CHALMERS
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Convenient charging system for electric cars

Concept development of a charging system for BEVs and PHEVs.

Master's thesis in Master Programme Product Development

Alexander Berggren

Department of Product & Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

MASTER'S THESIS 2016

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Supervisor: Johan Ekbäck, CEVT
johan.ekback@cevt.se, +46731-441700
Examiner: Andreas Dagman, *Product & Production Development*, Chalmers
andreas.dagman@chalmers.se, +4631-7721472

Master's Thesis 2016
Department of Product & Production Development
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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ALEXANDER BERGGREN
Department of Product & Production Development
Chalmers University of Technology

Abstract

"We are the first generation to feel the effect of climate change and the last generation who can do something about it." - President Obama, 23rd of September 2014.

In order to tackle the problem of climate change we need to change the way we are living and the technologies we are using. One area that needs to change is the car usage and the technology it is based on. We need to change to non-fossil fuelled car technologies. A suggested solution is the plug-in electric cars - such as Battery electric vehicles and Plug-in hybrid electric vehicles.

The plug-in electric car is an Electric vehicle that offers many advantages compared to traditional combustion cars. Nevertheless, when electric cars is offered at the same buying price and almost half total cost of ownership, compared to traditional combustion cars, the customers still hesitates. Despite the many advantages the concern regarding insufficient driving range, in combination with the charging availability and charging time, scares the customers. As the driving range, charging availability, and charging time of plug-in electric cars are highly dependent of the charging system for it, an improved and more convenient focused charging system could remove these concerns and obstacles for plug-in electric cars.

A convenient charging system for plug-in electric cars was found to require an Energy storage system in order to being able to deliver sufficient charging power as well as better utilise the electrical infrastructure. Furthermore, a convenient charging system for plug-in electric cars have three different chargers - standard (wireless) charger, availability charger, and fast charger. The different chargers targets different kinds of charging, and with the different power levels of <22kW, <3.6kW, respective >90kW. Where the last (and highest) power level is only necessary for Battery electric vehicles and could be excluded from Plug-in hybrid electric vehicles.

The standard charger have two different sub-systems, one home charger and one destination charger - both (but in different ways) sharing the principle of botherless bringing the charger to the car. Moreover, the whole charging system should easily be controlled and monitored via a mobile app, and enable a transition towards the close connected technology of autonomous drive and -vehicles. Furthermore, together with which the Electric vehicle may become a major disruptive technology.

Keywords: Plug-in electric vehicle, Electric vehicle, Battery electric vehicle, Plug-in hybrid electric vehicle, Wireless power transfer, Energy storage system, mobile app, Autonomous drive, Disruptive technology.

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Glossary

cannibalisation Short for market cannibalisation, and meaning when a product or service takes market shares on the behalf of another product or service.. xiii, 75, 76

disruptive technology A new technology that disrupt an other technology, and have an cannibalisation effect on the older technology's market.. v, xiii, 44, 76

electro-stimulating effect The human body uses electrical signals for its nervous system. Exposure to electromagnetic fields can lead to un-natural stimulation in the nervous system.. xiii, 18

SAR SAR is a acronym for 'specific absorbation rate', and is a measurement of power absorbed by a mass of tissue [W/kg]. It is commonly used in the context of electromagnetic fields, but may also be used for sound waves.. xiii, 19

summon Search tool of Chalmers Library. Searches within Chalmers Library's own database as well as other databases.. xiii, 34

waste time A term used for describing time when a user does nothing and perceives it as a waste of time.. xiii, 47, 71

well to wheels A way of comparing how efficient different energy sources for driving a car is, from its energy source to the movement of the car. EVs. xiii, 13

Acronyms

AD Autonomous drive. v, xiii, 21, 22, 46, 70, 71, 75, 76, 77, 79, 81
AV Autonomous vehicle. xiii, 21, 22, 70, 80

BEV Battery electric vehicle. v, xiii, 12, 35, 46, 47, 49, 63, 66, 70, 71, 73, 75, 79, 81

CAES Compressed air energy storage. xiii, 26, 29, 59
CEVT China-Euro Vehicle Technology. xiii, 1, 2, 49, I

EMI Electromagnetic interference. xiii, 14
ES Energy storage. v, xiii, 26, 28, 29, 59, 68, 69, 75, 76, 78, 81
ESS Energy storage system. v, xiii, 26, 59, 71, 76, 77, 79
EV Electric vehicle. v, xiii, xv, 1, 2, 13, 21, 23, 24, 26, 30, 38, 44, 46, 48, 49, 58, 63, 65, 66, 67, 69, 70, 71, 73, 76, 77, 79, 81

OLPT On-line inductive power transfer. xiii, 16

PDM Product development methodology. xi, xiii, 5, 7, 33
PEV Plug-in electric vehicle. v, xiii
PHEV Plug-in hybrid electric vehicle. v, xiii, 1, 2, 12, 35, 38, 47, 49, 67, 70, 73, 75, 79, 81

RIPT Resonant inductive power transfer. xiii, 14, 16, 44, 57

SMES Superconductive magnetic energy storage. xiii, 26, 28, 29, 59

WPT Wireless power transfer. iv, v, xiii, 2, 14, 16, 17, 43, 44, 45, 47, 48, 49, 57, 58, 62, 67, 70, 77, 79, 80, 81

1
Introduction

Following social, technological and environmental trends electric vehicle technologies have evolved in a rapid pace, and has increasingly acquired larger market shares in the passenger vehicle market.
The electric vehicle technologies are still in a relative early technological stage, and solutions as well as standardisations has yet to be defined. One important technological aspect of electric vehicles is the charging of their batteries.
The master's thesis 'Convenient charging system for electric cars' is a new product development project for the concept development of a future charging system solution.
This first chapter will present the background, problem formulation & purpose, project deliveries & research questions, delimitation's, and this report's structure.

1.1 Background

The master's thesis project 'Convenient charging system for electric cars' was provided by CEVT (China-Euro Vehicle Technology).
CEVT was founded 2013 as an subsidiary of Zhejiang Geely Holding Group, and is an engineering and development centre addressing the needs of the two passenger car organisations, Volvo Cars and Geely Automobile. CEVT's development work involves the aspects of the cars architecture, -power train & drive line components, -upper body structure, and -exterior design.[1]

1.2 Problem Formulation & purpose

CEVT has got the order to (among many things) develop a system for the future charging of an electric passenger car platform.
In the development of the new car platform, one important problem that has been identified is to develop a solution for how wireless charging of Plug-in hybrid electric vehicles (PHEVs) and Electric vehicles (EVs) could be made user-friendly, safe, effective and convenient.
The charging of EVs is one of the most distinguished differences compared to fuel based vehicles. A difference that often may be seen as a disadvantage compared to fuel based cars, for instance due to charging time and driving range. It is therefor important to find a solution that makes customers and users perceive the whole electric car as a better and more desirable product than fuel based cars.

The benefits of a easy-usable, wireless charging system for electric cars, have already been identified by CEVT as a future requirement. Hence, this project is to focus on a system solution that includes wireless charging technology.
Furthermore, another important aspect of a future charging system is its convenience.
Furthermore, the purpose of this project can be summarised into two major aspects:

- Investigate how to create a convenient charging system that creates trust and additional values for the electric car.
- Find out how wireless charging technology could increase the convenience of charging.

1.3 Project deliveries & Research questions

The deliveries of this project are technical specifications-, and CAD-models of the final suggested concept solution.
In order to successfully design a (wireless and convenient) charging system for a future car platform for EVs and PHEVs, some research questions need to be answered:

- What components are needed in a charging system (with wireless charging functionality) for cars?
- What current suitable technical solutions are there for cord- and wireless charging of electric cars. What benefits respectively drawbacks do they possess?
- How should a charging system (with wireless functionality) for electric cars be designed in order to be convenient and meet the needs of a future car platform developed by CEVT?
- How could a future charging system for charging electric cars address the needs and demands in the aspects of:
  - Human safety?
  - Ease of use?
  - Technical performance?
  - Low environmental impact?
  - Manufacturability?
  - Different usage environments?
  - Product lifetime?

1.4 Delimitation's

The project will be executed from the beginning of February to the mid of June 2016, and will use both Chalmers' and CEVT's facilities and resources. Furthermore, specific delimitation's are:

- The project will not cover calculations of the fields (physics), that derives from the usage of Wireless power transfer (WPT).
- No working physical prototype will be produced.
- The detail level of the CAD will be such as that the product, and its functionality may be fully understood and possible to assess. However, further development will be needed in order to produce a functional physical product.

- The definition of the product architecture will only include what is necessary for the charging system to function, not the entire car or -society.
- The environmental assessments will only be analysed with a subjective approach, mostly based on general environmental facts and theory.
- The legal and economical aspects will only be considered and not assessed in this project.

1.5 Report Structure

The structure of this report is as follows:

- Introduction
- Theory
- Method chapters
- Result chapters
- Discussion
- Conclusion
- Future work
- References
- Appendices

The introduction chapter explains why there is a need of the project, and what the project will look like - what background, purpose, aim and delimitation's it has.
The theory chapter contains areas of specific knowledge and data necessary for the projects outcome.
In the method chapters the activities, process and tools used will be described.
What is produced, through the methods described in the method chapters, will be described in the result chapters.
A Discussions chapter will then elaborate upon the results, after which an conclusion chapter will conclude what the project has delivered.
Finally, possible future research and -work will be suggested in a future work chapter.

2
Theory

This chapter aims to describe relevant theory for the project and its content. The theory for the project includes relevant scientific methodology description as well as important methods and tools used in the project. The theory of the content regards the theory needed to understand the problem and enables the creation of a final project delivery.

2.1 Product Development Methodology

There are different Product development methodology (PDM), for instance methods described by Paul & Beitz, Ullman, Roozenburg & Eekels, and Ulrich & Eppinger. In the book 'Product Design and Development' Ulrich, K. & Eppinger, S. (2012) [2] describes their methodology.
In this PDM Ulrich & Eppinger have divided the development process into six chronological phases. The phases are numbered from 0-5. The use of a '0'-phase is due to that this phase should be performed before a product development project is initiated, in difference from the other phases which should all be part of a complete product development project.

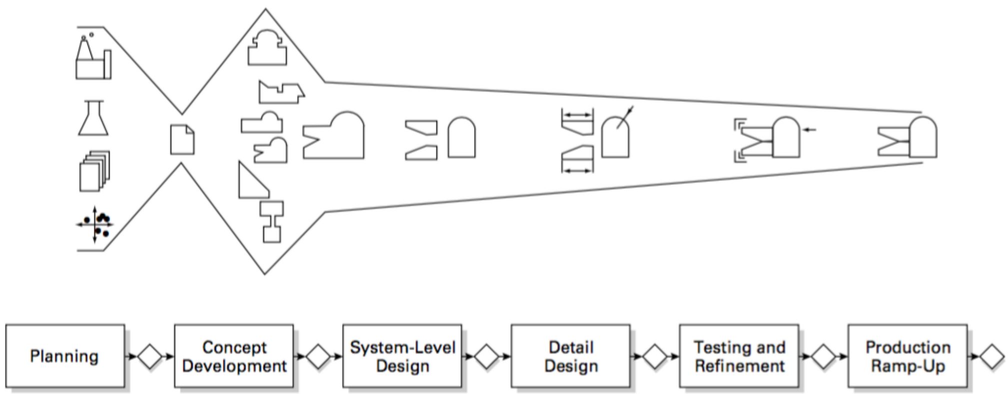


Figure 2.1: The six phases described in Ulrich, K. & Eppinger, S.'s (2012) [2] Product development methodology (PDM).

2.1.1 The planning phase

Ulrich & Eppinger [2] states that; in order to start with the actual product development process, the project needs to be approved. The approval may be gained through the process of phase 0 - planning.

In the planning of the project it is important to have an overall plan as well as more detailed plans. A tool for an overall plan is the gantt-chart (see chapter 2.2.1), and a tool for detailed plans is precedence diagrams (see chapter 2.2.2) with related description.

Furthermore, Ulrich & Eppinger states that the outcome of the planning phase is the mission statement, which specifies the target market, business goals, key assumptions, and constraints of the product.

2.1.2 The concept development phase

According to Ulrich & Eppinger [2], the first actual phase in product development is the concept development phase. This phase will start the development process according to the plan and opportunities identified in the planning phase.

In the concept development phase; stakeholder needs, competitive products, and feasible product concepts are identified. Furthermore, industrial design is started, along with development of concepts and building of prototypes. The concepts and prototypes are then assessed regarding production feasibility, estimated manufacturing costs, and legally feasibility.

One major part of the concept development phase is the concept selection process. The process described by Ulrich & Eppinger [2] (see figure 2.2), is an iterative process were product specifications are defined in order to generate-, screen-, analyze-, and test concepts.

The outcome of the concept development phase will be a first concept selection of one, or possible a few, concepts for further development.

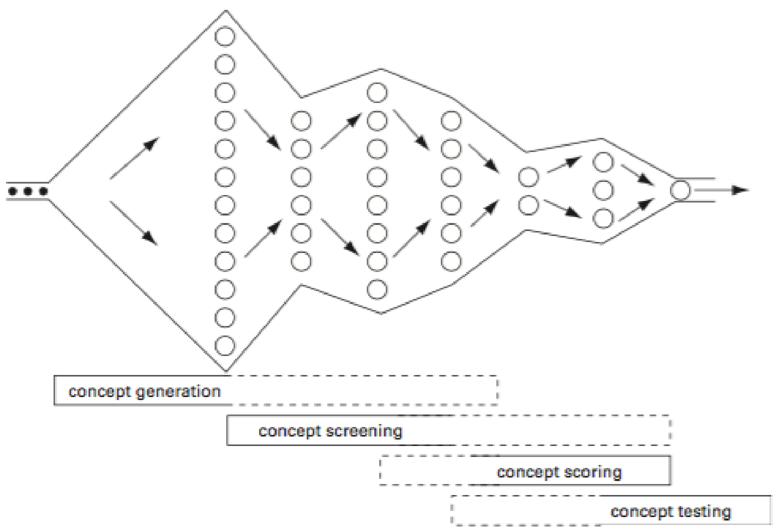


Figure 2.2: Concept Selection Process defined by Ulrich & Eppinger [2]

2.1.3 System-Level Design

During the system-level design phase, the product architecture is developed along with the industrial design, design for environment, design for manufacturing, robust design, and prototype development. Moreover, legal- and economic aspects should also be considered in this phase.
The purpose of this phase is to adapt and develop concepts into suiting the identified and defined system, for which the product is intended for.

2.1.4 Detailed Design

The detailed design phase, is initialised by the final concept selection. In this phase the detail level of the final concept selection is increased, and specifications as well as drawings of components are to be created and compiled.
The outcome of the detailed design phase is the final prototype delivery.

2.1.5 Testing & Refinement

As its name suggest, this phase is about perform tests on prototypes. The testing aims to reveal if further refinement of the prototype could and should be performed. Furthermore, this phase includes the creation of 'promotion and launch materials'.

2.1.6 Production Ramp-Up

The last phase in Ulrich and Epping's described PDM is the production ramp-up phase. This phase aims to start a small scaled production and evaluate the production method and get feedback on the final product from key customers.
The last and important part of this phase and the PDM is for the general management to conduct post-project review.

2.2 Product Development Tools

Cambridge dictionary explains the word 'tool' as *something that helps you to do a particular activity*. Hence, in order to perform the activities for a methodology, tools are needed. The major tools used in this product development project are: *gantt-chart, precedence diagram, brainstorming, affinity diagram, selection matrix, morphological matrix, concept-scoring matrix, survey,* and *semi-structured interview.*

2.2.1 Gantt-chart

Ulrich and Eppinger [2] argue that gantt-chart is the traditional tool used to show the timing of tasks in a project. The tasks are ordered vertically in the diagram. Moreover, each task is represented by a horizontal bar, thus showing the beginning, duration, and end of a task, along an horizontal timeline. To visually show the progress and whether a task is behind or ahead of schedule, a vertical 'current

date'-line could be used along with gradually color-filling the bars. An example of a gantt-chart may be seen in figure 2.3.
However, Ulrich and Eppinger states that the dependency between the tasks are not explicit displayed in a gantt-chart. The dependency for tasks describes if the relation between tasks are parallel, sequential or iteratively coupled. The dependencies are important to know in order to understand what must be accomplished before a tasks may start or end.

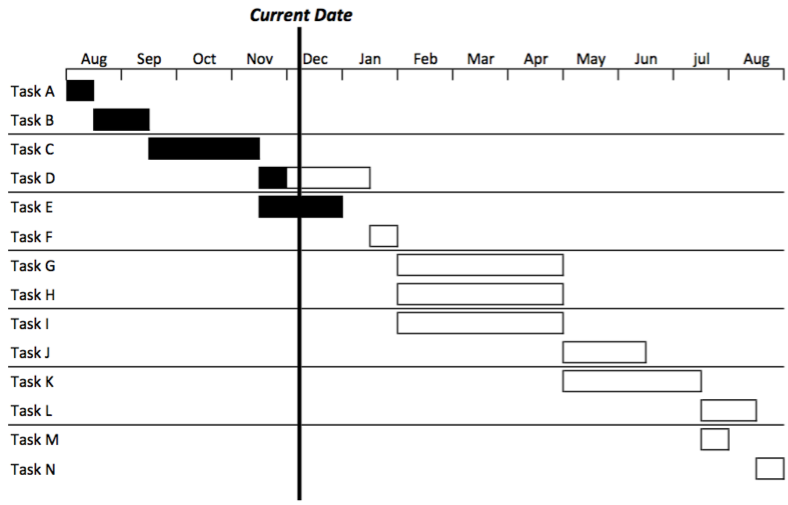


Figure 2.3: An example of a gantt-chart, where 'black' represent done progress. Hence 'white' to the left of 'current date' means tasks fallen behind.

2.2.2 Precedence diagram

According to Kezsbom, D.S. and Edward, K.A. (2001) [3] the precedence diagramming method is well suited and could be used for describing dependency between tasks.
The activities are made into a network, in which the activities are arranged sequentially with consideration to their respectively relations as well as the project objectives. The precedence diagram could in excess of showing the relation between activities also contain a proposed activity duration for each activity. In figure 2.4 a example of a precedence diagram is shown. Each activity is represented as a rectangle, with a letter for which task it is and a number of the proposed activity duration (time unit).

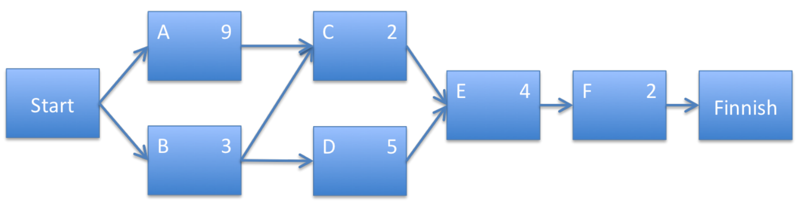


Figure 2.4: An example of an precedence diagram.

