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Lightweight infrastructure for electric vehicle charging

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Abstract

Electric vehicles need a charging infrastructure. In this paper, it will be argued that Sweden already has a charging infrastructure that potentially could provide all cars with electricity if they were electrified. The charging infrastructure consists of existing motor heaters sockets and outlets near e.g. villas and holiday homes which directly or for low cost can be rebuild to provide electric vehicles with energy. Building a lightweight infrastructure for electric vehicle charging consisting of simple sockets is roughly hundred times cheaper than building fast chargers or a charging infrastructure with Type 2 plug with charging modes Mode 2 or Mode 3. Therefore, it is wise to build a lightweight charging infrastructure for electric vehicle charging and use the connectivity of the vehicle to e.g. enable smart charging and other desirable services/applications. Parts of the conclusions and results in this paper have been established in a Swedish project denoted ELVIIS consisting of partners from research (Viktoria Swedish ICT), car industry (Volvo Car Cooperation), telecom sector (Ericsson) and utility industry (Göteborg Energi).

Keywords: electric vehicle, lightweight charging infrastructure, smart charging, cost analysis

1 Introduction

Electric Vehicles (EVs), which in this paper is referred to road vehicles that externally can be charged by electricity like **Battery Electric Vehicles** (BEVs) and **Plug-in Hybrid Electric Vehicles** (PHEVs), have a potential to reduce the greenhouse gas emissions and the oil dependency in the transport sector. Furthermore, EVs are quiet and have no local emission of pollutants when propelled by the electric motor, which enables indoor driving and driving on narrow streets. The characteristics of high performance and smooth driving make EVs very suitable in e.g. cities as a part of sustainable mobility solutions.

Despite all the positive characteristics of EVs, the majority of people still continue to buy fossil

fuelled vehicles since EVs are expensive to buy, and the life-span of batteries and the new technology are uncertain. In addition, many people think that BEVs will not fulfill all the needs of a regular car user.

The lack of charging infrastructure for EVs is often stated as a reason for why the adaption of electric vehicles is so slow in different countries, and can be added to the list of drawbacks related to EVs; often relations is made to the **chicken and the egg** problem causality dilemma. To get around the vicious circle of the high cost of vehicles, a low level of consumer acceptance, and the lack of recharging stations, the European Parliament agreed on the 15th of April 2014¹ on a directive on deployment of alternative fuels infrastructure that should break up the vicious circle by ensure the

¹http://europa.eu/rapid/press-release_IP-14-440_en.htm

build-up of alternative refuelling points across Europe with common standards for their design and use, including a common plug for recharging electric vehicles. Initially, the ambition of the directive was ambitious e.g. containing a minimum numbers of charging poles etc. for the member states², but in the end, the level of ambition decreased since due to lack of support. This is understandable, since building an infrastructure costs money, and there are no guarantees that the investment gives a boost for clean fuel vehicles.

Sweden has decided to reduce the greenhouse gas emissions by 40% 2020 compared to 1990 and the target is to have a vehicle fleet that is independent of fossil fuels in 2030³. An investigation pointed out in December 2013 what is needed in Sweden to reach the transport targets^{4,5}. Part of the solution is to become more energy efficient and use renewable energy sources and one of several potential solutions is EVs. No targets have been set by the Swedish government on the number of EVs, which some references wrongly point out. Before the last election (which was held on the 14th of September 2014), most parties in Sweden said that there will be investments in charging infrastructure⁶. However, there are different opinions between Swedish parties whether to support fast charging or slower alternatives.

The establishment and deployment of charging infrastructure for electric vehicles is a risky business in many aspects. There are still open questions around the charging infrastructure establishment, e.g. which charging speed is suitable for private and public usage, where the charging infrastructure should be located, how much money the customer is willing to pay for the electricity, if the charging should be made by a cable or wireless by e.g. induction, if battery swapping is a better alternative, or if charging should be done standing still or by Electric Road Systems (ERS) making it possible to charge while driving. The latter is more futuristic, but a topic under discussion in e.g. Sweden since this seem to be one of few solutions reducing the

carbon dioxide emission for heavy duty trucks driving long distances.

Even though many uncertainties exist, some private and public actors have started to deploy a public charging infrastructure. **Tesla Motors** has started to establish an infrastructure of superfast (up to 120 kW) chargers in North America, Europe and Asia⁷. The Tesla supercharger connector has its own standard and the Tesla cars can recharge for free. Indirectly, the installation and electricity is financed by the income of the car selling. Recently, it was announced that BMW and VW are joining with **ChargePoint** to help fund the development of a network of 24 kW or 50 kW fast-charging stations in U.S. with the SAE Combo connector. Furthermore, Level 2 chargers will also be supported. It costs money to charge at ChargePoint stations. Estonia sold its carbon dioxide emission quota to Mitsubishi which financed their electromobility programme including the financing of a grid of fast charging stations⁸. Norway, having the highest dense number of EVs in the world, has a well-established grid of charging stations⁹.

