parameters used for calculating the business cases of combined objects. Data based on interview with Florian Mesch.

Scenario		Description
1 object, 1 connection	1a	One combined object is connected to a 3x25A connection. The cluster regulation may not be used, so tax level 1 must be paid.
	1b	One combined object is connected to a 3x25A connection. The cluster regulation may be used, so power consumption can be clustered with all streetlights in a city and only tax level 5 has to be paid for the consumption of the charging points.
1 object, 2 connections	2	One combined object is connected to both a 3x25A connection and the PL grid. The cluster regulation may not be used, so tax level 1 must be paid.
Multiple objects, 1 connection	3a	Five combined objects are connected to a PL box with a 3x63A connection. The cluster regulation may not be used. However, due to the large consumption more than 10,000 kWh/year is used and partly tax level 2 can be paid.
	3b	Five combined objects are connected to a PL box with a 3x63A connection. The cluster regulation may be used, so power consumption can be clustered with all streetlights in a city and only tax level 5 has to be paid for the consumption of the charging points.
Multiple objects, 2 connections	4	Five combined objects are connected to a PL box with a 3x63A connection. The cluster regulation may not be used. However, due to the large consumption more than 10,000 kWh/year is used and partly tax level 2 can be paid.

Table 18: 6 scenarios for which the business case of combined objects is calculated.

Scenario	Objects connected	Connection size	Tax category	NPV per object (€)	Difference with reference scenario a (€)	Difference with reference scenario b (€)
1a	1	3x25A	1	-5.123,67	78,56	-597,66
1b	1	3x25A	5	-2.633,95	2.568,28	1.892,06
2	1	3x25A and PL	1	-5.202,22	0,00	-676,21
3a	5	3x63A	1 and 2	-4.611,13	591,10	-85,12
3b	5	3x63A	5	-2.678,95	2.523,27	1.847,06
4	5	3x63A and PL	1 and 2	-4.689,68	512,54	-163,67

Table 19: results of the business cases of combined objects per scenario.

It can be seen in table 19 that scenario 1a and 2 are about similar to the reference scenario, since the costs of the hardware that are allocated to the charging function are similar to the costs for a new charging station. In option 1b, however, there is a serious financial benefit because of the clustering regulation which might possibly be applied since only one grid connection is used. Option 3a and 4 have a small benefit compared to the reference scenario, since the combination objects results in large energy consumption and less energy tax has to be paid. However, the benefit is only small since high grid operator fees must be paid for the large grid connection, and thick cables must be pulled to the combined objects. Scenario 3b is, surprisingly, less beneficial than scenario 1b since the dispersion of costs over multiple objects does not outweigh the extra installation and grid operator costs of the large connection.

6. Discussion

This research has tried to minimize the existing uncertainties regarding alternative connections for public charging stations. For the evaluation of both combined connections and combined objects many results are found, which will definitely contribute to the understanding of the possibilities of alternative connections. Before drawing the conclusions, however, it is important to look at the quality of the results and if any limitations can have affected the results.

The main limitation of this research is that the results are only based on the situations in Rotterdam and Utrecht. Although much data was available on both municipalities, and both cities can be seen as representative for large cities that have difficulties with providing a sufficient charging infrastructure, the results cannot be generalized to all municipalities in the Netherlands. Especially for smaller municipalities the results might be different. The organizational structure of a smaller municipality, for example, might be less complex resulting in less complications when implementing alternative connections.

Besides that, it must be noted that the categorization of connections that is used in this research is a simplification of reality. The results that are applicable to a certain connection category cannot be generalized to each individual connection belonging to that category. If a certain connection category turns out to have great potential for being used as an alternative connection, this does not mean that each individual connection of that category has great potential. The connections of that category only have a higher chance of being suitable and beneficial than the connections of a category with low potential. The other way around, when a certain connection category has low potential, this does not mean that all individual connections of that category are unsuitable. Therefore, the findings of this research must be used as an indication of the possibilities of using alternative connections. It can help to guide policy makers in their search for alternative ways of installing charging infrastructure. However, when implementing alternative connections in practice, individual grid connections must be investigated to know which ones are suitable in practice.