2.2.3 Brainstorming

According to Wallace, S. (2015) [4] brainstorming is a method for idea generation through a creative process. Brainstorming is often performed by a group of people, but can also be performed individually.

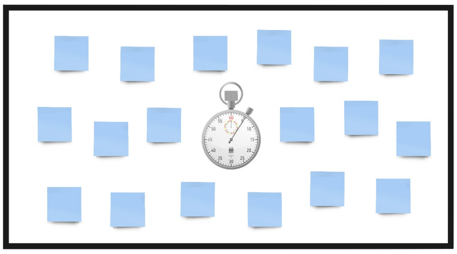


Figure 2.5: Illustration of brainstorming.

A brainstorming should be performed on a board (or similar visual space) and ideas are written down on notes that can be attached to the board. The brainstorming starts with a chose of topic, for which ideas then are generated and presented. Responses to an idea are immediately written down and added to the board uncritically and without editing (to not disturb the creative process). In order to identify what ideas are useful, all ideas are after each brainstorming session (or iteration) considered and discussed more freely. It is important to use the benefit and ideas of all participants. The brainstorming can be iteratively repeated to develop ideas further.

2.2.4 Affinity Diagram

Westcotte Russel, T. (2014) [5] explains that an affinity diagram is used to organise items of a large group into smaller chunks, in order to make it more manageable. Affinity diagrams are often used in order to organise the ideas from a brainstorming. The creation of categories (chunks) of an affinity diagram can either be created before or after the items to be chunked are known. An item may also belong to more than one chunk.

Moreover, Westcotte Russel, T. claims that another benefit with affinity diagrams, is that it creates discussion between individuals and the final diagram will be a collective mental model of what have been analysed.

The affinity diagram process may continue until the performers reckon it to be done. A typical affinity diagram process is illustrated in figure 2.6.

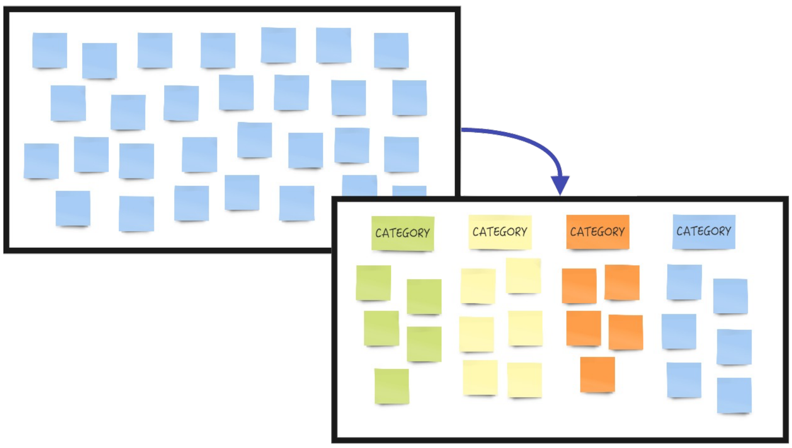


Figure 2.6: The creation of an affinity diagram.

2.2.5 Morphological matrix

According to Eversheim, W. (2009) [6] a morphological matrix is used for develop new ideas in the form of solution concepts, product concepts, and structuring ideas. A morphological matrix is applicable both individually and as a team.
First, in creating a morphological matrix, all functions of a product (system) are listed. Then solutions are developed for each respectively function. For a two-dimensional matrix, the functions are typically listed vertically on separate rows, with all the respectively solutions to the right, one per column. By choosing among these partial solutions of the different functions, a new total solution can be created. This new total solution will have all of the functionality of all the combined functions that were listed.
Moreover, Eversheim states that the major benefit with a morphological matrix is its good capability in developing solutions for complex problems and -product systems. However, the weakness with a morphological matrix is the huge number of different potential total solutions (number of combinations), which leads to difficulties in decision making of what combinations to create from the matrix. More so, the method does not have any real support for the decisions made in it, and not all combinations are feasible.

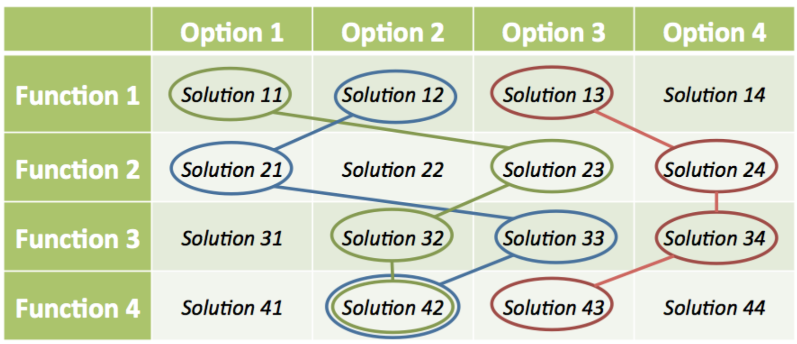


Figure 2.7: An example of a typical morphological matrix with three 'total solutions' - red, green, respective blue.

2.2.6 Survey

A survey represents the quantitative data collection, which Edward F. McQuarrie (2016) [7] suggest should imply responses counted in the hundreds. A quantitative research aims to acquire data in the form of precise numbers (numerically, frequencies and magnitudes), while qualitative research aims to collect data in form of human being functions - where not only 'what' is expressed is important but also 'how' it is expressed.
Edward F. McQuarrie claims that one of the first steps in designing a survey should be to define to whom the survey should target - the population. The survey should then through its questions and structure aim to divide the population into differentiated sub-populations, in order to later being able to draw conclusion on the data between different sub-populations.
Sub-populations could for instance be based on demographics or owners of a specific device.

Moreover, it is explained that a survey should be much more detailed than for instance interviews. Compared to interviews, the survey should not explore or discover - it should describe exactly and pin down precisely. Therefore, the questions are the same for all respondents and do essentially only allow responses according to predefined answers.

2.2.7 Semi-structured interview

In 'The Market Research Toolbox' by Edward F. McQuarrie (2016) [7], interview is defined to be a qualitative data collection tool. The interview should be design around three elements:

- Selecting the questions to be asked.
- Arranging the questions into an effective sequence.
- Deciding what if any supplements should be added.

When creating and selecting questions to be asked, considerations should be done regarding if a question should be 'close-ended' or 'open-ended'. Close-ended questions typically only allows predefined answers such as 'yes' or 'no', and multiple choices. In contrast to the close-ended question, the open-ended question leaves the formulation of the answer to the respondent.
In order to construct good interview questions the close-ended questions should be minimised (but not eliminate) and open-ended questions should be emphasised. That is, the interview time should mainly be allocated to, and lead by, the open-ended question, in order to trigger discussion. But the use of close-ended questions are a good support in the interview, to 'close' an extended discussion triggered by an open question.
The value of the interview lies not only in the spoken answers, but rather what the interviewer takes away from the dialogues.
McQuarrie also suggests that the interview and its structure should only be partly prepared in advance, in order to leave room for spontaneity and flexibility. The combination of prepared structured unprepared structure will give the best answers if the fluency and variation (exploring and confirmation) is good.

2.3 Convenience in products

Product development should according to Ulrich & Eppinger [2] be based on satisfying needs. The Cambridge Dictionaries Online defines the word 'convenient' in two ways:

1. *Suitable for your purposes and needs and causing the least difficulty.*
2. *Near or easy to get to or use.*

The definitions in Cambridge Dictionaries Online describes different dimensions, that can be related to what Ulrich & Eppinger describes as important in the identification process of finding- and satisfying user needs.
In an old article by Brown L.G (1989) [8] the meaning of convenience in the consumer product market is described. Brown suggests that the demand for convenience will

grow rapidly as a result of households increased amount of work and income. "With more money and less time, these consumers seek time-saving goods and services." Furthermore Brown suggests that convenience is a multidimensional construct with five dimensions, described in table 2.1.

Table 2.1: The five dimension of convenience.

1.	**Time Dimension**	Products may be provided at a time that is most convenient for the customer.
2.	**Place Dimension**	Products may be provided in a place that is more convenient for the customer.
3.	**Acquisition Dimension**	Firms may make it easier for the customer, financially and otherwise, to purchase their products.
4.	**Use Dimension**	Products may be made more convenient for the customer to use.
5.	**Execution Dimension**	Having someone else provide the product for the consumer.

Brown states that the five different dimension of convenience can both be used differently (from single time to continuously), and be combined in order to compete, on the market, in adding to a users' comfort.

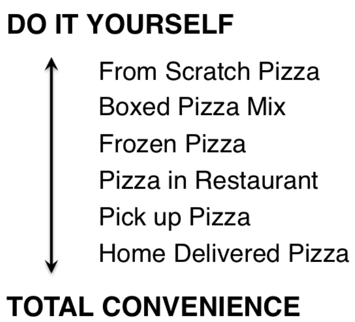


Figure 2.8: Convenience continuum for the 'pizza' product category.

Furthermore, Brown describes that the execution of the convenience dimensions results in an "convenience continuum". He uses the example in the product category of pizza, see figure 2.8. The place in the continuum should be an active chose by the company, as it may change the cost as well as the product's competitiveness. Finally, Brown concludes that "The continuum makes it necessary to consider both the nature of the product at different points as well as the distribution of customers." Moreover, convenience have been understood by the company as vital in the development of a future charging system for BEVs and PHEVs - hence the project title Convenient charging system.

2.4 Sustainable aspects of Electrical Vehicles

For a society Heinicke, M. & Wagenhaus, G. (2015) [9] claims that mobility is necessary in order to facilitate valuable forms of communication and exchange physical goods.
With the increasingly demand of non-fossil based and more sustainable vehicles (especially in urban environments) the EVs becomes more attractive, due to not having any direct CO2 emissions. Furthermore, Yong, J.Y. et al. (2015) [10] describes how the severe climate change and the green house gas emissions have reached a dangerous level, with effects as global warming and extensive melting of icebergs. The implementation of EVs could lead to an reduction of green house gas emissions.
However, Yong, J.Y. et al. also states that if EVs are charged via a power grid with polluting fuels generation, such as coal-fired, it can cause EVs to have a higher 'well to wheels' emissions than traditional combustion cars. Thought, with the increasingly electricity generation from renewable energy sources, the wells-to-wheels emissions for EVs will be reduced and below traditional combustion vehicles' emissions. Which also is the current situation for many European countries.
A benefit mentioned by Heinicke, M. & Wagenhaus, G. is that EVs have a significant lower direct cost of operation, compared to traditional combustion vehicles. This is due to that the technology enables a higher efficiency (less fuel/electricity), and more so as electricity is relatively cheap.
Another benefit with EVs is that they could increase the energy security, due to enable more and a greater variance in energy sources. Hence supporting the today's increasing number of renewable energy sources and production.
A hidden benefit of EVs is described in an article by Li, C. et al. (2015) [11]. It is described how big cities have problems with 'urban heat island effect', which is when the city becomes warmer than rural areas. This is claimed to be a major problem in big cities as Beijing, China. Increasing temperature in warm cities like Beijing, leads to higher usage of air conditioning, which also have a high negative environmental impact. Compared to conventional vehicles, EVs emits 80.2% less heat during operation. If conventional vehicles had been replaced by EVs in Beijing, during the summer of 2012, the city temperature could have been decreased with 0.94 °C. Due to decreased air-condition energy consumption, this lowering in temperature could have saved 14.4 million kWh and thus reduced the CO2 emissions by 10,686 tonnes, per day.

2.5 Wireless Power Transfer

One suggested (by the company) sort of technology in a convenient charging system for cars could be wireless power transfer.
There are different kinds of technologies that allows for wireless power transfer. In the article by Musavi, F., & Eberle, W. (2014) [12] they compared different wireless charging technologies that they thought to be interesting in electric vehicle charging applications. The technologies they investigated were:

- Inductive power Transfer (IPT)

- Capacitive power Transfer (CPT)
- Permanent magnet coupling power transfer (PMPT)
- Resonant inductive power transfer (RIPT)
- On-line inductive power transfer (OLPT)
- Resonant antennae power transfer (RAPT)

In the article, Musavi, F., & Eberle, W. describes the different technologies, and what benefits respectively drawbacks each technology possesses. They evaluated the different technologies feasibility regarding existing limitations in power electronics technology, cost, consumer acceptance, health hazards and limits for human exposure to radio frequency radiation. The comparison between their studied technologies is presented in table 2.2.
Furthermore, Musavi, F., & Eberle, W. suggests RIPT and OLPT to be most promising among the compared wireless charging technologies. RIPT and OLPT are similar technologies, but with different applications. RIPT typically only allows stationary charging of vehicles (vehicle is standing still), while OLEV allows vehicles to charge on the road while moving. In the article the authors claims RIPT to currently be the most popular technology for WPT.

2.5.1 Resonant Inductive Power Transfer

The currently most popular WPT technology is, according to Musavi & Eberle, the RIPT technology, which was initially pioneered by Nikola Tesla (1856-1943). With the use of modern electronic components the technology have recently become popular again.
The essential difference between IPT and RIPT is the method of creating resonance, with the use of resonant circuits. In short, this is created by tuning two or more resonant tanks with resonant capacitors in order to make the circuits resonate at the same frequency. This resonant circuit technique have the primary functions of:

- Maximise the power transfer.
- Optimising efficiency of transmission.
- Frequency variation control for the transmitted power.
- Variation compensation of the magnetic coupling.
- Compensate for magnetising currents (reduces losses).
- Matching coil impedance's.
- Suppress higher harmonics from the generator.

Furthermore, Musavi & Eberle claims that the advantages acquired with the use RIPT (compared to a non resonant inductive power transfer) are for instance:

- Increased transfer range.
- Reduced EMI.
- Higher frequency operation (in kHz range).
- Higher efficiency.

The increased transfer range and higher efficiency allows less constrained applications usages of the technology. However, the frequency operation range is suggested to be the technology's main advantages, as is supported by current state of the art

Table 2.2: Comparison over suitable wireless charger technologies for charging electric vehicles.

Technology	**Performance**			**Cost**	**Size/ Volume**	**Complexity of system**	**Suggested power level**
	Efficiency	**EMI**	**Frequency**				
Inductive power transfer (IPT)	medium	medium	10-50 kHz	medium	medium	medium	medium/high
Capacitive power transfer (CPT)	low	medium	100-500 kHz	low	low	medium	low
Permanent magnet coupling power transfer (PMPT)	low	high	100-500 Hz	high	high	high	low/medium
Resonant inductive power transfer (RIPT)	medium	low	100-500 kHz	medium	medium	medium	low/medium
On-line inductive power transfer (OLPT)	medium	medium	10-50 kHz	high	high	medium	high
Resonant antennae power transfer (RAPT)	medium	medium	1-20 MHz	medium	medium	medium	low/medium

power electronic technologies, thus enabling good efficiency at relative high power levels.

2.5.2 Standard for wireless power transfer

The global standard association SAE International [13] claims to be a knowledge source for the engineering profession over a broad spectrum of industries, by uniting over 128,000 engineers and technical experts.
SAE have defined two areas of priority:

- Encouraging a lifetime of learning for mobility engineering professionals.
- Setting the standards for industry engineering.

With emerging technologies and trends regarding wireless charging, SAE International have identified that there is a need to establish a standard for wireless charging of electric cars. Therefore, SAE International have now approved upon May 31st publish *SAE TIR J2954 Wireless Power Transfer for Light-Duty Plug-In/Electric Vehicles and Alignment Methodology.*
For the development of TIR J2954 important criteria that are addressed regards safety and electromagnetic limits, efficiency and interoperability targets, as well as acceptance of WPT.

Jesse Schneider (Chair of SAE International's WPT committee and Fuel Cell, Electric Vehicle & Standards Development Manager at BMW North America) said May 17, 2016 at Warrendale, Pa.:

Wireless power transfer, using SAE TIR J2954 is a game changer for PH/EVs. This first in a series of documents will enable consumers to simply park their vehicles into spaces equipped with TIR J2954 equipment and walk away without doing anything to charge their PH/EV," and "Standardization of both the vehicle and ground infrastructure WPT has started with SAE TIR J2954. The frequency band, safety, interoperability, EMC/ EMF limits as well as coil definitions from SAE TIR J2954 enable any compatible vehicle to charge wirelessly from its WPT home charger, work, or a shopping mall WPT charger, etc. with the same charging ability. All of this makes it possible to seamlessly transfer power over an air gap with high efficiencies. SAE TIR J2954 WPT automates the process for charging and extends the range for the vehicle customer only by parking in the right spot."

SAE TIR J2954 defines the frequency band for all light duty vehicle systems for WPT to be 85 kHz (81.39 - 90 kHz). Furthermore, four classes of WPT with different power levels are to be specified in SAE TIR J2954:

- WPT1 - 3.7 kW (specified in TIR J2954).
- WPT2 - 7.7 kW (specified in TIR J2954).
- WPT1 - 11 kW (to be specified in future revision of TIR J2954).
- WPT1 - 22 kW (to be specified in future revision of TIR J2954).

Moreover, even higher power levels may be included in future revisions of TIR J2954.

2.5.3 Shielding for electromagnetic inductive applications

In their article about Coil design and shielding for OLPT, Kim, J. et al. (2013) [14] describes how the coils could need shielding in order to meet the levels described in guidelines for electric and magnetic field exposure (see chapter 2.7). As described in chapter 2.5, OLPT and RIPT are based on the same technology, suggesting that this aspect of shielding should also be important for RIPT. Furthermore, Kim, J. et al. describes how the shielding of coils could improve the WPT efficiency, which in other case could decrease due to unwanted magnetic field leakage around the magnetic field source. The magnetic field leakage is due to induced currents in the surrounding conductive materials, like for instance typical materials of a car chassis. Furthermore, metallic shielding is described as popular, useful and effective for shielding in radio-frequency applications. However, by suppressing a WPT systems possible leakage of magnetic field, considerations should be made regarding the effects on the WPT's electrical performance.

2.6 Wireless Power Transfer & Vehicle alignment

In their article Birell et al. (2015) [15] describes how wireless charging technologies as inductive charging demands some degree of alignment in order to have a high efficiency or even function at all. With the conclusion that current inductive charging system have a typical tolerance of approximately ±10cm between transmitting and receiving coils. They have however found that in both of their two different studies, regarding parking alignment, that only 5% of the vehicles in their studies would have efficient charging, due to insufficient parking alignment.

Furthermore, it is stated in the article that the loss of efficiency in inductive charging also may endanger human safety. A good alignment between the two coils may enable wireless power transfer efficiency over 95%. To increase the tolerances of the inductive technology, a resonant circuit may be used. However, even with the use of resonant circuits the efficiency will drop rapidly at an approximately misalignment of 15cm in either air gap-, lateral-, or longitudinal distance. They also states that the angular misalignment have a major effect on the wireless transfer efficiency. It is described how they made two different tests for the displacement in parking lots. The displacements were plotted in a diagram such as is illustrated by figure 2.9.