So far, there is no data or analysis published confirming that a certain charging infrastructure leads to a faster adoption of EVs – e.g. the Estonia case does so far not indicate a mass adoption of EVs. In Norway however, it was concluded that the availability of a public charging network is important for an EV deployment [1], not necessarily a fast charging network. A study performed in Australia concluded that the installed charging infrastructure is only consistently utilized when there is an EV daily commuting to and from the station and does not seem economically viable while there is such a low population of EVs [2]. Studies in U.S.¹⁰ indicates that the usage of the fast charging stations increases during time, but it cannot be said that the availability leads to more EVs. The availability of fast chargers is sometimes pointed out as means for reducing range anxiety for people driving low range BEVs, but range anxiety is a complex phenomenon that can be cured in many ways¹¹. Studies from Japan show that the presence of chargers make the EV drivers

²http://europa.eu/rapid/press-release_IP-13-40_en.htm

³www.government.se/content/1/c6/12/32/52/b03e9aa8.pdf

⁴www.regeringen.se/content/1/c6/23/07/39/1591b3dd.pdf

⁵www.regeringen.se/content/1/c6/23/07/39/6048e8ad.pdf

⁶www.elbilsverige.se/riksdagsenkatt2014.pdf

⁷www.teslamotors.com/supercharger

⁸elmo.ee/charging-network/

⁹<http://nobil.no/>

¹⁰www.theevproject.com/cms-assets/documents/126447-30174.dcf-initexp.pdf

¹¹www.elvire.eu/IMG/pdf/The_phenomenon_of_range_anxiety_ELVIRES.pdf

more prone to drive in areas where public (fast) charging is available since the availability reduces the range anxiety¹². Range anxiety is a complex phenomenon and it can increase as well as decrease with experience, and it can depend on personal traits, as well as be affected by the situation in and outside the EV [3]. Investigations of the major factors influencing PHEV charging behavior is done in [4], and they conclude that the main factors that will determine the take up rates are complex and unpredictable. Despite the difficulties, there are papers pointing out strategies for infrastructure deployment, e.g. [5].

Since there still is a lot of charging infrastructure open questions, the purpose of this paper is to make a rough cost analysis of three potential charging infrastructure scenarios in Sweden to understand the level of investment needed – one scenario consists of using the existing and if necessary rebuild normal charging infrastructure in form of simple sockets, this is denoted a lightweight infrastructure. The second scenario consists of building a network of Type 2 chargers for normal recharging and the third scenario is a charging infrastructure of fast chargers. To perform the analysis, the entire Swedish transport road mileage will be recalculated to a likely yearly EV energy consumption; this is done in the first section together with a rough estimation of the available yearly charging infrastructure capacity in Sweden today. The cost analysis then follows in Section 3. The suggested lightweight infrastructure solution is then more thoroughly described in Section 4, followed by conclusions in Section 5.

The suggested lightweight infrastructure for EVs has originally been proposed and suggested in a Swedish project denoted ELVIIS [6]. The project was initiated by Viktoria Swedish ICT, a non-profit research institute, and was running between the years 2009 – 2013¹³ together with partners from car industry (Volvo Car Corporation), telecom sector (Ericsson) and utility industry (Göteborg Energi). The starting point of the ELVIIS work was to lowering EV barriers by make it simpler for the user to charge and pay for the electricity and at the same time give the energy companies a potential to influence the recharging of EVs, to avoid an unnecessary

¹²http://emc-mec.ca/phev/Presentations_en/S12/PHEV09-S12-3_TakafumiAnegawa.pdf

¹³The concept was presented the first time for the public in February 2012.

costly built out or reinforcement of the grid. Within the project, the costs were never calculated but the overall opinion was that this is cost efficient solution compared to other alternatives, which this paper will confirm.

The analysis in this paper is based on a collection of data from different sources, together with knowledge obtained through interviews and discussions with partners in both ELVIIS and other projects. Even though the results are specific for Sweden, the approach can potentially be used for other countries estimating their own costs for different charging infrastructure alternatives. The suggestion of the Lightweight charging infrastructure is generic.

2 Swedish data

2.1 Road transport data

Statistics of the Swedish transport system is publicly available by the Swedish government agency Transport Analysis. From the database¹⁴, the transport mileage for year 2013 can be extracted and is given in Table 1¹⁵.