Finally, further research is required on the legal and organizational aspects of implementing alternative connections. For the legal evaluation the existing ambiguities regarding the cluster regulation are explained clearly, however, it is still unclear if the cluster regulation can be applied to alternative connections. A practical implementation of alternative connections is required to state with certainty what the legal statement of the tax authorities will be. In the organizational evaluation of alternative connections many results are gathered, however, no clear solution was found for the organizational issues. Further research on how to structure the municipality when implementing alternative connections, is highly recommended. In this research only some suggestions could be made about how to structure the departments, however, this is not based on founded research and cannot be generalized. The only conclusion about the organizational evaluation that can be drawn based on this research is that internal conflicts can be expected when implementing alternative connections.

7. Conclusion

In this research it is investigated which existing municipal grid connections are suitable and beneficial to be used as an alternative connection, and how alternative connections can be implemented in practice. A distinction is made between combined connections and combined objects. It can be concluded that all types of connections are suitable for making a combined connection, except of streetlights connected to a PL grid. A PL grid has only very little capacity and must be replaced completely before being suitable for making combined connections. Due to the excessive work this requires PL grids are classified as an unsuitable for making combined connections. All other types of existing municipal grid connections are large enough for making combined connections, or can be increased easily. For making combined objects only streetlights and parking meters are suitable. All other objects are in almost no situations located directly next to a parking lot. Since it is not allowed to cross the pavement with a cable when plugging an EV into a charging point, only streetlights and parking meters are suitable for making a combined object.

The organizational structure of a municipality, however, might form a serious barrier when implementing alternative connections in practice. The crux of the problem is that municipalities work in strictly separated departments. Each department has its own responsibilities and an individual budget for reaching its targets. When making combined connections or combined objects, the interests of different departments get intertwined. As a result of this, very complex cooperation structures have to be invented, and people have to relinquish parts of their responsibilities and budget to other departments. It is experienced that people are very unwilling to do this. Since this problem is an organizational issue, it can, in essence, always be solved. However, it will take serious time and effort to change the organizational structure of a municipality, so significant benefits must be reached to make it worth implementing alternative connections. Therefore, only those alternative connections that have significant financial benefits can be seen as suitable options.

The financial benefits of using alternative connections differ per situation. For combined connections it can be seen that most financial benefits can be achieved when enough capacity is already available on the existing connection, so no enlargement of the connection is necessary. It is found that the current load on almost all types of connections is remarkably low, so there is a significant chance that enough capacity is available for making a combined connection. The larger the connection is, the larger the chance that enough capacity is available. Therefore especially bridges, sports accommodations and swimming pools have a high potential. Also an enlargement of a 1x35A connection to a 3x25A connection results in significant benefits, which also makes streetlights favorable for making combined connections. For combined objects only streetlights with a direct connection to the LV grid and five objects connected to one PL box result in reasonable financial benefits. These benefits only occur when the clustering regulation is applicable to combined objects and it is still questionable if this is allowed. However, combined objects have the significant extra benefit that implementing them results in less objects in public space.

To conclude; all types of existing municipal grid connections are suitable for making a combined connection, except of streetlights connected to a PL grid. Only streetlights and parking meters are suitable for making a combined object. However, using alternative connections is only favorable when the financial benefits of implementing it outweigh the large organizational conflicts that it entails. This is only the case in specific technical situations, which occur most often when making

combined connections of traffic lights, bridges, sports accommodations and swimming pools. In case the cluster regulation is applicable, there are also reasonable financial benefits of making combined objects of streetlights. Combined objects have the extra benefit that they reduce the amount of objects in public space.

8. References

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