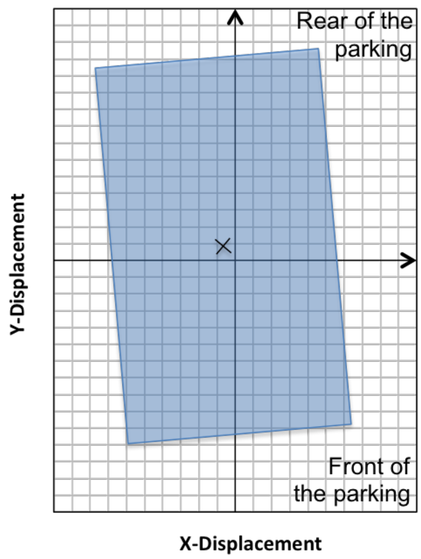


Figure 2.9: Illustration of the axis system for the measured values of 'displacement'.

One test, the *retrospective analysis*, was performed without the drivers of the cars knowing that their parking performance, of parking in a bay, was to be measured. In the other test, the *dynamic parking study*, the drivers were instructed to park a Nissan Leaf EV over an charging pad on an relatively open parking lot. Furthermore, the dynamic parking study was performed with the two scenarios of a charging receiver placed in the front, respective centre of the cars. The result from the retrospective analysis and dynamic parking study as presented by Birell et al. [15] can be seen in table 2.3 respective table 2.4.

Table 2.3: Mean displacement and distance in the x (lateral) and y (longitudinal) axis, and distance from the centre of the vehicle to the centre of the bay. 'Distance' is the absolute value of the displacement.

	Mean	Standard Deviation
X-displacement (cm)	-3.21	14.64
Y-displacement (cm)	15.59	25.02
Distance from centre (cm)	29.30	15.13
X-distance (cm)	12.12	8.74
Y-distance (cm)	23.73	29.12
Parking angle (°)	0.018	2.27
Absolute angle (°)	0.027	0.029

Table 2.4: Mean displacement and distance in the (lateral) and y (longitudinal) axis, and distance from the centre of the vehicle to the centre of the charging pad. 'Distance' is the absolute value of the displacement.

	Front		Centre	
	Mean	Standard Deviation	Mean	Standard Deviation
X-displacement (cm)	0.54	7.21	7.33	15.07
Y-displacement (cm)	-66.86	60.81	-34.05	92.09
Distance from centre (cm)	75.39	49.01	75.93	60.41
X-distance (cm)	5.95	3.61	13.20	9.64
Y-distance (cm)	74.65	49.71	72.31	62.92
Parking angle (°)	2.00	2.14	0.18	5.64
Absolute angle (°)	2.14	2.00	3.35	4.40

2.7 WPT & Health

According to Das Barman et al. (2015) [16] one major concern for wireless power transfer technology is the question about safety of the human body. The risk for the human body, in wireless power transfer, to be exposed to electric, magnetic, and EM fields is increased with higher power levels and transmission distances. The frequency in WPT-systems are an important factor, as it is necessary for magnetic and electromagnetic fields. Das barman et al. claims that there is a general crossover frequency at 100 kHz. Over 100 kHz the field has a dominating heating effect, while under 100 kHz the field has a dominating electro-stimulating effect.

Dar Barman et al. implies that the the magnetic and electromagnetic fields effects on the human body should be further researched, as there are still some uncertainties. Nevertheless, regarding human exposure guidelines WHO (World Health Organization) generally recommends two - IEEE's and ICNIRP's. The purpose of their respectively guidelines are:

- *The purpose of IEEE standard is to provide exposure limits to protect against adverse health effects to human induced by exposure to RF electric, magnetic, and EM fields over the frequency range of 3 KHz–300 GHz.*
- *The main objective of ICNIRP standard is to set up guidelines for limiting the EM field exposure to protect against harmful health effects. An adverse health effect causes a detectable impairment of the health of the exposed individual or of his or her offspring; a biological effect on the other hand, may or may not result in an adverse health effect.*

Moreover, there are some differences in their recommended values. A comparison of their recommended values regarding SAR and induced electric field levels are presented in table 2.5.

Table 2.5: Recommended SAR levels.

Regulation	**SAR (W/Kg)**			**Induced electric field (V/m), (f in Hz)**
	Whole body average	Head trunk	Limbs	All tissue
ICNIRP 2010	0.08	2 (10 g)	4 (10 g)	$1.35 \times 10^4 f$
IEEE 2006	0.4	2 (10 g)	4 (10 g)	2.1×10^4 - $6.3 \times 10^4 f$

Furthermore, in figure 2.10 and 2.11 the recommended limits stated by IEEE for controlled respectively uncontrolled environments are presented. ICNIRP's corresponding recommendations are presented in figure 2.12.

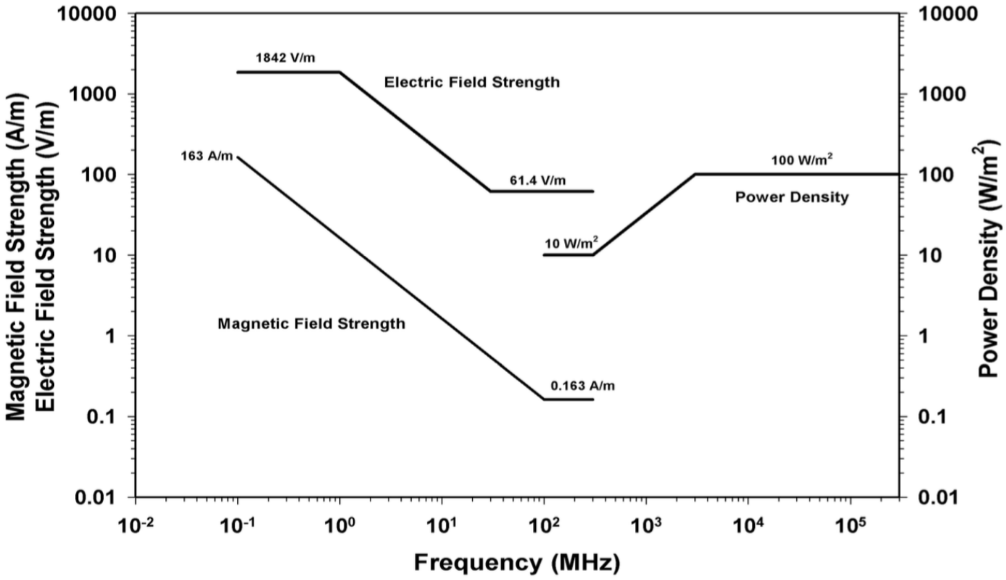


Figure 2.10: Field limits recommendations from IEEE for controlled environments.

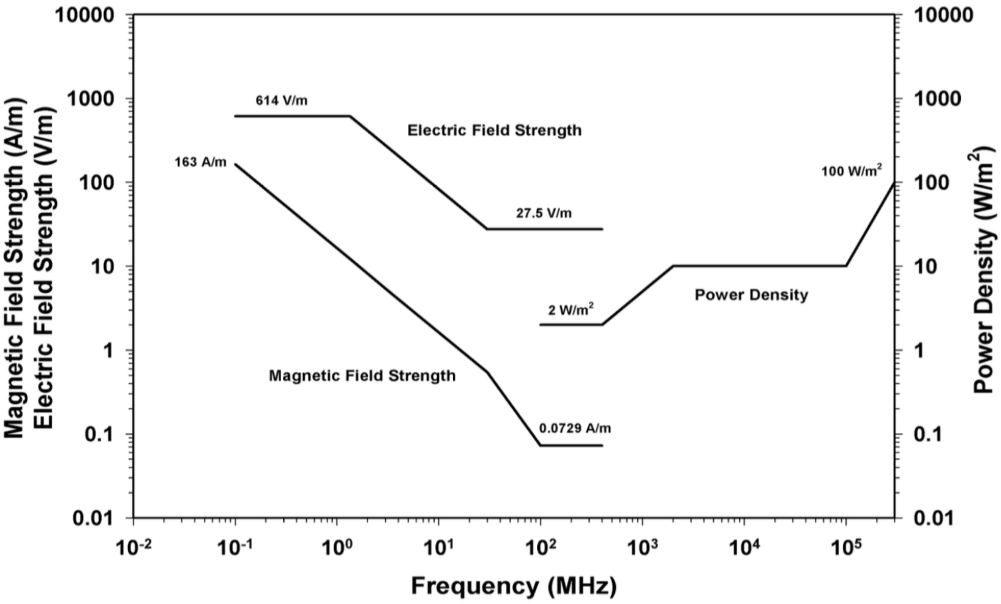


Figure 2.11: Field limits recommendations from IEEE for uncontrolled environments.

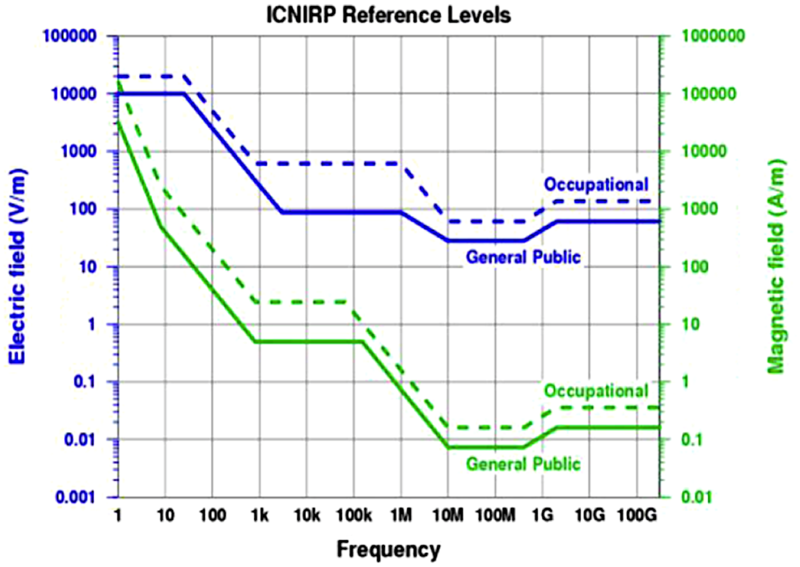


Figure 2.12: Field limit recommendations by ICNIRP.

2.8 Autonomous Drive

Suggestions of what positive aspects Autonomous drives (ADs), (in a vehicle also referred to as Autonomous vehicles (AVs)), could bring to the future United Kingdom is presented in the publication 'Making better places - Autonomous vehicles and future opportunities' by R. Skinner and N. Bidwell (2016) [17].
According to R.Skinner and N.Bidwell the introduction of driver-less and AVs are on its way, and the technology will bring transformation in the aspects of quality of life, economic growth, health, and social connections.
Moreover, they describe AVs by using the definition of the UK Department for Transport - *A fully autonomous vehicle is capable of completing journeys safely and efficiently, without a driver, in all normally encountered traffic, road and weather conditions.*
Furthermore, it is suggested that EVs not only need to be able to drive themselves, but that they also should use the possibility to communicate with other vehicles. There are different levels of AD, which makes differences regarding if, and to what degree, a qualified person needs to sit behind the wheels and be ready to (if required) take over the control of the vehicle.
Concerning **COMFORT** the suggested benefits with AVs are:

- A more smooth travel, due to better driving with less risk for shockwave breaks.
- Instead of driving, other tasks may be performed.
- No need to search for and drive to parking places.

Regarding the aspects of **PARKING**, they suggests and claims:

- Between 30-45% of city centre traffic is due to drivers searching for parking spaces.
- AD could eliminate the need of parking space at destination.

- Autonomous vehicle zones (only for AVs) could increase the developable area between 15-20% compared to a typical central urban layout. As cars can travel more efficiently and drive to designated parking hubs with possible charging infrastructure.
- AD and the use of parking hubs could eliminate the need and benefits of private parking lots at 'home'. Thus enable area for other things, such as more green areas.
- AD and parking hubs could reduce the general parking areas. General parking coverage for cities such as London, New York, Paris, Vienna, Boston, and Hong Kong is between 15-30%.

Among the benefits mentioned, the ones that concerns **SAFETY** were for instance:

- AD have the possibly to reduce the number and severity of road accidents substantially. Due to that upwards to 90% of all accidents are caused by driver error. Less accidents saves costs for the city. With reduction in road-related casualties of 50% and 90% there could be cost saves of £360 million respectively £650 million per year.
- Today's cars use 5% of a typical motorway lane at any given time, under good conditions. Considering safe distances due to driver response time, a fully driver-less motorway with communicating cars could allow as much as 3.7 times higher capacity, compared to today.

The **UTILISATION** of AVs is suggested to be:

- More fundamentally; AVs should enable higher utilisation rate of vehicles, as they can move while empty.
- The traffic flow and journey time reliability should be improved.
- ADs could decrease the number of cars, as AVs could be used in greater proportion of time. Research suggests that for UK a typical car is parked 96% of the time (80% at home and 16% elsewhere).
- Two different market options have been identified for AVs; private ownership and shared use (as in a service).
- Shared vehicles travelling 24,000 km per year may have cost savings up to 75%, compared with typical running costs of non shared vehicles.

2.9 Electric Power at Home

According to the Swedish company Vattenfall AB (2013) [18] an average Swedish house ($144m^2$) have the total electricity consumption of 26.200 kWh. Of this total power consumption 57% is for heating, 19% is for heating water, and 24% is for household electricity.
Vattenfall AB states on their website [19] that the total power consumption of a house is dependent on the sort of central heating system of the house, for instance if it uses district heating, heat pump, or electric heater. Furthermore, it is stated that it is important to chose a main fuse which may deliver enough power for the house. In recommendations [18], which is presented in table 2.6, they suggest what size of the main fuse is suitable for different yearly power consumption spans, and what

respectively maximal power outtake they stand. The yearly power consumption recommendations considers that the power usage varies over the day's, and thus not the the fully utilised yearly output (maximal total output for all hours á year).
Moreover, at Vattenfall AB change of the main fuse size may only be performed once per a twelve months period.

Table 2.6: Recommendation table for main fuse selection made by Vattenfall (Vattenfall, 2013). The fourth column is a calculation of; Maximum Power Output all hours á year (set to be 8766 hours). The fifth column is the Vattenfall AB's yearly price for respectively main fuse size [20].

Main Fuse Size	Yearly Power Consumption	Maximum Power Output	Fully Utilized Yearly Output	Yearly Cost
16 A	0-20 000 kWh	11 kW	96 426 kWh	3 675 kr
20 A	20 000-25 000 kWh	14 kW	122 724 kWh	5 140 kr
25 A	25 000-30 000 kWh	17 kW	149 022 kWh	6 425 kr
35 A	30 000-40 000 kWh	24 kW	210 384 kWh	8 795 kr
50 A	40 000-55 000 kWh	35 kW	306 810 kWh	12 640 kr
63 A	55 000-70 000 kWh	44 kW	385 704 kWh	17 050 kr

2.10 Swedish EV capability

In the master's thesis by Knutfelt, M. (2015) [21], it is investigated what charging capability Sweden has for EVs. Knutfelt, M. describes available power produced and the assumptions that EVs are charged during the night and using a dynamic charging (for maximal utilisation). Dynamic charging is described as that all the charges are connected and a charging plan is set up after all the charging stations individually needs and demands. One conclusion in the thesis is that the Swedish car fleet could at highest (for function all year around) consist of 30% electric cars, that is about 1.4 million cars.

2.11 China EV capability system

In the book 'Electric power and energy in China' the author Liu, Z. (2013) [22] describes what the EV energy supply model looks like in China, and compares it to the world.
Liu, Z. describes that there have been a rapid development of the EV-market in the world. This has led to rapidly increasing infrastructural demands. To meet the demands, the Chinese governmental company State Grid had at the end of 2011 built and put in operation 13,000 AC charging poles, and 243 standard charging and battery swapping stations, resulting in that China become the largest charging and battery swapping operator in the world.

According to Liu, Z. cities are the focus area for EV development. This could be problematic for China, due to its differences to developed countries. Where developed countries have a norm of living in detached houses with dedicated parking spaces and possibly garages, China have a situation with dense population, high-rising apartment buildings, and with extreme shortage of parking spaces (even more so in the future). The construction of infrastructure (such as charging stations, transformers, lines, and meters) in public spaces and residential areas faces challenges in the aspect of cost and time. Considerations should also be taken regarding the possibility of revamp and upgrade the charging infrastructure, which could be difficulty and costly.
Furthermore, the fast charging mode still faces problems with its negative impact on battery life, and further technological breakthroughs should be needed for it to gain popularity.
Liu, Z. claims that China has a somewhat limited potential for improving its energy supply. With aspects such as environmental capacity and the developing conditions of the country (due to rapid economic & social growth), China faces immense demands in guaranteeing future energy supply.
However, development of EVs is significantly optimising and restructuring the energy consumption. Due to development of EVs the USA is estimating to annually save 15% of its oil consumption year 2030, but with only an corresponding increased electricity demand of about 5-6% (compared to a scenario with no EVs).
As may be seen in figure 2.13, China's electricity production is at largest based on thermal power, which is mainly coal.

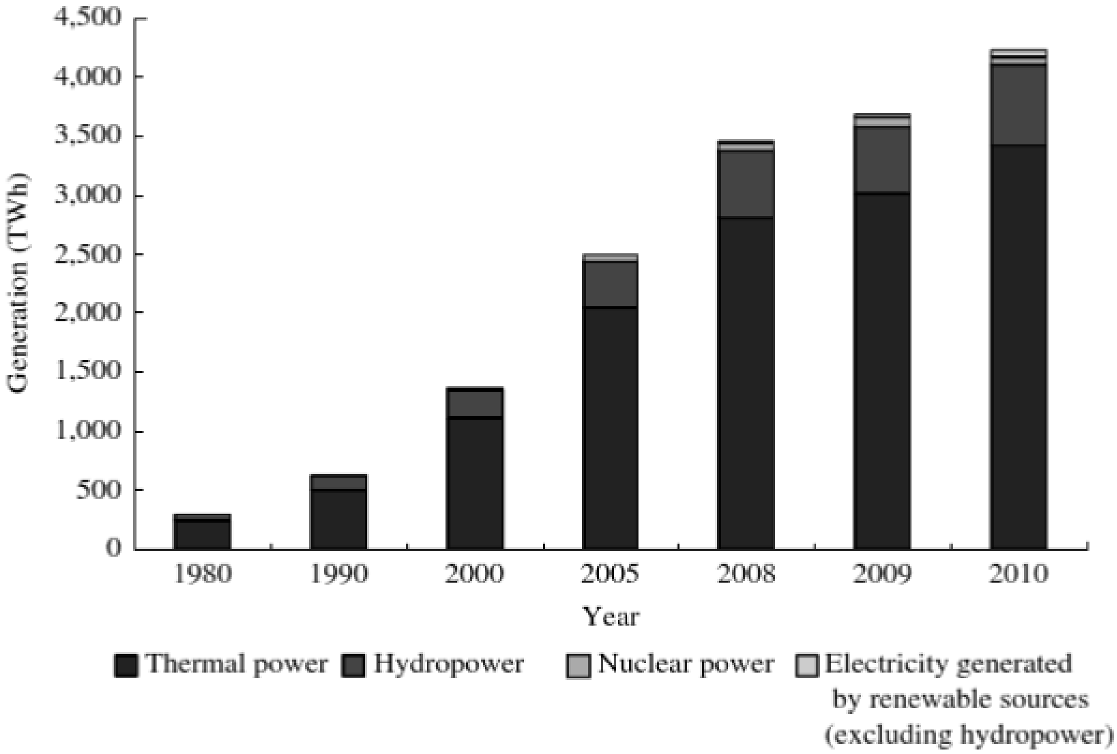


Figure 2.13: China electricity production distribution.