Table 1: The transport mileage in Sweden 2013 for different categories of vehicles

	Cars	Light Trucks	Heavy Trucks	Buses
Number	$45 \cdot 10^5$	$4,9 \cdot 10^5$	$0,8 \cdot 10^5$	$0,2 \cdot 10^5$
Total driving distance (10 km)	$63 \cdot 10^8$	$8,1 \cdot 10^8$	$4,0 \cdot 10^8$	$0,96 \cdot 10^8$
Mean driving distance (10 km)	1 223	1 418	4 156	5 475

2.2 Electrification of the vehicle fleet

Assume a mean electric energy consumption of the different vehicle categories listed in Table 1 according to:

¹⁴http://trafa.se/PageDocuments/Fordon_2013.xls

¹⁵Dividing the total driving distance (Row 2) by the number of vehicles in traffic (Row 1) in Table 1 gives a slightly different mean driving distance (Row 3). The reason is that new vehicles are registered and old one deregistered during a year while the numbers given in Row 1 are the number of registered vehicles in the end of the year. For the rough analysis in this paper, the difference is not important.

- Cars: 2 kWh / 10 km
- Light trucks: 6 kWh / 10 km
- Heavy trucks: 18 kWh / 10 km
- Busses: 12 kWh / 10 km

One can always challenge if these numbers are accurate predictions of a future EV vehicle fleet. However, only a rough estimate is needed in this paper serving as a reference case. A Tesla model S and Nissan Leaf consumes 1.8 kWh / 10 km and 1.2 kWh / 10 km respectively according to their specifications, which in reality is the minimum consumption under perfect conditions, so 2 kWh / 10 km is probably not too unrealistic. The other numbers are estimated simply by assuming that a light truck, heavy truck and bus consume 3 times, 9 times and 6 times more energy respectively.

By multiplying the assumed numbers by the assumed mean consumption listed in Table 1, for every vehicle category, an electrification of the Swedish vehicle fleet leads to an electric energy usage shown in Table 2.

Table 2: The yearly electricity consumption for an electrified vehicle fleet in Sweden

	Cars	Light Trucks	Heavy Trucks	Buses
Electric energy usage (TWh)	13	5	7	1
Mean power consumption (GW)	1.5	0.6	0.8	0.1

From the table, it can be concluded that if the entire vehicle in Sweden was electrified, the total yearly electric energy usage will roughly be 25 TWh, split on half for car transportations and half for truck and bus transportations.

2.3 Available charging infrastructure

Sweden is a country in the North of Europe and has a cold winter climate parts of the year, especially in northern Sweden. This means that there are many motor heater outlets installed at parking lots at home, work, shops etc. with the purpose of pre-heating the vehicle engines; see Figure 1 for an example.

The exact number of motor heaters in Sweden is unclear but most often, the number 600 000 is mentioned [7]. The wires to the motor heaters is usually sufficiently proportioned to be used for

EV recharging at a power level of 2.3 kW to 3.7 kW, but some of them (uncertain how many) have timers that prevent several hours of charging but this can be solved by a simple conversion kit. The existence of motor heaters gives Sweden a unique possibility for charging EVs.



Figure 1: Example of motor heater installations

Based on statistics from [Statistiska Centralbyrån](#), the numbers of villas/houses, holiday cottages, and apartment building in Sweden 2013 are 2 million, 0.57 million and 2.3 million respectively. The statistics give no hint on how many people that have access to an outlet near the parking lot, but it is likely so that most villas/houses and holiday cottages have outlets adjacent to or very near the parking lot. The socket outlets in Sweden are of [Schuko](#) type which is a type of earthed plug that is standard in several European countries including e.g. Sweden, Germany, Norway, Spain and Finland. Schuko connectors are normally used on circuits with 230 V, 50 Hz, for currents up to 16 A. Normally a house in Sweden has at fuse of at least 20 A, which means that charging EVs with at most 10 A should be safe. Therefore, a rough estimation is made that at least 2 million outlets that can be used for EV charging at a power level of 2.3 kW to 3.7 kW.

2.4 Power to potential energy supply

Table 3 indicates different power levels corresponding to common charging possibilities. The first three rows correspond to the potential power obtained using a charging AC voltage of 230V and different amperages of 10 A, 16 A and 32 A respectively. The fourth and fifth row corresponds to a semi-fast AC charging and the last two rows fast and super-fast (Tesla's) DC charging. Column two is calculated by multiplying the power level by 24 hours/day and 365 days/year resulting in 8760 h/year which multiplied by the

power level gives a potential yearly electric energy supply. Based on the earlier assumption that an electric vehicle consumes 2 kWh/10km, the third column is calculated by dividing this number by the power level.

Table 3: Power level and its potential yearly energy supply and charging time

Power level	Potential energy production	Charging time (2 kWh / 10 km)
2.3 kW	20 MWh/year	52 min / 10 km
3.7 kW	32 MWh/year	32 min / 10 km
7.3 kW	64 MWh/year	16 min / 10 km
11 kW	96 MWh/year	12 min / 10 km
22 kW	193 MWh/year	6 min / 10 km
50 kW	438 MWh/year	2.4 min / 10 km
120 kW	1180 MWh/year	1 min / 10 km

2.5 Number of charging points

Table 2 indicates the yearly electric energy usage if the Swedish vehicle fleet was electrified, and by dividing this number by the potential yearly electric energy supply given in Table 3, the number of potential chargers for different power levels is obtained (100 % usage). For cars (using 13 TWh/year), the numbers are given in Table 4.