Furthermore, Liu, Z. claims that the long-term emphasis of power generation and to little regarding power supply, has resulted in imbalance of power grid and power source development. The network structure is irrational and have a weak cross-regional backbone network, resulting in a weak capacity to possible accidents and severe natural disasters. In combination to the rapidly increasing demands, complexity of external environment, and a large number of new generating units, Liu, Z. states that *"there is a real risk of widespread blackouts across power grids"*.

2.12 Energy Storage System

In the research of by Oberhofer, A. (2012) [23] it is stated that the amount of electricity demanded in an electric grid by consumers must always be met with the same level of electricity fed into the grid. This is necessary for preventing blackouts and damage to the grid. Furthermore, the demand and consumption of electricity in a electrical grid varies over hour, day and year.
In an article written by Faria et al. (2014) [24] they have analysed the electricity power consumption of a typical Portuguese residence, for three work days (figure 2.14, diagram 'a') and a weekend (figure 2.14, diagram 'b').

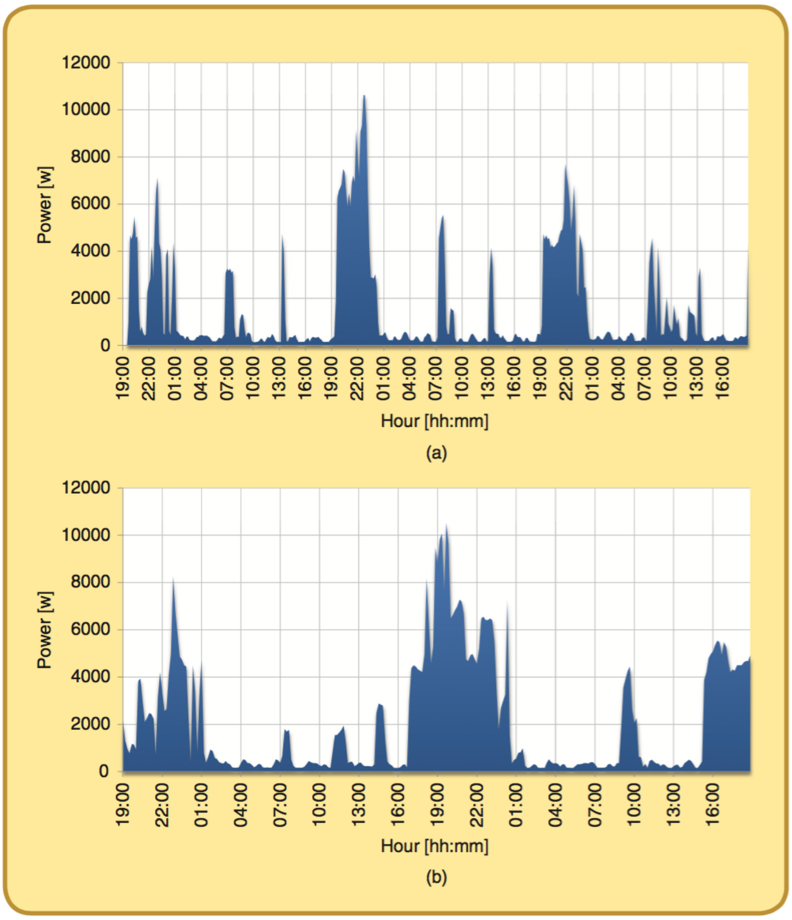


Figure 2.14: Elecric power consumption for a residence for a) three work-days, and b) a weekend (two days).

Moreover, Faria et al. states that it is not only private residences that have a high variance in electricity consumption, the whole electricity grid have a high variance over hour, day, month and year (due to electricity consumption). It can therefore be difficult and costly to always met the electricity consumptions with the same level of electricity fed into the grid.

According to Yong, J.Y. et al. (2015), the system cost for the electric grid can be reduced up to 60% in a future controlled EV charging. In a controlled EV charging system the charger only charges when it needs and when it does not create or add to peak consumptions in the grid. Hence, distributing potential peaks, such as the ones at some occasions occurs in the diagrams of figure 2.14. With more (fluctuating) renewable energy (especially wind energy) the cost reduction would be even better.

Moreover, Yong, J.Y. et al. also describes another study that have been performed, regarding investigation of what impact EV charging will have on the Germany's grid-load profile, in year 2030. In the case of all conventional internal combustion engine vehicles (claimed to be 42 million) were to be replaced by EVs that charged uncontrolled, then the peak load would be increased by about two times.

Another aspect and finding Yong, J.Y. et al. describes is that by using EVs for grid stabilising storage's a reduction of 16% on the maximum peak lead may be achieved.

According to Oberhofer, A. (2012) [23] there will be a great need in the future to distribute the demanded electric power. The increasing share of wind and solar generation of electricity creates a more fluctuating power generation and with less stability. In order to deliver sufficient energy and power at specific times (according to demands), the energy needs to be stored. Energy storage systems (ESSs) is a technical solution that can store (electric) energy, and when needed make it available to the grid.

By storing the energy the electricity consumption is not directly dependent to the current electricity availability in the grid, only to what is stored in ESSs. Hence, power which is not available in the grid may be available from the ESSs.

There are different kinds of ES technologies described by Oberhofer. Each ES technology have it respective strength and weaknesses, which makes them suitable for different applications and usages. Some described ES technologies are:

- Li-ion batteries.
- Flywheels.
- Flow batteries.
- Superconductive magnetic energy storage (SMES).
- Compressed air energy storage (CAES).

The different technologies can typically be differentiated by their differences regarding discharge duration (energy loss), and for which level of electrical power demand application they are suitable for. This relation is presented in figure 2.15.

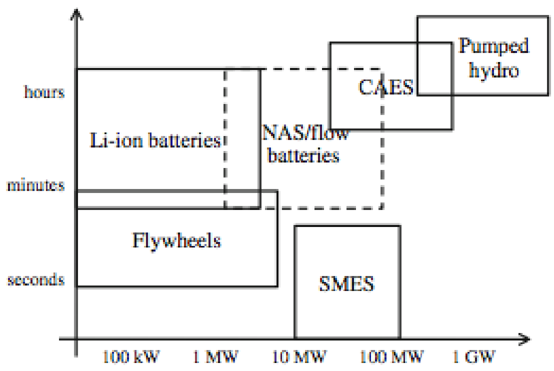


Figure 2.15: Comparison diagram of discharge duration versus rated power for some energy storage technologies [25].

2.12.1 Li-ion batteries

Oberhofer, A. (2012) [23] describes that a Li-ion (or lithium-ion) battery is like all batteries a device that through a chemical reaction produces electrical energy. The chemical for li-ion batteries is lithium ions (just as the name suggests) but the chemical compound, in which the lithium is contained, may vary between different sorts of Li-ion technologies. The battery is divided into two sides or chambers - anode and cathode. The chambers are separated by a separator, where only the lithium ions may pass. By using external electrical energy, the lithium ions is drawn to the anode (through the separator). When the battery is used/discharged the lithium ions is instead drawn to the cathode, as the electrons moves from the anode to the cathode.
The advantages ('+') and disadvantages ('-') listed for Li-ion batteries are:

+ The commercial battery with highest energy density, and a future with huge potential.
+ Higher cell voltages (3.7V compared to 2.0V for lead-acid batteries).
+ Low energy losses (about 5 percent per month).
+ Resources available in large amounts (lithium and graphite).
− Expensive.
− Cells are ruined if completely discharged.
− Typical 5 years life-cycle (deteriorates even if unused).
− In contact with atmospheric moisture, lithium is flammable.

2.12.2 Flywheels

The principle of a flywheel is described by Oberhofer, A. (2012) [23] to be a disc (wheel) with a defined mass is mounted on an axis. The axis is connected to an (combined) electric motor and generator. By using the electric motor to set the disc into rotation, the disc acquires a kinetic energy. The kinetic energy can then, when desired, be transformed into electricity through the use of the generator. The kinetic energy is dependent on the mass of the disc and its rotation speed.

The advantages ('+') and disadvantages ('-') listed for a flywheel are:

+ Long lifespan (up to 20 years) and low maintenance.
+ Almost no carbon emission.
+ Low response times.
+ Components and material are non-toxic.
− High cost for procurement.
− Relative low ES capacity.
− Self-discharges at a high rate (3-20 percent per hour).

2.12.3 Flow batteries

Oberhofer, A. (2012) [23] explains that there are different kinds of flow battery technologies, two of them are redox-flow battery and sodium battery.
Redox-flow batteries are like conventional batteries (such as li-ion batteries), but the electrolyte with the electrical charge may be replaced.
The advantages ('+') and disadvantages ('-') listed for Redox-Flow batteries are:

+ Possible to recharge by refuelling.
+ Long life span (about 40 years).
− Low energy density (35Wh/kg compared to<200Wh/kg for Li-ion).

The sodium, or the liquid sodium sulphur battery is still being developed. It has relatively high energy density, long life span, high efficiency. Thou, it has some disadvantages such as only operational at high temperatures, and liquid sodium reacts easily with water in the atmosphere.
The advantages ('+') and disadvantages ('-') listed for Sodium batteries are:

+ High energy density (up to 240Wh/kg).
+ Long life span (10-15 years).
+ High efficiency (75-90 percent).
− High temperature needed to operate (around 350°C).
− Liquid sodium reacts in atmosphere.

2.12.4 Superconducting Magnetic Energy Storage (SMES)

In a SMES the energy is, according to Oberhofer, A. (2012) [23], stored as a electromagnetic field around a coil. In order to keep the field around the coil (without great losses), the coil needs to be a superconductor. In theory the storage should be loss-less (due to the superconductor phenomenon), but practically it is made at an 90-95% efficiency.
The major problem and disadvantage of SMES is that current superconducting materials are only superconductive below very low temperatures (less than -253°C). However, superconductors functional at higher temperatures is being developed.

Nevertheless, the need to keep the superconducting material cold enough have a high impact on the technology's storage efficiency.
The advantages ('+') and disadvantages ('-') listed for SMES are:

+ Low respond times.
+ Able to discharge both partial and deeply.
+ No environmental threat.
– High self-discharge rate (about 12 percent per day).
– Very costly production and maintenance.
– Efficiency losses due to required cooling process.

2.12.5 Compressed air energy storage (CAES)

Oberhofer, A. (2012) [23] describes that the CAES technology stores energy by compressing air into tanks or caves, and it is an CO2 neutral technology. Only two CAES plants exists and are used in the world today. These plants were built for 25-30 years ago, indicating the long lifespan of the technology.

By using an electric compressor, air is compressed to about 60 bars and stored in underground spaces (such as old salt caverns). The stored compressed air may then be used to power turbines, which through generation produces electricity (when it is demanded). However, the two major problems of CAES derives from compressing and decompressing a gas (air). When the air is compressed heat is generated, which if unused creates power loss. When the air is decompressed, it freezes material it comes in contact with. Thus, the power turbines of a CAES needs to be heated in order for not to freeze. The technology is still not mature, and a currently in development plant in Germany tries to solve the great power losses (due to the two mentioned major problems) by an "Advanced adiabatic"-CAES. Instead of letting the heat generated from compressing air dissipate into the environment, heat exchangers will transfer the heat to a thermal storage. This stored heat may then be used to prevent the power turbines from freezing, when there is a demand of produce (return) electricity again. With this advanced adiabatic technology, the CAES technology may enable up to about 70% efficiency.
The advantages ('+') and disadvantages ('-') listed for CAES are:

+ Huge ES capacity.
+ Up to 70% efficiency (with heat exchanger for produced heat).
+ Low response time.
+ Very low cost for storing energy.
– Economical for storing energy up to one day.
– Requires sealed storage caverns.
– Competes against other needs of storage (natural gas, and hydrogen).
– The technology is not yet fully developed.

2.13 Reference EV-car specifications

As references for BEV and PHEV cars the Tesla Model S respectively VW Passat GTE Plug-in Hybrid. Their specifications, as presented in table 2.7, where acquired from the website 'laddaelbilen.se' [26][27].

Table 2.7: Specifications on reference models of BEV respectively PHEV.

Reference models' specifications		
Car	Tesla Model S (BEV)	VW Passat GTE Plug-in (PHEV)
Maximal Velocity	177-209 km/h	225 km/h, 130 km/h in E-Mode
Acceleration, 0-100 km/h	4.4 - 6.5s	7.6s
Battery type	Lithium-ion	Lithium-ion
Electric Engine	<324 kW	85.5 kW
Combustion Engine		115.5 kW
Combined Engine Power	<324 kW	163 kW
Battery capacity	85 kWh	9.9 kWh
Battery Charging		Mode 3 - 3.6 kW
Fast Charging	Yes, 90 kW	No
Electric Range	483km	50 km
Electricity consumption	ca 1.88 kWh per 10km	1.98 kWh per 10km
Fuel Consumption		2.0 l/100 km (NEDC)
Emissions, CO2	0	0 or 45 g/km
Length x Width x Height	4970 x 1960 x 1430 [mm]	4767 x 1832 x 1477 [mm]
Weight (NB)	2180 kg	1665 kg
Battery Warrant	8 years	8 years/160 000 km
Price, basic/low (in Sweden)	Ca 607 000 - 950 000 SEK (+36 000 SEK in "reservation fee"), with subventions	Sedan from 409 900 SEK, without subventions Wagon from 419 900 SEK, without subventions

2.14 Traditional charging connectors

Current charging for electric cars of today in Norway (a country with a large share of EVs) is typically only based on wired solutions with different connectors and respective charging power capability. The Norwegian electric car association [29] and 'ladestasjoner.no' [28] describes different charging connectors on their websites. Two typical connectors are the Schuko and Type 2. These two connectors is used as references for traditional charging connectors in this master thesis.

Schuko is the name of the standard connector for grounded home electronic devices in countries such as Sweden and Norway. The Type 2 connector is made for charging electric vehicles, and is common on charging poles of larger infrastructural charging systems for electric cars, such as the one used in Norway.
Both connectors are for AC charging systems. While the Schuko typically allows charging powers around 2.5kW (but a maximum of 3.6kW), the Type 2 connector enables charging powers up to around 43kW.

2.15 EU regulations of drivers' hours

From the 'European Union (EU) rules on drivers' hours and working time - Simplified guidance' regarding the 'Regulation (EC)561/2006' (2016) [30].
The guidlines are divided into the three aspects of Driving, Breaks, and Rest.
Driving

- 9 hour daily driving limit (can be increased to 10 hours twice a week).
- Maximum 56 hour weekly driving limit.
- Maximum 90 hour fortnightly driving limit.

Breaks

- 45 minutes break after 4.5 hours driving.
- A break can be split into two periods, the first being at least 15 minutes and the second at least 30 minutes (which must be completed after 4.5 hours driving).

Rest

- 11 hour daily rest; which can be reduced to 9 hours no more than three times a week (or split into 3 hours + 9 hours as often as desired).
- 45 hours weekly rest, which can be reduced to 24 hours, provided at least one full rest is taken in any fortnight. There should be no more than six consecutive 24 hour periods between weekly rests.

3
Method

The method that this project was based on is the PDM described by Ulrich, K. & Eppinger, S, (2012)[2]. Extensive work had to be performed in order to interpret their methodology into a suitable process for this project.
This interpretation and process planning was created in the first phase - 'Planning & Opportunities' (corresponds to Ulrich & Eppingers described 'phase 0'). Furthermore, the other phases, which the process is divided into in the method used, is 'Concept development', 'System-level design', and 'Detailed design', which corresponds to Ulrich & Eppingers 'phase 1', 'phase 2', respective 'phase 3'.

3.1 Planning & Opportunities

The planning phase of the project started with an preliminary project scope, -definition, and expected deliveries. The main methodology were decided to be a product development methodology. Due to earlier experiences and practising the methodology described in the book 'Product Design and Development' by Ulrich, K. & Eppinger, S. (2012) [2] were chosen for this project.
The methodology of Ulrich & Eppinger describes a general methodology for a complete product development process in a company. Aspects of how an organisation could set up a strategy, project teams, find opportunities, and prioritise project is some of the aspects they include in the planning phase. As the project were proposed by the company CEVT, assumptions were made that some of the initial planning phase tasks had already been performed. Furthermore, this project is a master thesis project performed by one student. Therefor, the planning phase of this project have been narrowed down to consist of following tasks, where 7.1 & 7.2 are the deliveries (illustrated in figure 3.1):

1. Research market & technology.
2. Reflect upon possible technological developments.
3. Define possible opportunity.
4. Forming of initial plans.
5. Initial system boundary.
6. Analyse the findings.

7.1. Define a project mission statement.
- Product description.
- Benefit proposal.
- Key business goals.
- Primary market.

- Secondary market.
- Assumptions & Constraints.
- Stakeholders.
- Technological trajectory.

7.2. Set final Gantt & Detail plans.

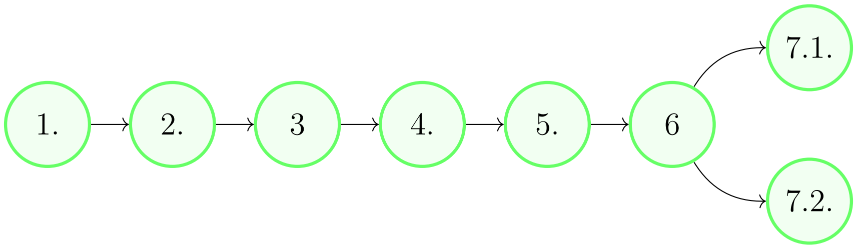


Figure 3.1: Precedence diagram of *Phase 0 - Planning*

3.1.1 Research market & technology

The initial scope of the project was 'wireless charging for electric cars', and thus 'research market & technology' was focused on exploring and gather information regarding current market and technologies for that scope. Relevant technologies and existing solutions were researched and documented to help further research. In general the databases search tool of Summon and Xplore (IEEE) were used for searching articles and data, while free searching and browsing of the Internet were used for probing.
Further research were to be made during the whole project, if necessary, but the important part taking place at this stage.

3.1.2 Technological trajectory & Opportunities

When sufficient data had been acquired, regarding market, and technological- & technical solutions, a '2. Reflection upon possible technological developments' was made in order to '3. Define possible opportunity'. The opportunities gave an suggestion of what the project should deliver in order for it to be successful.

3.1.3 Initial plans & System boundary

When the opportunities had been identified and an initial understanding of the projects content and extent had been understood, it continued with the '4. Forming of initial plans'. A Gantt chart was created for the overall project plan along with precedence diagrams for the different phases of the product development process. An '5. Initial system boundary' for the system were then defined.

3.1.4 Analyse findings & Define mission statement

By '6. Analyse the findings' of all previous steps enough data could be concluded to '7.1. Define a project mission statement'. The project mission statement was expressed to answer the areas defined in the list defined for step 7.1.

3.1.5 Set final plans

With the project mission statement set, adjustments were made in the plans to '7.2. Set final Gantt & Detail plans'.
Furthermore, the outcome of the planning phase was also a change in scope and aim of the project, from 'wireless charging for electric vehicles' to 'convenient charging system for BEVs and PHEVs.

3.2 Concept Development

The concept development phase had the following process (may be seen in figure 3.2):

1.1. Define market & stakeholders.
1.2. Explore market & competitive products.
1.3. Identify needs.
2. Set target product criteria.
3. Establish a initial system boundary.
4. Concept generation.
5. Concept screening.
6. Concept scoring.
7. Concept testing/review.
8. First concept selection.
9. Analyse the concept(s) selected with respect to the identified system..

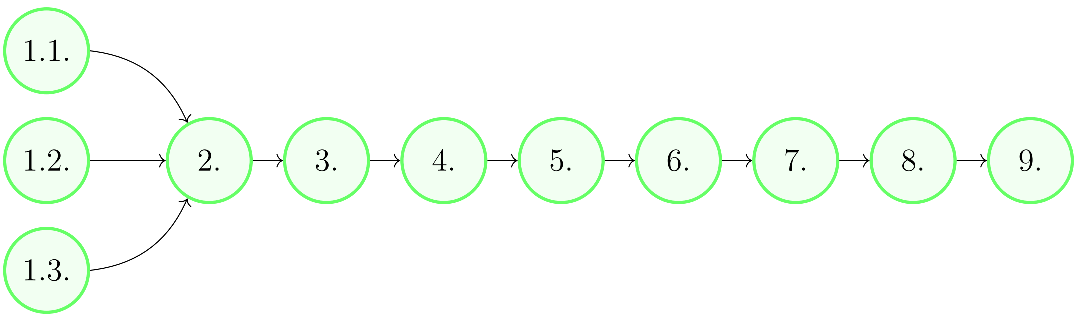


Figure 3.2: Precedence diagram of *Phase 1 - Concept Development*

3.2.1 Market, stakeholders, & Competitive products

The project mission statement from the end of the planning phase was thoroughly reviewed and the market, stakeholders and competitive products were initially understood and -defined before the needs in the market and for the stakeholders were to be identified.

3.2.2 Identify needs

The data collection method for identifying the needs were secondary research, one survey, and three semi-structured interviews.
When the data of needs had been collected, it was reviewed and interesting findings and answers was individually formulated in a list of 'customer statements'. A 'interpreted need' was formulated for each respectively 'customer statement'. The 'interpreted needs' list was reviewed and similar needs was combined, in order to create the final 'customer needs list'.
In order to create a 'metrics list', metrics were created for each respectively need. As for the previous refinement of the needs list, the metric formulations were reviewed and similar metrics were combined. Thus one metric could represent more than one need. When each need had a respectively metric, the measurable unit for each respectively metric was defined. These measurable units could be subjective, yes/no, compared to listed data/values, or a physical unit. The metrics list was complete when all metrics had measurable units.

3.2.3 Set target product criteria

Next step was the creation of a 'target product specifications list'. A target product specifications list is created by setting initial target values for each respectively metric (in its respective unit). However, due to time constraints, sufficient research was concluded to not be possible. Instead, the metric list was decided to be sufficient to use instead of the target product specification, but then referred to as 'target product criteria'.

3.2.4 Establish a initial system boundary

With the acquired understanding of problem and target product criteria, next step was to establish an 'initial system boundary'. The system boundary is a schematic and drawing of the essential parts that the system solution has been identified to have. The system boundary were to be reviewed and redefined at later stages in the process. The importance of the initial system boundary was to support the concept generation, concept screening, concept scoring, and concept testing.

3.2.5 Concept generation

From the initial start of the project every idea that were had, was instantly documented in a project book (see figure 3.3. Therefor, some concepts did already exist before the planned concept generation process were initiated. In order to generate more concepts, the already generated concepts were categorised with an affinity diagram. The diagram's categories were created with considerations to the current identified system boundary. One 20 minutes brainstorming for each respectively category was performed to generate more concepts.

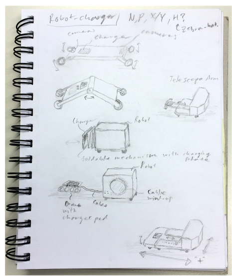


Figure 3.3: Picture of a page in the project book.

3.2.6 Concept screening

When concepts had been generated they were screened with 'selection matrices'. The concepts had through the affinity diagram been divided into the three separate screening categories
The selection criteria were defined through finding suitable areas and aspects for satisfying all the identified needs in the needs list.
For each respective concept category the same full system reference was used.
The concepts were screened and 'graded' as 'Develop', 'Not Develop', and 'Combine'. A 'not develop'-graded concept could also be marked as interesting, if it had potential to be interesting at later stages or for discussion.

3.2.7 Concept scoring, -testing, & first concept selection

The concepts that passed the concept screening were analysed, refined, and divided into the functional groups (categories) Standard Charger, Robot Charger, Supercharger, Emergency Charger, Alignment, and Energy Storage System.

3.2.7.1 Defining a developed system boundary

With these new functional groups along with the growing understanding of the problem (partly due to continued secondary research), a new 'developed system boundary' was defined. This new system boundary was an important support to further concept development processes.

3.2.7.2 Morphological solutions

In order to move from sub-system concepts to full system concepts a morphological matrix with the six different functional groups was created. In total seven full system concepts were morphologically created at this stage.

3.2.7.3 First concept-scoring matrix

In order to score these full system concepts a concept-scoring matrix was created. The selection criteria of the matrix were created from the target product criteria. In comparison to the selection matrix (during the concept screening) these selection criteria were more detailed, larger in number, and also weighted.
The different weights were established by first give the same weight to all criteria. Then subjective analysing of all collected and researched data in combination with the identified system boundary, allowed for increase the weight for the more important criteria, and thus have to decrease the weight from the least important criteria. This ended when a the weighting were considered good.
All of the full-system concepts were compared and scored in relation to a reference concept. The four concepts with highest total scores were then analysed.
To analyse the four full-system concepts, each specific criteria scores, for all concepts together, were used for calculation of average and maximal score results. The criteria scores' results between the average score and halfway up to the highest score were colour-graded in a white to green scale, where highest score were the most green

colour. The score results higher than the colour range also had the most green colour. This enabled to visually see the criteria that (with weight) made the different full-system concept good.
The four full-system concepts were then one-by-one (and as a whole) compared and analysed with the help of the colour grading. Each one of the four full-system concept was graded according to 'Develop', 'Combine', 'Analyse', and 'Not-Develop'. The Develop, Combine, and Analyse concepts were used to, with iterations from the morphological matrix, create one new single best full-system concept. This new full-system concept had (after the allowed iterations) the highest scores in the concept-scoring matrix, and when that happened also appointed as the (initial) first concept selection, but to be reviewed.

3.2.8 Review of first concept selection

In order to test assumptions, ideas, and the first concept selection, a field-trip to Oslo (Norway) was performed as well as participation in a seminar-day called 'Kraftforum', Gothenburg.
Oslo is commonly known to have a relatively large proportion of BEV and supporting infrastructure. It was an two days field-trip, made by travelling in an PHEV (VW Passat Plug-in, see reference cars chapter 2.13). In Oslo, visits and unstructured interviews were made with first the municipal (and person responsible for the charging infrastructures), and then with an representative of 'The Norwegian Electric Vehicle Association'.
The field-trip gave an increasingly understanding that both strengthened and dismantled some of the thoughts and ideas.
At the seminar-day 'Kraftforum', representatives from Swedish companies and universities, with interests of the future electricity grid and users of it (for instance EV users), participated. The seminar-day was interesting and gave a further deeper understanding, strengthening the ideas and findings from the field-trip.
The ideas and findings from the field-trip to Oslo and the participation at 'Kraftforum' were concluded and documented into a brief report. This report in addition to analysing the concepts previously marked as 'develop', 'combine' and 'analyse', led to the creation of a new full-system concept - the review concept. This new full-system concept was compared to the (initial) first concept selection by inserting it into the final concept-scoring matrix.
The best concept in this final concept-scoring matrix was chosen as the (final) first concept selection. The system boundary was reviewed according to the (final) first concept selection, which led to the creation/establishing of the 'final system boundary'.

3.3 System-Level Design

When the concept development phase was concluded and both a first concept selection as well as a final system boundary were set, the system-level design phase began. The process of the system-level design phase were as follow:

1. Set final product specifications.
2. Establish product architecture.
   - Create a schematic of the product.
   - Cluster the elements of the schematic.
   - Create a rough geometric layout.
   - Identify cluster interaction.
   - Platform planning - differentiation & commonality.

3.1. Develop industrial design.
3.2. Design for environment.
4. Begin prototype development.

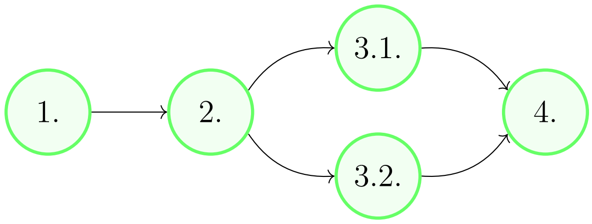


Figure 3.4: Precedence diagram of *Phase 2 - System-Level Design*

3.3.1 Final product specifications

The system-level design phase started with setting the final product specifications. This was performed by consider the first concept selection (outcome of the concept development phase), final system boundary, user needs, target product criteria, as well as researched constraints and feasibility's.

3.3.2 Product Architecture

The process of creating a product architecture began with creating an initial schematic of elements, of the system. The schematic was based on the identified system (final system boundary) and first concept selection.
The elements of the schematic were then clustered and made into an initial cluster design. The initial cluster design were reviewed and refined in a rough geometrical layout. With a rough geometrical layout the respectively cluster's interactions could be better understood, identified and combined. However, it was decided to be to time-consuming to create a full geometrical layout for the whole product architecture. Therefore, only a rough geometrical layout, which was enough to show the interface principles to the car, was created for the final product architecture. In order to complete the establishing of a product architecture, a short descriptive text were written about the platform and modularisation aspects of the product architecture.

3.3.3 Industrial Design

After a product architecture had been established an industrial design were created. While creating the industrial design considerations were also made regarding the aspects of environmental, manufacturability, and robust design. As defined in the introduction the industrial design was not to be comprehensive, due to limited project resources. Thus, no cost figures were calculated and can be presented. Decisions was based on subjective estimations with limited research data.

3.3.4 Prototype Development

In order to enriching and support the drawings of the industrial design, simple CAD drawings of the ’standard charger’ and ’destination charger’ were created.

3.4 Detailed design

The detailed design phase has the following process (may be seen in figure 3.5):

1. Final concept selection.
2. Complete industrial design.
4.1. Assess environmental impact.
4.2. Assess Convenience
5. Overall assessment.
6. *(Eventually)* Refinement.
7. Complete specification.
8. Finale delivery.

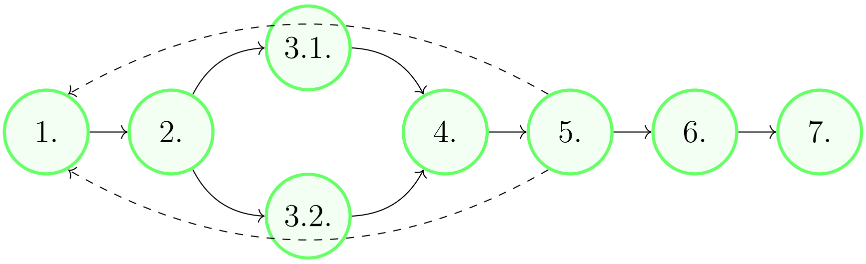


Figure 3.5: Precedence diagram of *Phase 3 - Detailed Design*

Due to time limitations and satisfaction with the development of the concept throughout the industrial design and prototype development, the decision was made that the current concept solution would be sufficient as a 'final concept selection'. Therefore, the detailed design phase started with the industrial design and the final concept selection consisted of the stages of industrial design and prototype development.
Furthermore, the part geometry were also to be based on the industrial design and prototype development.
After a industrial design had been created, assessments were done in the areas environmental impact and convenience.
The findings of the assessments resulted in minor redefinitions in specifications of the final industrial design and prototype. However, only the changes in specifications were implemented into the final industrial design and prototype.
With the changes of specifications, the finale delivery could be compiled.

4

Results

The result for this masters' thesis project covers all from the creation and planning of the project, to the process, -findings, and -final deliveries. In this chapter the result of the 'Method & Process', 'Research', 'Project mission statement', 'Survey & Interviews', 'Concept selection', 'System-level design results', 'Final concept selection & development', and 'Complete specifications and final delivery'.

4.1 Method & Process

Among the results of the initial phase 'Planning & Opportunities' (see chapter 3.1), was the process plan for the whole project. As Ulrich & Eppingers described methodology could not be directly applied to this project, a original version (thou based on their methodology) had to be created.
For each respective phase in the method used, a the process plan was defined in detail with a descriptive process list and supporting precedence diagram (see example in figure 4.1).
Despite slightly change of scope and a lot of needed research, the overall plan and detailed plans could be used throughout the whole project with only minor changes. Except until the end of the project when it was determined that there were not time to complete all of which was planned. Parts had then to be cut, and compressed. But the method and overall plan were still basically the same in the beginning and end. Hence, the result for the planning of the project is to be considered good.

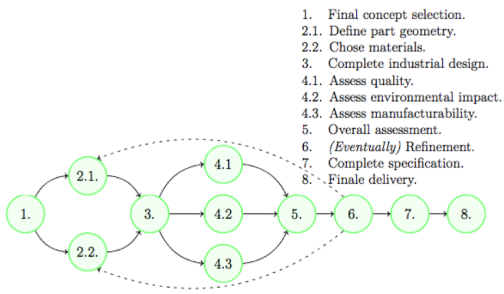


Figure 4.1: Illustration of how the process was described with a list and precedence diagram.

4.2 Research

This project would turn out to be an extensive research project. Much of all that was research were not relevant enough to be written in this report, even less so in this result chapter. Nevertheless, the areas of research about which results are to be presented in this chapter is:

- WPT technologies.

- Behavior & Convenience.
- Health & Safety.
- Autonomous Drive.
- Power Availability & EV capability.
- Reference products and -system.

4.2.1 WPT Technology research

There are many companies with different Wireless power transfer (WPT) technical solutions. The use of different technologies and technical solutions differentiates them.
Through the research in this masters' thesis project, several companies with their respective technologies solutions have been investigated. Moreover, different kinds of WPT technologies have been researched, for instance microwaves, ultrasonic sound, laser, magneto dynamic couplings, and different kinds of applications of the inductive technology. However, with support of an technological comparative article refereed to in theory chapter 2.5, only some WPT technologies were considered.
Furthermore, the final recommended technologies (as described in 2.5) were RIPT and OLPT. It was found that it would be beneficial to follow the more popular technology in the market currently, namely the RIPT technology. Despite early suggestions, the final technological chose was made during the system-level design phase, and it became the RIPT.

4.2.2 Driver Behaviour & Convenience

It was important to consider the driver behaviour in order to develop some strategy thinking for the convenience, due to that the driver behaviour inclines what the user could perceive as convenient (both spoken and unspoken convenience).

4.2.2.1 Convenience Strategy

The simple definition of the word 'convenience' was *causing least difficulty* and *near and easy use*. However, the meaning of 'convenience' was found to be more extensive and important to consider for a product development.
It was found that convenience is dependent on the important factors of *perceived time saving* and *perceived cost.* By consider the dimensions of convenience in relation to the problem to solve, it was found that a disruptive technology (which EVs are considered to be) needs to have a high target for all five dimensions, in order to break through on the car market. This is due to that the perception of EVs have yet to be improved. Currently the perception creates doubt over if the products will fulfil the customers (often overestimated) needs. However, the acquisition dimension would rather be managed by political decisions and -incentives. Thought, a car manufacturer should have a big interest in the strategy of the acquisition dimension.
Furthermore, for the execution dimension it was found that a high degree of 'total convenience' should be aimed for in the charging system. Especially considering the developing autonomous drive technology and possibilities to connect the system to a mobile app (mobile phone application). But to tackle the lack of trust in

the technology a parallel functionality of the system should allow an alternative usage, with a higher degree of 'do it yourself' instead of 'total convenience' (on the convenience continuum).

4.2.3 The SAE TIR J2954 standardization

"Wireless power transfer, using SAE TIR J2954 is a game changer for PH/EVs. This first in a series of documents will enable consumers to simply park their vehicles into spaces equipped with TIR J2954 equipment and walk away without doing anything to charge their PH/EV" - Jesse Schneider (Chair of SAE International's WPT committee and Fuel Cell, Electric Vehicle & Standards Development Manager at BMW North America), May 17, 2016 at Warrendale, Pa.

The wireless functionality have been identified and confirmed to enable charging systems with a higher degree of convenience. However, partly what makes the functionality convenient also makes it inefficient - the positioning and alignment. Compared to wired connectors that have a Boolean connection (either they are connected or not), wireless 'connectors' have an optimal position/alignment that decreases with the displacement - angle, horizontal and vertical. In order to not lose convenience in a wireless charging system, the alignment and positioning must be optimised without adding non convenient demands of the user.
As in the writing of this master thesis, the complete extent of the SAE TIR J2954 standardisation is not known. For instance, how will the standardisation regard the different dimensions of convenience and the alignment dependent performance. What is known is the guidelines for power levels and frequency. It was decided that the recommended frequency range of 85 kHz (81.39 - 90 kHz) as well as the maximum power level of 22 kW (despite announced as 'to be specified in future revision of TIR J2954'), is to be suitable for this convenient charging system.