Table 4: Number of needed car chargers for different potential power levels (100 % utilization)

Power level	Number of car chargers
2.3 kW	650 000
3.7 kW	406 000
7.3 kW	203 000
11 kW	135 000
22 kW	67 000
50 kW	30 000
120 kW	11 000

From this table, it can be concluded that 650 000 2.3 kW chargers are sufficient to deliver the energy if all cars were electrified. Remember that Sweden has 600 000 motor heaters mentioned earlier which potentially can supply energy of 12 TWh/year which almost is sufficient to supply all cars with energy. Adding additional 2 million outlets with a potential of further 40 TWh/year means that the existing charging points do not need to be 100 % utilized.

From this, it can be concluded that Sweden potentially could provide energy to all cars if electrified (and light and heavy trucks and buses as well) so there is no lack of charging infrastructure in Sweden.

2.6 Recharging speed

As comparison to the recharging time numbers in Table 3, the refilling of a fossil fuelled vehicle (gasoline or diesel) is approximately 1 s/10km. This is based on the assumption that a pump roughly delivers 2000 litre/hour (it varies of course) and the energy content of the fuel is approximately 10 kWh/litre fuel (gasoline and diesel), which gives a power supply of 20 MW (2000 litre/hour multiplied by 10 kWh/litre). Assuming that e.g. a gasoline vehicle has a mean fuel consumption of 0.6 litre/10 km, this corresponds to a consumption of 6 kWh/10 km (0.6 litre/10 km multiplied by 10 kWh/litre), which gives the charging time of 1 second /10 km driving if 6 kWh/10 km is divided by 20 MW.

Another way to illustrate the charging speed of an EV is to consider the case driving an EV long distances e.g. on a highway. Highway driving in e.g. 100 km/h requires more energy than slower charging, since the air resistance increases with the cube of the speed. Hence, assuming a car consumption of 2.5 kWh/10km means an electricity consumption of 25 kWh for one hour of driving. It takes half an hour to fill it with a fast charger of 50 kW, so 2 time units of driving and 1 time unit of stop and filling electricity is required.

Tesla's fast chargers are fast, but still roughly 60 times slower than filling gas or diesel from a pump¹⁶, under ideal circumstances. Under winter conditions, the difference is larger since the battery deteriorates in cold climate.

3 Rough cost analysis

This section gives some rough numbers on how much the cost is of a charging infrastructure for different power levels corresponding to normal charging and fast charging respectively and with different type of socket types and charging modes. The numbers are based on Swedish experience and data [8] and are the prices valid today.

3.1 Costs upgrading the existing normal charging infrastructure

Since Sweden already has approximately 600 000 motor heaters and roughly 2 million outlets at

¹⁶Note that since the electric vehicle is roughly three times more efficient than fossil propelled vehicles, it is somewhat misleading to compare the power level of 120 kW to 20 MW and conclude that it is 17 times faster.

villas etc. the investment for adjusting these for EV charging is low. If the motor heater consists of a Schuko socket¹⁷ that cannot continuously deliver a power level of maximum 3.7 kW, it needs to be changed which roughly costs 10 €¹⁸ in hardware for each socket (classified ip67 which is water and dust proof and that handles up to 63 A). This gives a maximum cost of 6 M€ (600 000 multiplied by 10 €).

If the motor heaters have timers that prevents several hours of continuously recharging this can be solved by a simple conversion kit which costs approximately 500 € per unit¹⁹ (including a Swedish tax of 25 % which is added to all prices in this paper). It is hard to estimate how many of the available motor heaters that needs an upgrade, but to be on the safe side the maximum cost would be to upgrade them all which results in 300 M€ (600 000 multiplied by 500€).

It should be possible to charge EVs by the existing approximately 2 million outlets near the parking at villas/houses etc. without any adjustments, as said earlier. Some of the sockets might not be able to continuously deliver a power level up to 3.7 kW, in which case they need to be upgraded. The maximum cost for this is roughly 10 € each as indicated above. This gives a maximum cost of 20 M€ (2 000 000 multiplied by 10 €).

The electricity industry recommends not using a Schuko connector for long time EV recharging due to the risk of a potential fire. Instead, it is recommended to install a **Type 2** connector, which European Parliament agreed in the directive mentioned in Section 1. The installation of a Type 2 connector, potentially providing a continuous powers rate of 3.7 kW, costs roughly 1000 €²⁰. This means a cost of 2.6 billion Euros to upgrade all the 2.6 million Swedish potential outlets (2.6 million outlets multiplied by 1000€) to Type 2 connectors.