4.2.4 Alignment & Positioning

The results of the data collection indicates that drivers have the most problem with estimate the position of the car in relation to the depth (y-axis) of a parking lot. Furthermore, parking bays improves the drivers performance in parking. Without consciously trying, drivers do as standard park within a deviation of about 25cm in depth and about 15cm in sideways ('depth' is the long side and 'sideways' the short side of a parking bay).
Furthermore, it is suggested that a parking bay improves the angle to a standard deviation of 0.029°absolute angle, from the parking bays centre line (in 'depth' direction).
Regarding the aspects of front or centred mounted wireless charger, data suggest front to be much better, if the driver is to try park optimal. Thou, as the driver possibly could non-consciously park with a sufficiently high accuracy in a parking bay, the importance of the placement of the charger may be discussed. Especially, when considering the likely development of autonomous drive. What in the end led to the result of placing the charger in the centre of the car, was to increase the user convenience. It was found that there are non typical preferred way of parking,

regarding forward or reversed parking. Hence, to support the convenient and non-consciously parking for the driver (until autonomous parking is standard), both forward and reversed parking should be possible in this charging system solution. Moreover, it was regarded that the solution of having a double-set of receiving coils on the car - one in the front and one in the rear, would not bring sufficient net value in relation to aspects such as for instance weigh, complexity, cost, environmental, manufacturability and robust design.

4.2.5 Autonomous Drive

Autonomous drive in vehicles is a rapidly developing technology. The visions and aspects of what it may improve (compared to manual driving and parking) regards the aspects of:

- Increased comfort.
- Efficient & effective parking.
- Safer traffic.
- Higher infrastructural utilisation.
- Economical savings.
- Environmental sustainability.

All these aspects mentioned in chapter 2.8 is considered to be important for a convenience strategy of EVs as well as a sustainable future for transportation. However, one interesting result of the AD research was the aspects of parking hubs, which for instance could be placed underground, be automated, and also made human free, thus enabling a more (highly financially valuable) efficient space utilisation.
Despite only a related technology and not part of the charging system, the AD will lead to an increasingly convenient transportation system, in which the charging is important. Therefore, the AD is understood as a technology in symbiosis with the charging system. Especially since it could enable a improved wireless charging, as a result of a more precised parking and also human free parking hubs.
The AD will improve the utilisation of not just the car but also whole urban environments. It will free urban areas from traffic and make room for urban development areas.
All benefits of AD results in both economical savings and increased environmental (and social) sustainability.

4.2.5.1 Driving range & battery capacity

The driving range is connected to the charging system in the aspect of how often and where to charge.
From the EU-regulations of drivers' hours (for professional drivers) it is understood that a break á 45 minutes is necessary and must be 'completed' after 4.5 hours of driving. This break á 45 minutes may be split into two breaks á minimum 15 respective 30 minutes.
Assume a BEV is driving in 120 km/h on a motorway. In 4.5 hours the car have at most travelled 540km. In a probably not to unlikely or inconvenient scenario, the car

would have taken a 15 minutes break during the 4.5 hours (for instance toilet visit), and will now take a 30 minutes break (for instance eat something). Using existing fast charging (as reference car Tesla) of 90 kW, 15 minutes will ideally result in 22.5 kWh of recharged of battery. According to the reference cars about 0.2 kWh/km could be seen as a possible reference recharge ratio (due to driving, without consider the speeds impact on the consumption). A recharge of 22.5 kWh will therefore correspond to 112.5 km. If subtracting 112.5km from 540km we get 427.5km (and thus the possible range before a 15 minutes break). However, research suggest a lithium-ion battery (as could be regarded as standard for EVs) should not be completely depleted, hence an estimated 20% will in this case be reserved. 427.5km should therefore be regarded as the 80% of the battery capacity, thus dividing it with 0.8 will result in a likely maximal demanded driving range of 534.375 km. By multiply this range with the electricity consumption (discharge) for driving set to be 0.2 kWh/km (compared to Tesla's 0.188 kWh/km), the battery capacity of 106.875 kWh is obtained. This should be considered to be the likely maximal demand of any driver. Even thou this could be regarded as a convenience reference, beyond which the driver should never have to worry, it is suggested by research that few needs this distance and these few also needs it very few times.
This value should also be compared to the reference BEV car Tesla, which battery capacity is 85 kWh, electricity consumption about 0.188 kWh/km, and electric range of 483 km.
However, it has also been identified through research that a car user regards a waste time of about 11.5 minutes to be acceptable. Adding these 11.5 minutes to the occasion (or before) of the 15 minutes break will result in a user approval (likely maximal) driving range of about 426km, resulting in a demanded battery capacity of about 85 kWh.

The result of driving range & battery capacity is that a minimum of 85 kWh battery capacity and fast charger at the currently feasible power level of 90 kW should be the lower convenient limit for a future BEV.

Also to compare this BEV case to the case of a PHEV, the reference PHEV (Volkswagen passat plug-in) has a electric range of 50 km and thus a battery capacity of 9.9 kWh. Furthermore, this capacity and range is not limiting the overall range of the vehicle, as it also has an combustion engine. Hence, the driving range and battery capacity will not be regarded in detail.

4.2.6 Health & Safety

The health and safety aspects of a charging system have been found to be most crucial in the aspects of under-dimensioning of cables and power component (which may result in fires), and also the concerns related to field of WPT system.
Health and safety aspects have been identified to be necessary to consider. Regarding the convenience, the matter of health and safety should be a total convenience - the user should not need to do anything for the system to always be safe (in any weather and any place).
Therefore, the charging should automatically adopt to the infrastructure and sur-

rounding where it is charging, and make sure no one or anything is hurt or damaged (as a result of the charging or the charging system). Should the adoption affect the charging such as that it affects the convenience of use (-dimension) for the user, the user should be notified. To limit this disturbance of convenience, a support service could be created (depending on charging place), which the user easily may chose to use at the time of the notification.
Concerning the aspects of a WPT charging system, the levels of SAR, magnetic fields and electric field should not exceed the recommendations made by IEEE and UCNIRP (as described in chapter 2.7). Should the guidelines recommend different values for certain 'situations', the one with the lowest should be regarded as the current limit. Furthermore, the system should automatically identify if foreign object comes to near, and if the power is not transfer correctly or with sufficient efficiency (as it could demand unnecessary strong fields).

4.2.7 Power Availability & EV capability

Through research and collected data (survey, interviews, field trip, and seminar) it became clear that in order to create a convenient charging system, which should be available and easy to use, the aspects of power availability would have to be considered.
Data suggested that customers of a future charging system solution would need more power than what there current household supports or is prepared for today. Furthermore, current charging system solutions take poor considerations to where and how people are living, or rather often presumes residential living. Approximately half of the Swedish population lives in apartments and need to consider many factors before buying a electric car. In countries such as China, the share of whom lives in apartments are even greater. Future charging system for EV need to create a good solution for people living in apartments, as well as put overall low demands of what the buyer/user needs to consider before buying and using an EV.

In chapter 2.9 it is presented that, due to variance in power consumptions over hour and days in a typical Swedish residence, the needed power capability leads to recommendations of a five times greater energy capacity than what is needed. If electric energy could be stored and used when demanded, this factor between power capacity and energy capacity could be decreased, thus also create a more stable electric grid.
Furthermore, research and collected data suggests that for future charging systems residential owners could need to further increase their maximum power capacity, if they were to start using electric cars. This as a result of faster charging rates (higher power levels for charging), and likely higher expectations by the user. To increase a households maximum power capacity (if possible, which it not always is) leads to greater yearly costs, and some preparing planning by the user to get a higher power capacity from the electricity providing company, needed before acquiring a electric car. This is even more important when regarding the increasing share of households with multiple cars. Should both cars be EV, or if a guest with an EV arrives, the power capacity could be a major issue.

With current car-fleet share of EVs countries such as Sweden should manage the charging, even in apartment buildings and shared garages. But as the share of EVs grows, the problem of sufficient power delivery will be problematic to solve. Due to a limitation in what the municipal can offer to connect.

In order to target the probably future shortcoming in power capacity, the use of energy storage system could be beneficial. By storing electric energy from low consuming hours, higher power consumption than what the grid allows can be available for the charging of EVs. Furthermore, energy storage systems may be beneficial for the grid stability as well as be compatible with small and large scale electricity production from fluctuating energy sources such as solar and wind. The renewable energy sources (such as solar and wind) could pose a threat to the stability of the electricity grid, should there share (of the total electricity production) be to large. Hence, not only could the electricity grids need energy storage systems in order to tackle the stability demands of an increasing number of EVs, but also to enable a future stable electric grid with higher power capability and that also is based on renewable energy.

4.3 Project Mission Statement

Among the results of the initial planning phase was a project mission statement. The project mission statements is presented in table 4.1.

Table 4.1: Project mission statement table.

Project mission statement: Future charging of electric cars	
Product Description	• Car battery charging system for BEVs & PHEVs, with wireless charging functionality.
Benefit Proposal	• The car will be operational whenever the user desires. • The charging system should have positive impact on how the customer perceive the benefits with BEVs or PHEVs, compared to standard fuel based cars. • Fully functional in an standard home and living environment. • The solution supports an overall higher environmental sustainability relative the market. • Flexible usage with high performance.

Key Business Goals	• Environmentally friendly. • High charging performance (high energy transfer rate). • Easier to understand and use optimally, compared to present wired charging solutions on the market. • No usage risks regarding physical injuries, of both humans and animals. • Serve as platform technology for future passenger cars of Volvo Cars & Geely Automobile.
Primary Market	• Private customers in city-regions interested in passenger cars for daily usage and max. driving distances of 50 km at a time. • Customers with private/designated parking lots. • Car fleet market.
Secondary Market	• Customers with shared parking lot. • Carpools and rental cars.
Assumptions & Constraints	• The availability of high electricity power outlets. • Human- and animal safety (due to high power transfer). • Wireless power transfer (WPT) technology. • Different capacities of electricity grids over the world. • Demands of battery capacity. • Market development for BEVs & PHEVs. • Price development of special necessary technology (e.g. batteries).
Stakeholders	• Purchasers & users. • CEVT (technology development company) • Car manufactures (Volvo Cars and Geeley Automobile). • Car service companies. • Infrastructure suppliers. • Governments of cities & regions. • Neighbours & the society. • Commercial markets (e.g. dine while charging). • Subcontracted manufactures of components.

Technical Trajectory	• Wireless power transfer (WPT) technologies will probably develop fast and much. • Battery technology (capacity, performance and cost) is in great development. • The electricity grids development and ability to supply satisfying power distribution for a growing BEV & PHEV market. • Future system and properties of electricity grids are not certain. But there will probably be technological changes that will affect the future electric car market. • Self-driving car technology develops rapidly and will probably affect the way the car is used.

4.4 Survey & interviews to needs & metrics

The needs for an convenient charging system were identified with an survey, with 65 answers, and three semi-structured interviews with plug-in electric car owners, á 30 minutes each.
The survey was design to answer the following questions:

- What user segments are there?
- What are the current car-user behaviours?
- How do different situations affect the refuel/recharge behaviour?
- What are the user perception of driving breaks - do they see any value or benefits?
- What do users in general appreciate or value with the car usage?
- What charging possibility and capability do users have?

The survey with its' layout and questions used can be seen in appendix B. The survey was first created in Swedish, then each question was translated into English, in order to let the respondent (during the answering of the survey) chose language. The interviews were performed in Swedish, due too the aspect of more quality in the questions and answers in a native language, as well as the minimisation of risk for miss-understandings. The interview was designed to answer the same questions as the survey, but with more open-ended questions (in order to trigger discussion), and with the view of only plug-in electric car owners. Some additional areas of questions were added. These regarded inbuilt car assistant tools, and autonomous driving & parking of cars. The interview questions (in Swedish) may be seen in appendix C.
The data from the survey and the interviews were used (together with the researched data) to create the user need list and metrics list. Some of the identified needs and some of the metrics may be seen in table 4.2 respective in table 4.3. The complete needs list and metric list may be seen in appendix D respective appendix E.

Table 4.2: Some of the needs identified through survey & interviews.

Some of the needs		
No.	**Interpreted Need**	**W/R/S**
1	The charging system solution will mainly make use of time and occasions when the user does not have to wait for the charging.	R
2	The solution has a neutral or positive effect on the future aspect of car sharing and autonomous vehicles.	R
9	The system solution is environmental friendly.	R
10	The system solution allows convenient charging management, monitoring and notifications.	R
13	The system solution is neutral or reduces the time to park in designated parking places (both forward, reversed & parallel)	W
14	The system solution have a solution that enables multiple charging parking places at workplaces and their parking fields.	W
16	The recharging of the car adds minimal waste of time to travels.	W
17	There is always a charger available where the car is most often charged.	S
26	The charging solution may store energy in order to increase the daily capacity and possibly the performance of the charging, with minimum efficiency loss	R
27	The system solution makes use of low-usage time on the electricity grid.	W
30	The solution will not be an obstacle on the parking lot, no matter what the ground is made of.	W
31	The charging solution charges itself and only notify the user when human assistance is assumed to be required.	W

End of table 4.2

Table 4.3: Some of the metrics created from the identified needs in table D.1.

Some identified metrics				
Metric No.	**Need No.**	**Metric**	**Imp.**	**Unit**
1	1, 27	Times for standard charging.	5	Time
2	2	Functional or integrational with future autonomous vehicles.	2	Y/N
4	4	Amount of harmful exposure levels on the human body (due to charging).	5	SAR & mT
8	9	Overall system usage impact on the environment (energy and efficiency)	5	CO2 & %
11	12	Divergence from 'optimal' parking on parking fields (direction and alignment).	5	cm
13	14	Amount of electric cars that can be managed in the charging system on a workplace parking field.	4	Units
16	17	Availability (geographically) for "emergency" charging	3	Sub.
19	22,28	Connectible with different standard power sockets/outlets specifications.	4	List
21	24	Functional for different normal seasonal weather situations.	4	List
22	25	Possible amount of deliverable energy transfer and efficiency.	5	kWh & %
26	30	Convenient removal of possible obstacle component of the system on the parking lots.	2	Sub.
27	31	Semi-automatic operated it-system managing charging.	3	Y/N
End of table 4.3				

4.5 Concept selection

The results from the concept selection phase are, in chronological process order:
- Target product criteria.
- Initial system boundary.
- First concept generation & Affinity Diagram.
- Developed system boundary.
- First selection matrix.
- Morphological selection matrix.
- Concept-scoring matrices.
- First Concept selection.
- Concept review.
- Final system boundary.

4.5.1 Target product criteria

Due to expanding solution system a proper target specification list were not created. Instead the metrics list (see appendix E and the table E.1) was used as a 'Target product criteria'-list for the concept development phase.

4.5.2 Initial system boundary

The initial system boundary, which is illustrated in figure 4.2, was created through analyzing the findings of phase 0 and the target product criteria.
In figure 4.2 the dark blue boxes represents components, where's the non-filled box represents a 'function' needed for the system but that is not a part of the solution, in this case the driver. The light-blue box represents a 'function' that is component parts of the system but only partly a part of the solution.
The dotted lines represents 'input' signals, the non-dotted but small lines represents physical interaction, and the large arrow represents energy input.

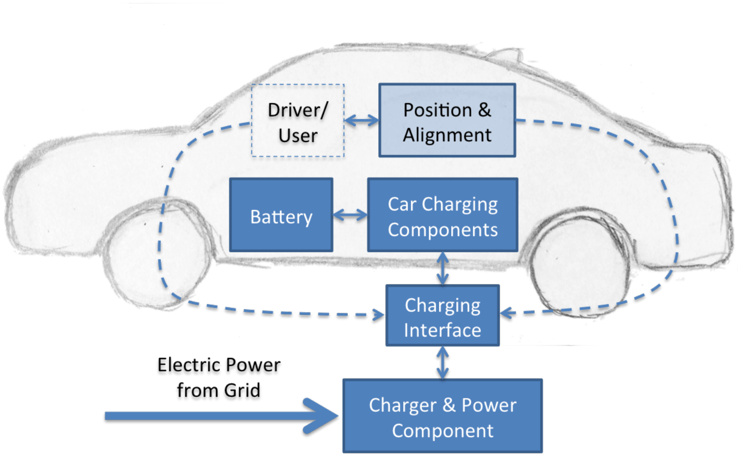


Figure 4.2: Illustration of the initial system boundary with components and interactions.

4.5.3 First concept generation & Affinity Diagram

The concepts that already had been generated were added to the concepts from the brainstorming at the first concept generation. The concepts that were to be investigated may be seen in appendix D.
Through a (digital) affinity diagram the concepts were, with respect to the initial system boundary (figure 4.2) grouped into three groups - 'Charger', 'Alignment', and 'Other'. The group of 'other' was made as the 'other'-concepts were to few to be divide into more groups.

4.5.4 First selection matrix

The first selection matrices (see figure 4.3) resulted in not only selecting concepts, but also understand the system better. Miniatures of the matrices are portrayed in figure 4.3, and the full size matrices may be found in appendix G. The sub-concepts in the matrices can be found in appendix D.

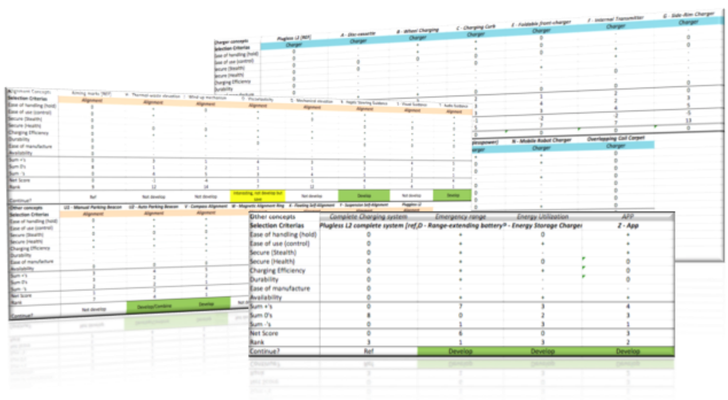


Figure 4.3: Illustration of the three selection matrices.

4.5.5 Developed System Boundary

The developed system boundary (see figure 4.4), defined after analysing the results of the selection matrices, were more extensive and complex than the initial system boundary.

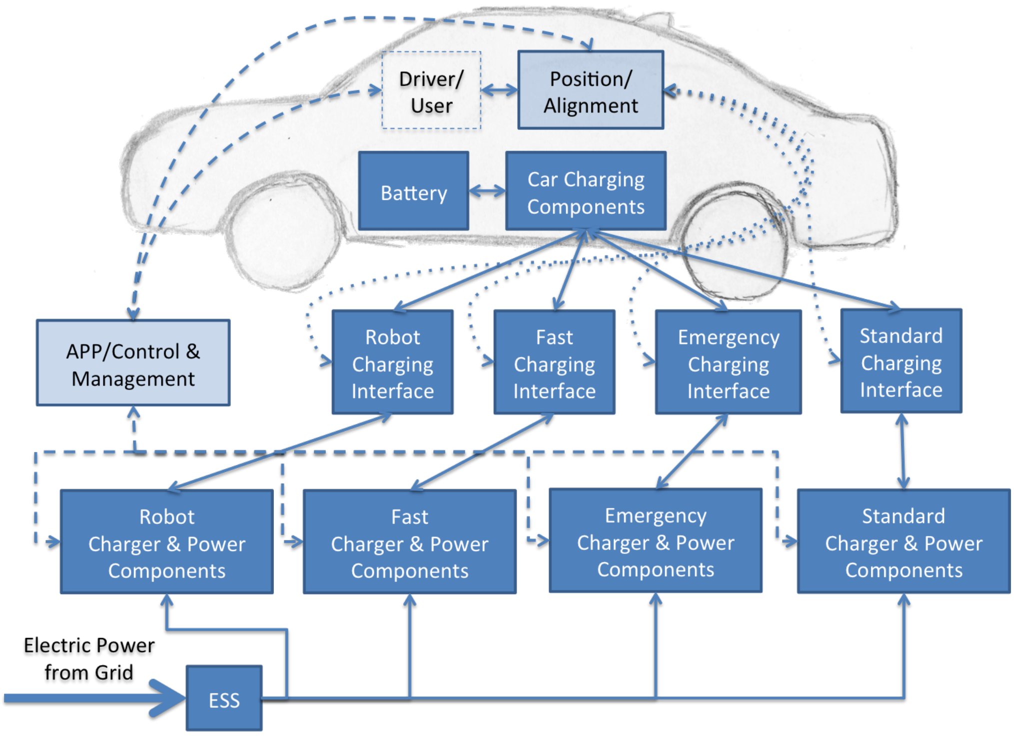


Figure 4.4: Illustration of the developed system boundary with components and interactions.

4.5.6 Morphological Selection Matrix

The screened and developed concepts were put in a morphological selection matrix, with the setup as shown in figure 4.5. All of the morphologically created full-system concepts may be seen in appendix H.

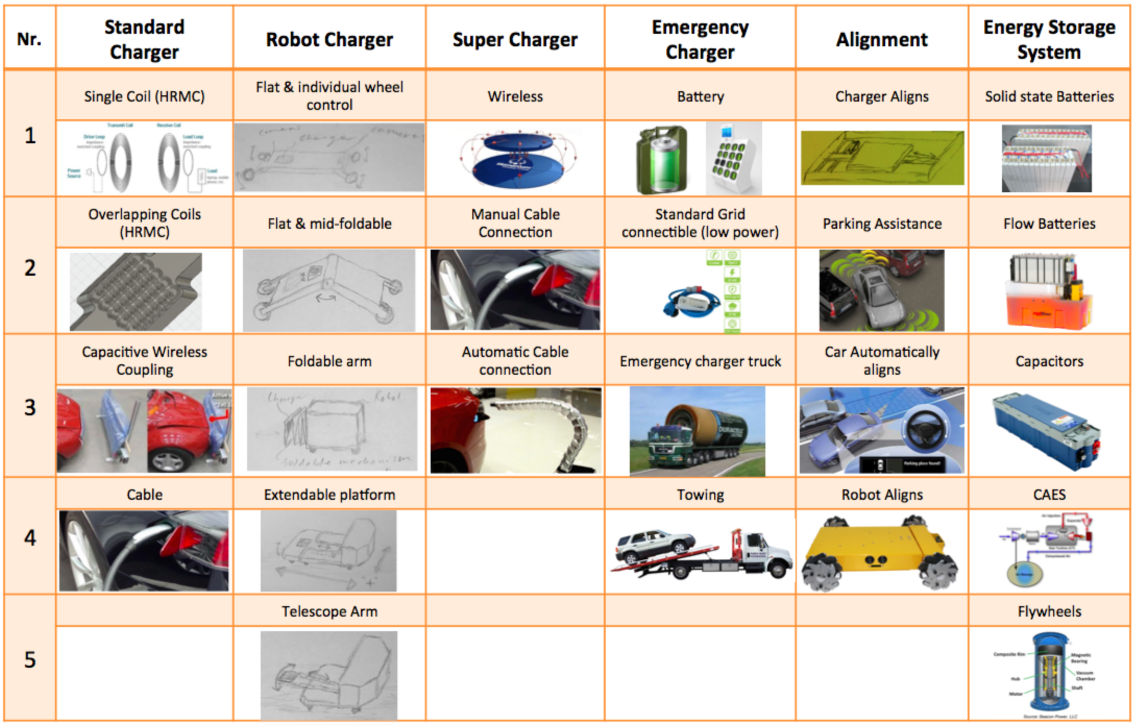


Figure 4.5: The setup of sub-concepts in the morphological matrix.

The sub-concepts in the morphological matrix (4.5) can briefly be described as follows:

1. **Standard Charger**
   1.1. *Single coil (HRMC)* - One pair of coils with RIPT, one coil in car and one outside.
   1.2. *Overlapping coils (HRMC)* - The transmitter have several small coils overlapping each other, and using advanced resonance circuit to enable high transfer performance as well as allow higher misalignment to the cars receiver coil(s).
   1.3. *Capacitive wireless coupling* - Short distance WPT between two plates. Demands a free line-of-sight.
   1.4. *Cable* - Non wireless solution with a plug and matching connector in the car.
2. **Robot Charger** All sub-concepts partly assumes the interface to the car is somewhere under the car, but they may also (to some extend) be used differently.
   2.1. *Flat & individual wheel control* - flat enough to drive in and fit under parked cars. Uses individually steered wheels with adjustable height, to

align and compensate for uneven ground.

2.2. *Flat & mid-foldable* - Very flat construction that fits under parked cars. The ground clearance is enabled by the mid-folding. The mid-folding also makes the robot easier to spot, when the robot moves between cars (and its station).

2.3. *Foldable arm* - An arm is folded out from the robot and possible in under the car.

2.4. *Extendable platform* - The robot is partially flat, and the flat end consists of an extendable platform, which enables a further reach in under the car.

2.5. *Telescope arm* - The transmitting charging pad (of the robot) is placed on an arm construction. The arm is extendable, and may be swinged in different directions, enabling alignment to receiving charging pad (on car).

3. **Super Charger** The power level is about the level of the fast/super charging of the Tesla reference car (chapter 2.13).

   3.1. *Wireless* - A WPT solution, could perhaps be integrate with the standard charger, depending on standard charger concept.

   3.2. *Manual cable connection* - As used in the fast/super charging system of the Tesla reference car (chapter 2.13).

   3.3. *Automatic cable connection* - Some kind of mechatronical solution for connecting a plug to a cars connector.

4. **Emergency Charger**

   4.1. *Battery* - A range extending battery pack module possible to attach into a socket in the EV. The battery pack modules is available at stations along the way. The batteries are not possible to own, only rentable (for a specific period of time). The batteries do not need to be returned to the same place as they were picked up.

   4.2. *Standard grid connectible (low power)* - An emergency charger for low power, but which should work anywhere were there is a electric infrastructure or electricity power generator with standard conductibility.

   4.3. *Emergency charger truck* - If an EV runs out of electricity, an mobile charing station (in form of a vehicle) may be sent out and charge the EV where it is.

   4.4. *Towing* - Uses current infrastructure and service for towing the EV to the nearest or best location (home, destination or charging station).

5. **Alignment**

   5.1. *Charger aligns* - The charger pad/connector automatically aligns to the car, after the car have been parked.

   5.2. *Parking assistance* - The user needs to park the car with precision, but have the informative help from a sophisticated parking assistance system (visually, haptic, and/or audio).

   5.3. *Car automatically aligns* - When the car is to park the driver gives over the control to an autonomous parking system, which parks the car automatically.

   5.4. *Robot aligns* - After the car has been parked, an robot charger (possibly the same as the robot charger system) automatically drives to the car and aligns itself to enable a high performance charging.

6. **Energy storage system (ESS)** See chapter 2.12 for different ES technologies.
   - 6.1. *Solid state batteries* - Such as Li-ion (lithium ion).
   - 6.2. *Flow batteries* - Such as redox-flow batteries.
   - 6.3. *Capacitors* - Such as SMES.
   - 6.4. *CAES*
   - 6.5. *Flywheels*

4.5.7 First concept scoring matrix

The seven generated full-system concepts were compared and scored against the full-system reference - 'Plugless L2' (see appendix F). The four best concepts of the first iterations concept-scoring matrix (see table J.1) were the following concepts (after rank) with their scores (the reference had 2.72p) and grading:

1. Robotic Cable - 3.63p, Develop.
2. Go the extra mile - 3.57p, Develop.
3. Capacitive Wireless - 3.42p, Don't develop but Analyze.
4. Simple-Fast-Tow - 3.37p, Don't develop but Analyze.

The 'Robotic cable' and 'Go the extra mile' was developed through combining and iteration into the full-system concept 'last iterated', which may be seen in figure 4.6 (and also in appendix F).

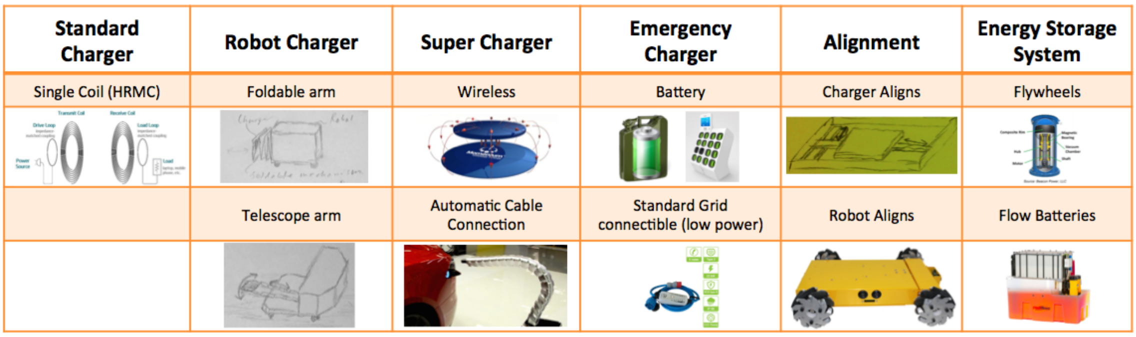


Figure 4.6: The developed 'last iterated' full-system concept.

4.5.8 Initialisation of the industrial design

The initialisation of the industrial design started with creating a design drawing for the 'last iterated' full-system concept, as described in figure 4.6. The initial design drawing may be seen in the figure 4.7 and 4.8.

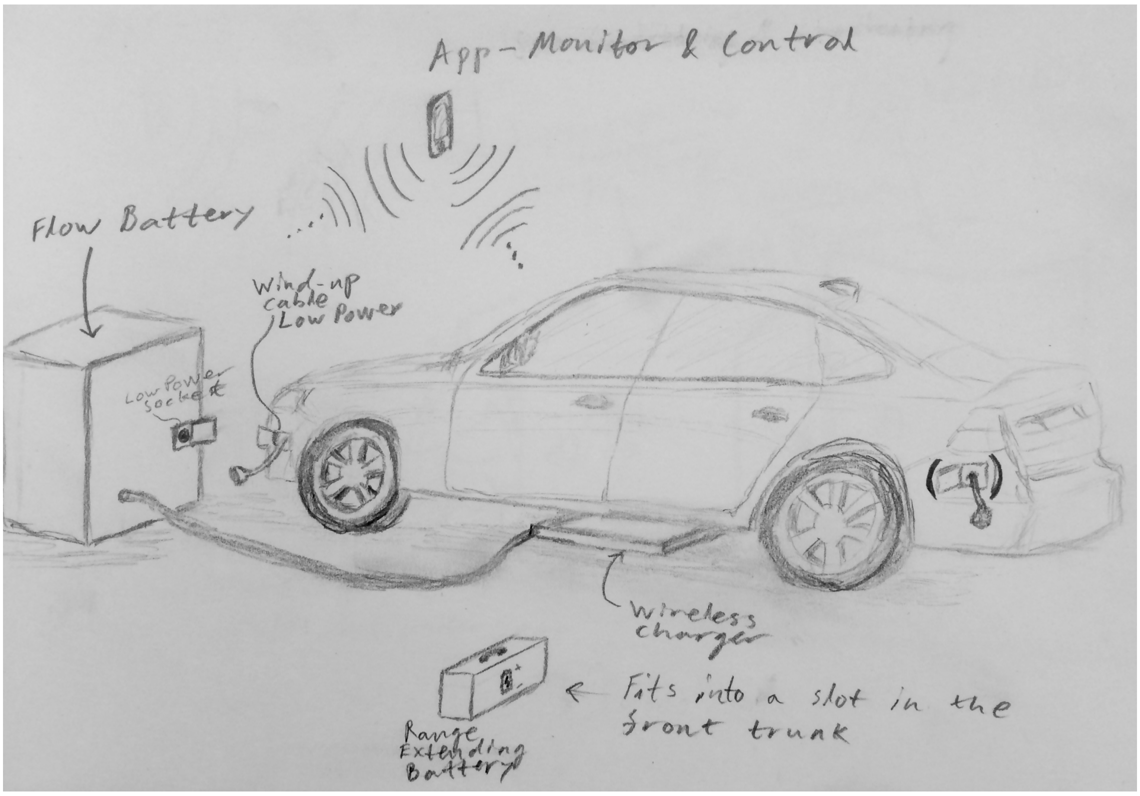


Figure 4.7: The "Home" part of the first concept selection.

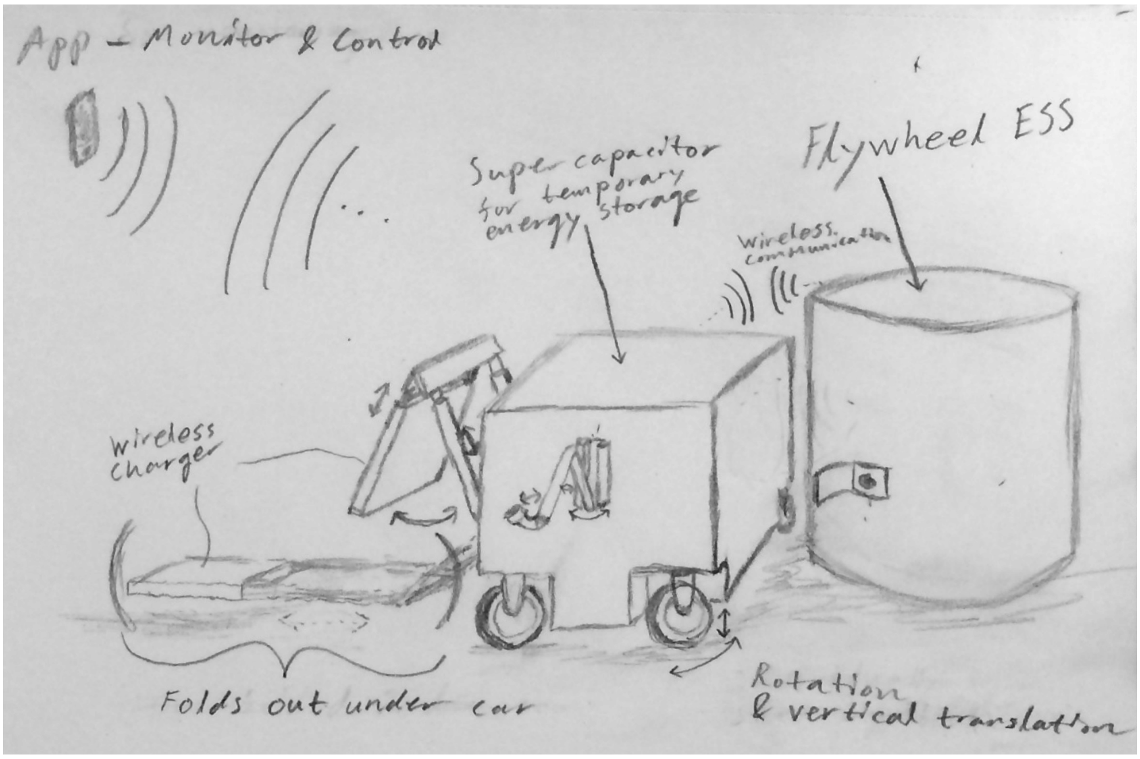


Figure 4.8: The "Destination" part of the first concept selection.

4.5.9 Concept review

The findings from the concept review (as described in chapter 3.2.8) were concluded into a separate document, which may be seen in appendix I.
The concept review resulted in the creation of the 'reviewed' concept, which may be seen in figure 4.9 (and also in appendix F).

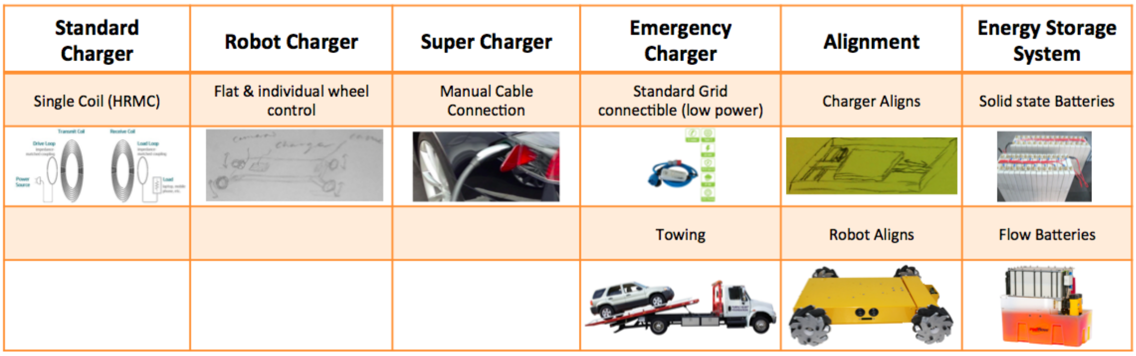


Figure 4.9: The 'reviewed' full-system concept.

4.5.9.1 Reviewed and final scored concepts

The scoring of the 'last iterated' concept and the 'reviewed' concept resulted in the following ranking and scores:

1. 'Reviewed' - 4.05p.
2. 'Last iterated' - 3.64p.

The 'last iterated' had higher score than the original four full-system concepts of the first concept scoring matrix (in chapter 4.5.7), but the 'reviewed' concept had even higher. Therefore, the 'reviewed' full-system concept became the final first concept selection.

4.5.10 Final system boundary

From the findings of the concept review and the selected final first concept selection (the 'reviewed' concept) a 'developed system boundary' was created (see figure 4.10, which also were to be the initial system boundary for the system-level design phase.