To summarize so far it can be said that by far, the cheapest way is to recharge EVs using the existing Lightweight infrastructure, which

potentially can provide all cars if electrified with a margin of at least three times. If upgrading is needed, it costs at most 26 M€ in which case all sockets have been upgraded to ones able to deliver a continuously power of 3.7 kW. Since only 406 000 outlets is needed to fulfil 13 TWh annually, according to Table 4, a comparable cost used later on is roughly 4 M€ (406 000 multiplied by 10€) which is the maximum price of the cheapest way to charge all cars being EVs in Sweden. Most likely, there are at least 406 000 outlets in Sweden that without adjustments can provide a potential fleet of only EVs in Sweden with electricity.

The alternative of upgrade all sockets to Type 2 connectors is by far more expensive. A comparable price is approximately 400 M€ (406 000 multiplied by 1000€), which is at least 100 times more expensive having a Lightweight infrastructure.

Added to above is the installation of a new connector, which roughly should cost at most 200 € for each installation (two hours for travelling and installation for a certified electrician), adding up to additionally 80 M€ (406 000 multiplied by 200 €).

The calculations are summarized in Table 5.

Table 5: Upgrading the existing infrastructure in Sweden

Lightweight infrastructure (3.7 kW)	Unit price	Numbers	Total cost
Hardware	10 €	406 000	4 M€
Installation	200 €	406 000	81 M€

Type 2 infrastructure (3.7 kW)	Unit price	Numbers	Total cost
Hardware	1 000 €	406 000	406 M€
Installation	200 €	406 000	81 M€

3.2 Costs building new normal charging infrastructure

Even though it is not necessary in Sweden but merely for the sake of completeness, or if the infrastructure is at the wrong location, assume that a new normal charging infrastructure needs to be build that potentially could provide all cars in Sweden with electricity if they were electrified. Besides the hardware costs, costs for digging and cable and grid installation is added. It is in general

¹⁷ Schuko socket outlets are referred to as simple outlets since they only consists of “two holes in the wall” (and earthing). A network of simple outlets is referred to as a “Lightweight infrastructure”.

¹⁸ Googling “Schuko ip67” shows several alternatives.

¹⁹ <http://elbilsexperten.se/index.php/laddningsloesningar>

²⁰ <http://shop.norrpro.se/product/laddbox-typ-2-socket>

hard of course to estimate this since it depends on e.g. how far a potential pole is from a grid termination point. Regarding the hardware, a simple outlet on a simple pole costs roughly twice the price given above which means a cost of maximum 8 M€ (406 000 multiplied by 20 €). In a similar manner, the hardware cost for installing a Type 2 compliant connector is also roughly doubled since the outlet is integrated in the pole ending up in a price of 2000 €²¹. Hence, in this case the total cost is around 800 M€ (406 000 multiplied by 2000 €), still 100 times more expensive than the hardware for a Lightweight infrastructure.

Additionally, it is assumed that the digging and grid installation is in the magnitude of 1000 € adding up to additionally around 400 M€ (406 000 multiplied by 1000 €).

3.3 Costs building a fast charging infrastructure

The cost of installing fast charger providing up to 50 kW also varies due to uncertainties in how much digging is needed etc. The hardware price for a fast charger providing up to 50 kW is 25 000 € – 80 000 € according to [8] (the conversion rate of 10 SEK for 1 € is used), whereas the hardware and facilities costs in mean 40 000 € and the installation around 12 500 €. A 50 kW power level means that 30 000 charging poles are needed to provide all cars if electrified in Sweden according to Table 4, which gives a total cost of around 1.6 billion Euros.

3.4 Comparison

Summarizing the results building a new infrastructure in Sweden gives Table 6.

Table 6: Building a new infrastructure in Sweden

Lightweight infrastructure (3.7 kW)	Unit price	Numbers	Total cost
Hardware	20 €	406 000	8 M€
Installation	1 000 €	406 000	406 M€

Type 2 infrastructure (3.7 kW)	Unit price	Numbers	Total cost
Hardware	2 000 €	406 000	806 M€
Installation	1 000 €	406 000	406 M€

²¹ <http://www.windon.se/laddstolpar.html>

Fast charging infrastructure (50 kW)	Unit price	Numbers	Total cost
Hardware + facilities	40 000 €	30 000	1 200 M€
Installation	12 500 €	30 000	375 M€

As can be seen, the hardware total cost for a Lightweight infrastructure is roughly 100-150 times cheaper than Type 2 and fast charging infrastructures. The installation cost is in the same magnitude for all alternatives (but have larger uncertainties than the hardware cost).

Calculating the Total cost divided by the Total energy produced during a year is the same as the Unit price divided by the Power level, which is a faster way comparing different power level installation options to each other.

4 Lightweight infrastructure and EV communication

From the previous section, it can be concluded that from a cost perspective, it is better to use the existing charging infrastructure as much as possible and potentially all cars in Sweden, if electrified, can be supplied with energy from existing motor heaters and simple outlets in garages etc. close to villages/houses etc. Another conclusion is that introducing communication possibilities between the EV and the outlet is expensive. However, there are alternatives as suggested in the ELVIIS project.

Even though no cost analysis was made before or under the ELVIIS-project [6], it was clear for the participants that using the existing simple outlets or building new simple ones if needed, must be the cheapest way to charge EVs. Schucko type sockets have no communication capabilities (cf. Mode 1 with grounding). Instead, necessary communication is done via the EV over the existing mobile phone network. Future cars, and especially EVs, will be connected so there is no additional cost in doing so (aside from increased communication traffic and associated costs for that; however, that is quite low and negligible compared to other potential data traffic in the vehicle). ELVIIS is an acronym for “ELectric Vehicle Intelligent InfraStructure” and refers to the concept schematically illustrated in Figure 2.

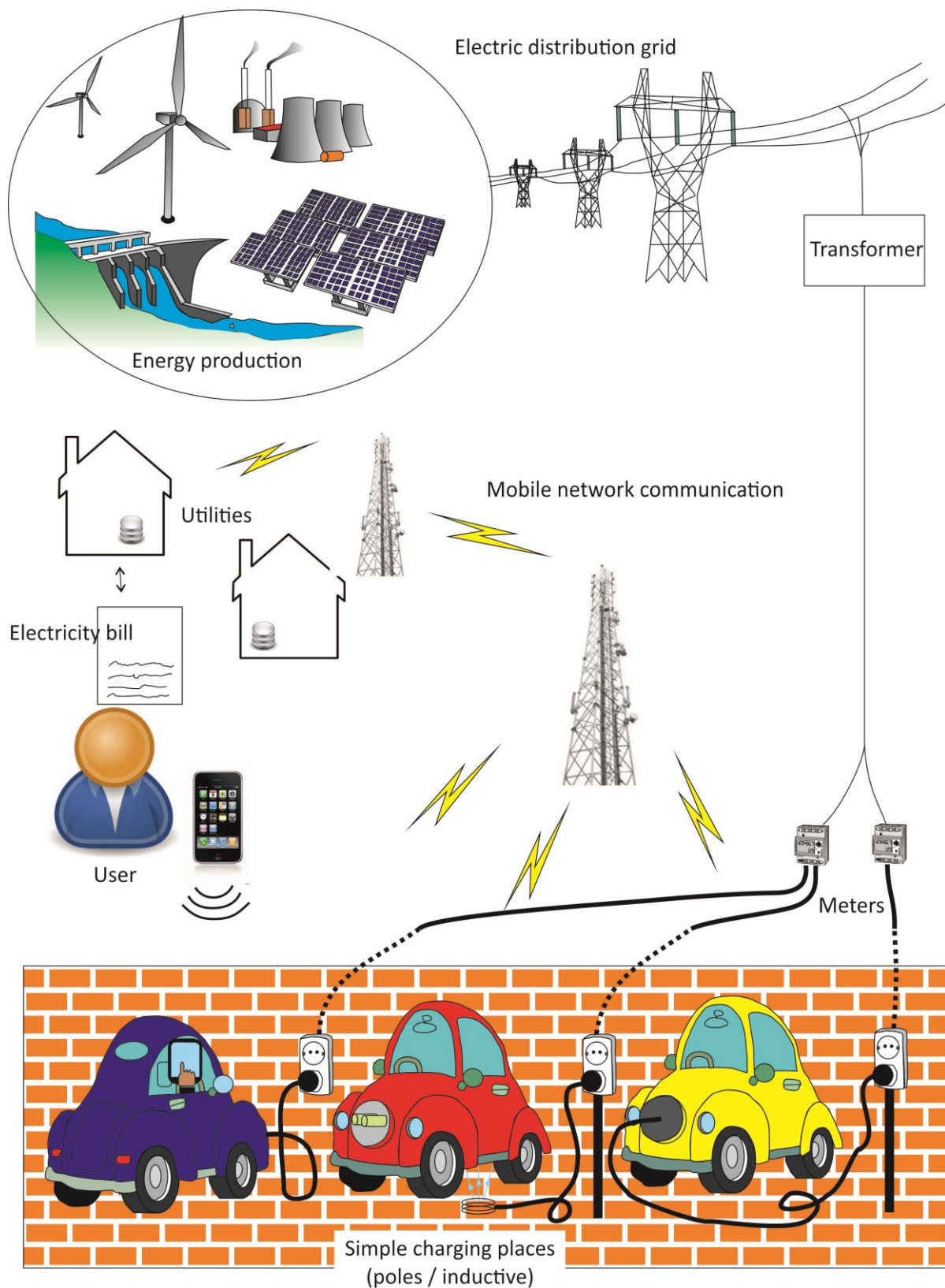


Figure 2: The ELVIIS system consisting of a Lightweight infrastructure for EV recharging with communication via the EVs over the mobile phone network allowing services like charging and payment

In the very heart of ELVIIS, is the vehicle ICT (Information and Communication Technology) platform whose screen is glimpsed in the side window of the (blue) car to the left in Figure 2. On this platform, different application/services can be implemented, as illustrated in Figure 3.



Figure 3: Car communication platform hosting different services/applications

The idea of using an ICT platform in the vehicle came originally from ideas from the cooperation between Viktoria Swedish ICT and SAAB resulting in the Saab IQon Infotainment System that was shown for the public in 2011²². The IQon platform used Google's Android operating system allowing third-party developers to implement services on the platform.

The ELVIIS system has been implemented in ten vehicles for demonstration and research purposes, with implementations of the two fundamental EV services: *Charging* and *Billing*.

4.1 Smart charging

The most fundamental EV service is charging, at least for BEVs since these have no alternative source of energy supply than electricity. In a typical charging procedure today, the user connects the cable from the charger pole or socket to the car that starts to recharge immediately (possibly after the user have pushed a button) having a recharging power set by the limits of the charging pole and the vehicle. The charging continues until the battery is fully recharged. As long as the charging infrastructure locally can deliver the power and the vehicle can receive it without overheating, and the number of electric vehicles are few in numbers, then there are no problems at all, at least not for strong grids like the one in Sweden. However, as the number of electric vehicles increases, the situation will be different and the amount of power needed to charge them will be substantial, see e.g. [9], [10].

If most people recharge their electrified vehicles during the same time period, typically coming home from work or to the working place, there might be electricity power production or local distribution problems [9], [10]. As the number of electric vehicles increase, the problem might be solved by strengthening the distribution grid and building new power plants. However, this is quite an expensive solution.

Another solution, implemented in ELVIIS, is to support the EV users to be more flexible when charging their cars. In the ELVIIS recharging service solution, the car starts to recharge immediately and as fast as possible when the car is connected to the grid. However, this is kept on only until a certain recharging level is reached corresponding to a user specified minimum range. The car is then recharged based on a scheme that the utility decides. The only restriction for the utility is that the car should be completely filled at a certain time specified by the user. Having this flexibility for the utility, the recharging can be made at times that suits them and potentially charging can be avoided at peak times when much electricity is used, or at least be smoothed out. This "peak-shaving" possibility potentially means that costly investments can be avoided, or at least be kept down. A thoroughly description of the *Smart Charging* service in the ELVIIS project is described in [11]. Other intelligent concepts using the connectivity of the chargers can e.g. be found in [12].

²² www.youtube.com/watch?v=8BOd9oX1p4s

4.2 Billing

The EV recharging electricity is not free but is of course paid by someone. However, it is common that existing public recharging or charging e.g. at someone's house is free for the EV users since the electricity consumed at every recharging occasion is quite low. Having the energy for free is of course an enjoyable situation and a nice incentive promoting EVs. However, as the number of electric vehicles increases, having larger and larger batteries, it is reasonable that the vehicle users need to pay for the consumed electricity, also at a friend's house. Paying for the recharging electricity already started to happen e.g. at the public infrastructure handled by ChargePoint mentioned earlier and in certain places in Norway and other countries.

In ELVIIS, the payment has been solved by measuring the charging energy consumption in the vehicle by the voltage and current sensors that anyway need to be in the vehicle for a proper control of the battery, powertrain and vehicle. The amount of energy corresponds to an amount of money, given a specified price per kilowatt hours, which is debited the vehicle user²³. Having the electricity user identified means that it is possible to make a compensation for the used energy, which is credited the one paying for the electricity. In theory, it might be possible to have different price settings for the electricity user and the vehicle user. The electricity users have their deals with the electricity supplier/aggregator and the vehicle users might have deals with the same or other electricity suppliers. This opens up a new energy market for electric vehicles, which if properly defined, may be beneficial for electric vehicle users.

Identifying the electricity user may be solved in a more or less complicated manner. In the end, it is beneficial to have a proper identification that is

²³ *Electricity user* is the term used for the consumer or trader who signs a network agreement with the owners of the tap point in the network where the consumer's consumption facility is connected. An invoice and payment will be directed to the electricity user based on the consumed energy, measured by the energy meters at the tap point, and a pricing of the energy. We will correspondingly use the term (electric implicit and usually neglected) *vehicle user* for consumers or companies etc. that pays for the electricity used when charging the electric vehicle.

as cheap as possible. In ELVIIS, the identification is based on GPS-positioning. All meters owned by Göteborg Energi have GPS (Global Positioning Systems) positions. In the same way, the Volvo C30 EVs used in the project have built-in GPSs. By matching these positions, the electricity user can mostly be uniquely identified.

4.3 Characteristics of ELVIIS

An essential characteristic of ELVIIS is the communication from the vehicle to the information cloud (e.g. utilities or other actors for other services). Normally, the communication is from the vehicle to the charging pole and up in the information cloud (to the one owning or managing the charging equipment). With the ELVIIS solution, data can be collected even for simple outlets like the one of Schuko type by using the car communication platform to reach the information cloud via the mobile phone network. Since there are a lot of simple outlets in Sweden (and other countries), this is a big advantage keeping down the costs as seen earlier.

Two potential hindrances for a mass-adaption of EVs are roaming [13] and being able to separate EV recharging from other electricity consumption. Roaming is about enabling EV charging across geographical and service provider boundaries [13], which requires the introduction of international EV standards, universal charging hardware infrastructure, associated universal peripherals and user-friendly software on public and private property [14], which partly is the purpose why the European Parliament decided on the directive mentioned in Section 1. One important aspect of EV roaming is the lack of standardized payment solutions, when fees are introduced. It was implicitly assumed in ELVIIS that the user thinks that it is inconvenient to pay individually to all potential charge point owners using different paying methods (payment cards), at every charging occasion. It is reasonable to assume that the vehicle user would like to pay using the same method (card). Furthermore, even though the electricity consumed at every charging occasion is low, the added contributions can be significant. Since EVs means a new type of technology and it in general will be different for people to learn to fill the vehicle with power and kilowatts consuming energy and watts, instead of gasoline and diesel in liters, there will be uncertainties in the beginning and hard to get an overview of the costs for filling the vehicle unless clearly stated. It seems reasonable that the vehicle user would like

to have the electricity consumption and costs on the same invoice, to have control of their costs. This is illustrated in the middle part of Figure 2.

One reason for the desire to separate the EV recharging from other electricity consumption, the second potential hinder for a mass-adoption of EVs mentioned above, is that e.g. in Sweden it is mandatory to have a valid energy declaration for new buildings and for buildings that will be sold or rented out²⁴. Charging at home means that the electricity consumption for the vehicle ends up on the electricity bill for the household energy, and this can in total add up to a significant amount and hence should be separated from other electricity consumption.

Using car communication, the car charging and associated payment can be potentially handled also for simple sockets of Schuko type.

The main drawback of ELVIIS is that there is a lack of communication standardization for the car to mobile network interface and in the end information cloud. Furthermore, the car manufacturers are fully busy adapting to the existing standards interfacing the charge point equipment. Ubitricity has proposed a solution where the charging cable is doing the communication to the information cloud. They claim that their solution enables a 90% cost reduction for EV charging infrastructure by using mobile metering technology²⁵, which also is confirmed in this paper. However, this is so far a proprietary solution that still needs the car manufacturers to give access to important signal information in the vehicle. A system similar to ELVIIS has been proposed by IBM and partners²⁶, released only two months after the ELVIIS concept was announced.

5 Conclusions

If the vehicle fleet in Sweden is electrified approximately 26 TWh is needed, where half is needed by the cars and the other half by light and heavy trucks and buses. Sweden has an existing charging infrastructure that potentially can provide all vehicles in Sweden with electricity if

the vehicle fleet was electrified. The cost of adjusting this, compared to other potential infrastructure deployment, is low and in the magnitude of maximum one hundred million Euros for a Lightweight infrastructure consisting of Schuko sockets and five times higher than using Type 2 connectors.

Rough figures indicate that building a new normal charging infrastructure with Type 2 chargers providing 3.7 kW or a fast charging one providing 50 kW is in the same magnitude of one to two billion Euros for Sweden and can potentially provide all vehicles in Sweden with electricity if the vehicle fleet was electrified. In reality, the costs will be larger since 100 % utilization has been assumed, which of course never will happen. However, it is still uncertain what usage levels on a total level that can be expected for a charging infrastructure.

Building a Lightweight infrastructure for EV charging is several magnitudes cheaper than installing a Type 2 or a fast charging infrastructure and is by far the most cost efficient solution. The Type 2 connector gives an additionally safety level and incorporate control for charging modes Mode 2 and 3 and this type of hardware intelligence costs 100 times more than simple outlets, which is surprisingly high and adds up in the end to the already expensive EV costs. Therefore, promoting a Lightweight infrastructure using the car communication platform as shown in this paper would be wiser. The authorities, car manufacturers etc. should have this option in mind and standards should be worked out promoting also this solution.

The speed of charging is one potential factor important to follow in future research studies since it indicates whether fast charging is needed or not. If today's fast chargers are fast enough is still an open question. Section 2.6 indicates that one time unit of driving roughly is followed by half a time unit of recharging. Furthermore, even Tesla's super-chargers are much slower than filling fossil fuels.

Since today's vehicles are parked most of the time, there is plenty of time for normal charging. Fast charging wear out the batteries quicker (a cost that is not estimated in this report) so normal charging is preferable in most cases. For cost reasons, a Lightweight charging infrastructure as the one suggested in ELVIIS and shortly explained in this paper is in most cases preferable.

²⁴ www.boverket.se/sv/byggande/energideklaration/vad-ar-en-energideklaration/

²⁵ <https://ubitricity.com/en/our-solution/ubiquitous-electricity/>

²⁶ <http://www-03.ibm.com/press/us/en/pressrelease/37398.wss>

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