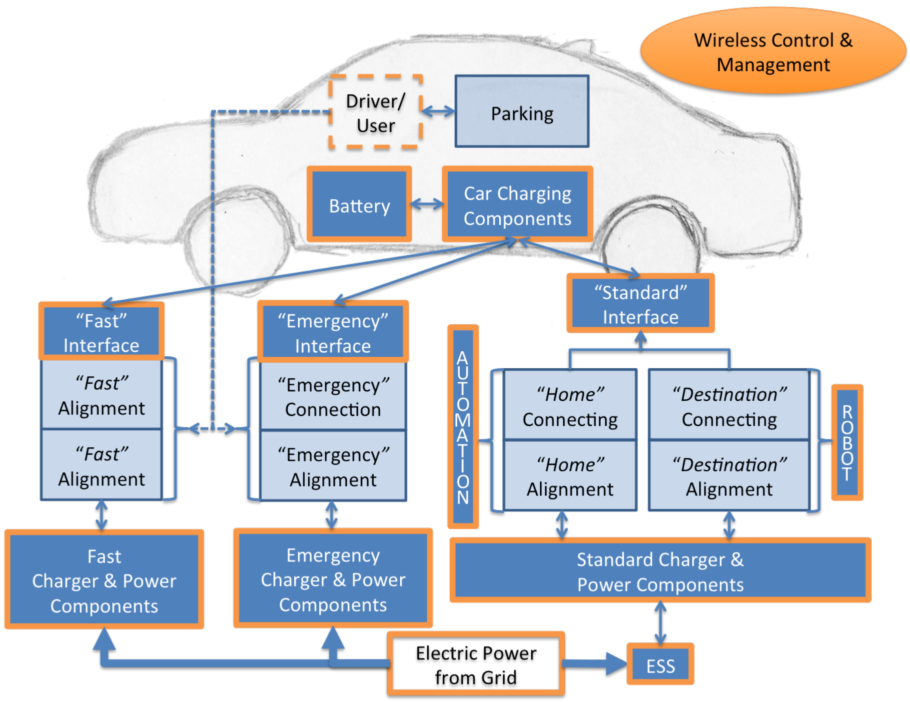


Figure 4.10: Illustration of the final system boundary with components and interactions.

4.6 Final product specifications

The final product specifications were based on the 'Target product criteria'-list, later collected data (such as appendix I), the first concept selection, and the final system boundary.

1. Standard charging possible directly when car arrives home respective destination, and as fast charging as possible, without affecting or being affected by other electrical consumption demands.
2. The charging system is functional or integrational with future autonomous vehicles.
3. The charging system includes three different power levels of charging:
   - Low power - up to 3.6kW, for the availability aspect.
   - Medium power - up to 22kW, for the standard charging.
   - High power - from 90kW, for the fast charging.
4. The standard charger charges 10kWh under one hour, to meet the average occasionally charging demands.

5. The WPT automatically turns of if an foreign object comes withing a proximity that could be against the guidelines stated by IEEE and ICNIRP.
6. The charging system should be compatible and controlled by an app-based control and monitoring system.
7. The standard charging station should be perceived with more value per cost (and still affordable) than the complete installation cost of charging poles, which is about 60,000 SEK.
8. The system should enable an lower environmental impact than the system of traditional combustion cars and their refueling.
9. The driver should not have to park with precision for the standard charging, and is only informed and asked to re-park if the standard charger in the car is displaced more than 30cm from the parking charger (at the home station).
10. The system solution should enable a BEV with at least 85kWh battery capacity to travel at least 400km (with the use of fast charging).
11. Allowed 'waste time' due to a charging occasion is allowed to be up to 11.5 minutes.
12. The system solution has a on-board charger, which is able to charge from the standard (grounded) power outlets of the current country.
13. Components which the user interacts with should be ergonomically designed, in the aspects of: form, weight, enlightenment, safety, usability, and left- as well as right handed handling.
14. The system functions in all normal seasonal weather, and if it does not work it will notify the user.
15. The energy storage system stores at least 10kWh per 'designated' EV.
16. The system solution provides a solution for sufficient charging of multi-BEV households, as well as shared parking areas.
17. The system solution enables easy available data of charged electricity, in the case of charging via someone else charger or power outlet.

4.7 Product architecture

In order to create a product (system) architecture, elements were defined and then clustered into chunks of the different identified components. The initial clustering into chunks of the product architecture is illustrated in figure 4.11.

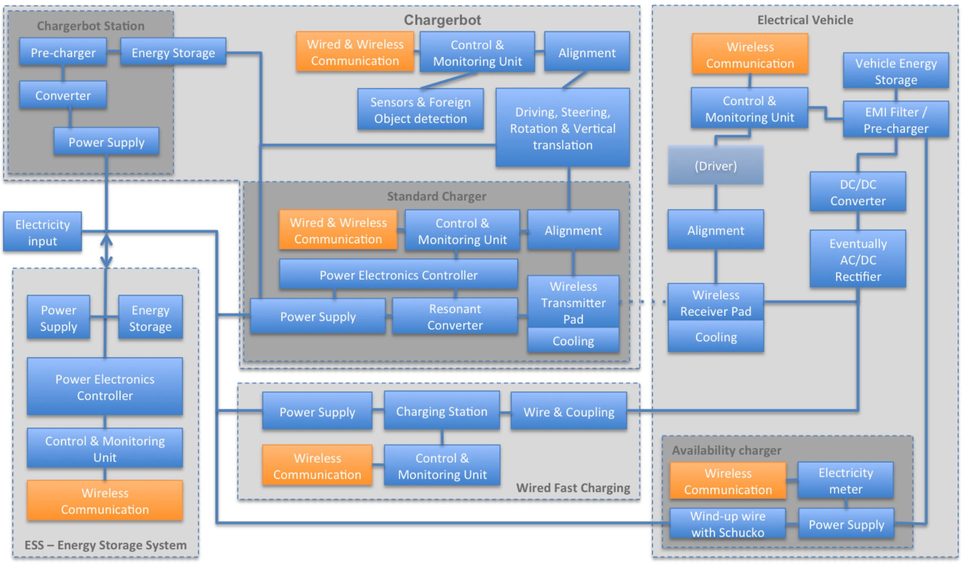


Figure 4.11: The initial cluster design of the product architecture.

By reviewing the initial cluster design, some clusters and chunks could be redefined and combined (in order to create simplicity and modularity). Furthermore, the detail level and complexity of the initial cluster were found to make the product architecture hard to understand understand. Therefor, the product architecture was refined and simplified. The final product architecture may be seen in figure 4.12.

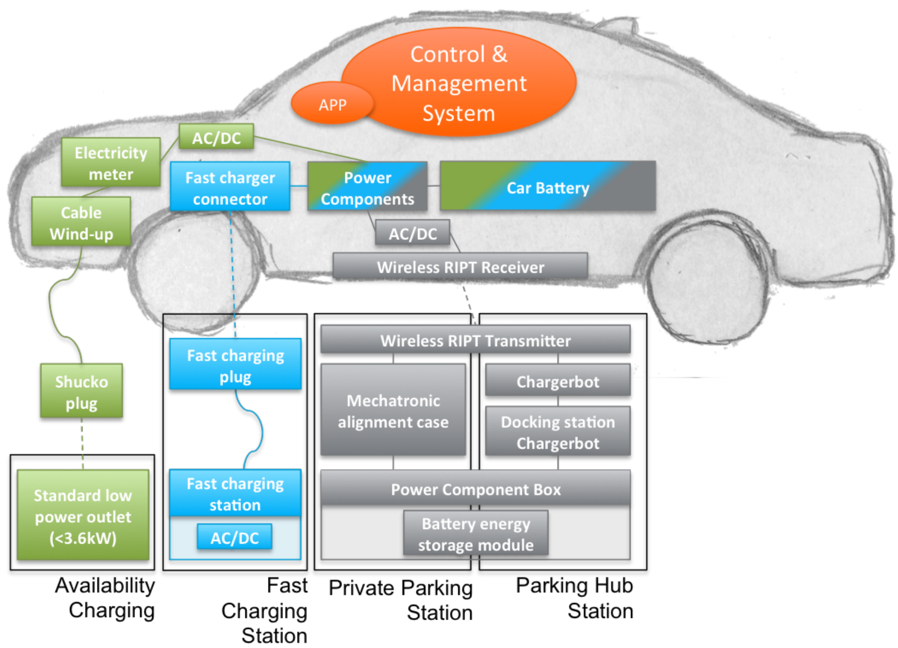


Figure 4.12: Final product architecture. 'Green' represents 'Availability charger', 'Blue' represents 'Fast charger', 'Grey' represents 'Standard Charger', and 'Orange' represents the 'Control & Management system' of the architecture.

The final product architecture has four different types of charging. However, Parking Hub Station and Private Parking Station have been understood to benefit from a shared modular platform (not just shared charging type). Moreover, the Mechatronic alignment case and Chargerbot is considered to hold the difference between the private parking station and parking hub station. A modularity between these two elements were found to enable a possible modular solution.
Furthermore, all different types of charging strives to have as little elements and components as possible in the car, except the availability charger. This is due to that it should be possible to use everywhere without external components.
Moreover, all components in the car is placed in the front and bottom of the vehicle, to enable a good balanced car and the convenient charging coupling interfaces.
The control & management system is not connected with the other parts in the product architecture, as its functionality and part of the system were delimited from this project. However, a system such as that (with an possible mobile app), has been found to be important if not crucial for a convenient charging system of electric cars.

4.8 Industrial Design & Prototype development

The final industrial design was based on the initial industrial design (chapter 4.5.8), but new industrial design of the changes that had to be made (due to change in concept and system boundary) where not made, except for the "private parking station" and the "chargerbot", for which industrial designs were made as simple CAD-models. The CAD-models were part of the final delivery.

4.9 Final delivery & solution description

The final solution have three different charging (power) levels, but four different ways of charging. As was initially described in chapter 4.7 about the final product architecture, the system's four different ways of charging are:

- Availability charging - up to 3.6kW AC through standard power outlet (Shucko).
- Fast charging station - from 90kW DC charging station.
- Private parking station - up to 22kW wireless AC.
- Parking hub station - up to 22kW wireless AC.

4.9.1 The availability charger solution

The availability charger is supposed to be an 'emergency' charger, which purpose is to create greater trust for the usage of EVs. It enables charging wherever the car travels, as long as there is a standard-infrastructure of electricity. As the power level is relative low, it is possible to have all components on-board (as they becomes relative small), including the cable. To store and make the cable easy usable it is mounted on a wind-up. Hence removing tangled cables and minimising the risk of getting dirt from cable. The availability charging wind-up cable is placed in the

front of the car, as the front is a short-side and thus probably requires the shortest cable for typical occasions. The connector for the availability charger is the electrical standard outlet called Shucko. The Shucko support power levels up to 3.6 kW. But some electricity system may not be able to deliver the maximum power level for a longer time, or at all, due to insufficient dimensions on wires, fuses, or connectors. Therefore, a automated regulation system would have to be created for adjusting the current drawn to the car, in order to prevent damage of the electrical infrastructure with for instance risk of fire. Moreover, due to conversion losses (from AC to DC) the charging power into the battery will be even less than what is transferred to the EV.
Furthermore, customers are used to having the main trunk in the back of the car. By placing the wind-up cable at that short-side would result in that power components should be placed there as well (for efficiency and safety), and potentially create a user perception of stealing valuable trunk space. The power level of the availability charger should be sufficient for normal usage (if the car is allowed to charge during night), but for along the road charging and standard charging its total convenience is insufficient compared to the fast charging respective standard charging (private parking respective parking hub).

4.9.2 The fast charger solution

The fast charger targets the need of charging along the road when travelling, when the car will not be able to reach the final destination (due to battery capacity) and the driver do not want to experience waste time at a stop. The fast charger have a high power level, resulting in relative (the availability charger) large power components. However, by making it into a DC charger much of the large power components may be placed outside of the car, in an external charging station.
Furthermore, the fast chargers power level and even more the density in geographical infrastructure of its stations, are the major factors for how much battery capacity the car needs. Therefor, the charging should at least support a 90 kW power level if an EV (primary BEV) have at maximum around 85 kWh battery capacity and the distance between fast charging stations is less than about 300km (with the critical limit of only 20% battery capacity left at about 340km). Should the infrastructure be scarcer, the power level of the fast charger (as well as a BEV's battery capacity) should be higher, and vice verse if the infrastructure should be denser.
With consideration to how users perceive a car, the charging connector on the car should (if no better innovative solution is found) be placed in a similar manner as fuel-caps on traditional combustion cars. This placement combined with the usage of fast charging and standard charging, makes the user perceive the fast charging as the 'only' real re-fuelling of the car (it should be the only time the user needs to perform the re-fuelling process).
The large power level of fast charging results in a relative heavy connection cable. The cable should have a supporting suspension (possibly as a exoskeleton, or through feathers, wires and hanging rack), making it easier to use the cable. Furthermore, the connector and handle should have ergonomic design and functions, at least suitable for the 95th percentile. The design and functions regards for instance good

shape and inbuilt light when its dark outside, and especially enabling a good usage for both right handed and left handed people. The right handed and left handed aspect includes which side the user needs to stand on the side of a possible cap over the outlet. As the swinging side of a cap could be bothersome for either left handed or right handed persons. Furthermore, if possible a collaboration with other companies (preferably that already have some kind of fast charging DC) should be entered. Enabling the same charging stations, but possibly different handles and maximal supporting power level.
Should it mean any major cost savings, it could be possible to remove the fast charging function for PHEVs, and encourage building of infrastructure for standard charging at for instance shopping centres or other relative urban locations. This due to a WPT with power level of 22kW would be as a fast charger for PHEVs.

4.9.3 Standard charger solution

The standard charger is supposed to be as convenient as possible. Some efficiency losses and negative environmental impact is allowed in order to enable a growth of EVs through perception and popularity. The growth of EVs is considered to weight up possible negative environmental impact, due to a less efficient charging solution. The standard charging system consists of two different charging solutions that is used for the different situations of home charging - private parking station, and destination charging - parking hub station.

4.9.3.1 Private parking station solution

The concept idea of the private parking station is visually represented in figure 4.13. The private parking station is aimed for reserved parking bays, and consists of a charging pad on the ground that automatically aligns to how the car is parked, provided that the transmitter and receivers for the WPT is at most horizontally displaced by 30cm. The private parking station is placed on the ground and is flat enough to easily be driven over and fit under a parked car. The outer dimensions of the private parking station is about 180x90x8 cm (length, width and height). The case of the station naturally withstands the pressure of being driven over, and most of its necessary components is placed within the case.

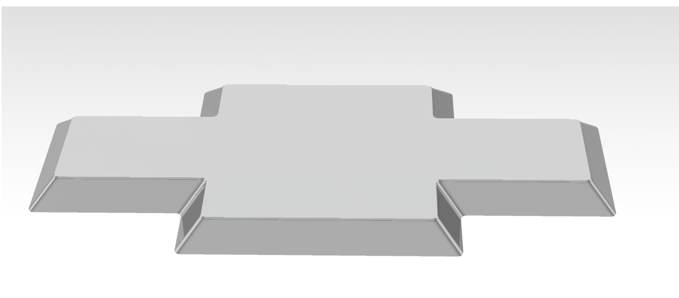


Figure 4.13: The private parking station.

The case does not move, instead the centrally placed transmitter coil is mounted on a two axis motorised linear slide/stages, enable it to align to the car and enable optimal energy transfer efficiency. The principle is illustrated by an early concept drawing in figure 4.14.
The lid and internal space of the case, may be seen in figure 4.15 and 4.16.

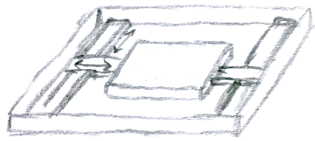


Figure 4.14: Concept of the motorised linear slides for the charging pad, inside the 'case'.

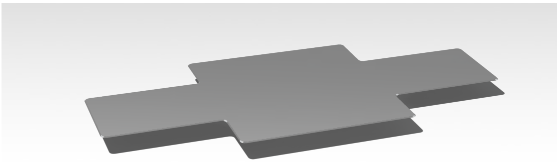


Figure 4.15: A removable lid to the internal compartment of the private parking station.

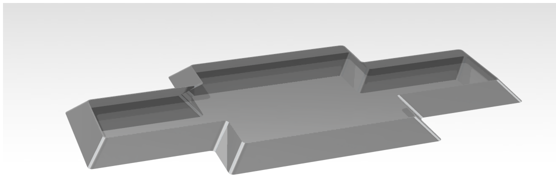


Figure 4.16: The inside of the private parking station, without any components or supporting structure.

Among the components in the case of the charger is a (at least) 10 kWh ES, which may be either a lithium-ion battery or redox-flow battery. The redox-flow battery is suggested due to enable a faster charging system for the parking hub stations' chargerbot.

4.9.3.2 Parking hub station solution

In order to limit system cost as well as improving the functionality, a modular solution for the parking hub station. The main module of this modularisation is the private parking station. By adding chargerbot modules, which may be seen in figure 4.17, and a home charging station the private parking station is turned into a robot charger.

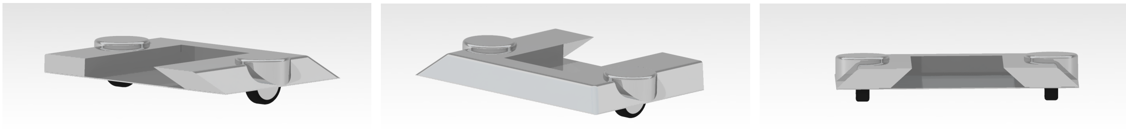


Figure 4.17: The chargerbot module.

The chargerbot module contains the additional components and system needed for the robot to be able to drive and perform its duty. Moreover, the relation between the chargerbot modules and the the private parking station module may be seen in figure 4.18, and the modules combined (creating the complete chargerbot) may be seen in figure 4.19.

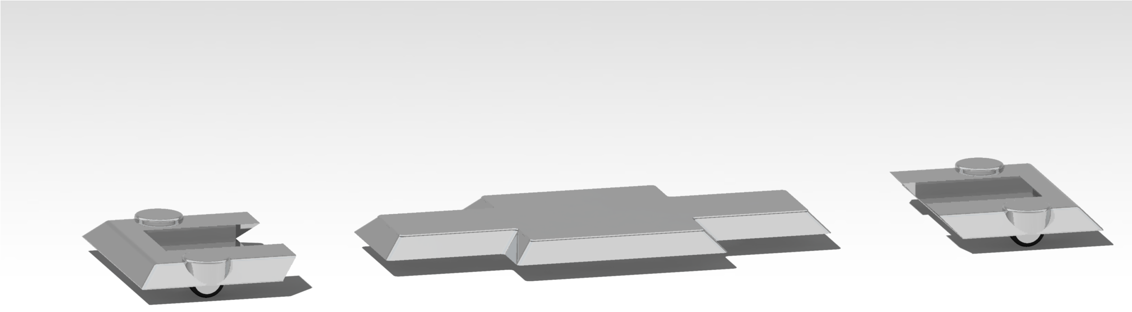


Figure 4.18: The relation between chargerbot modules and the private parking station module.

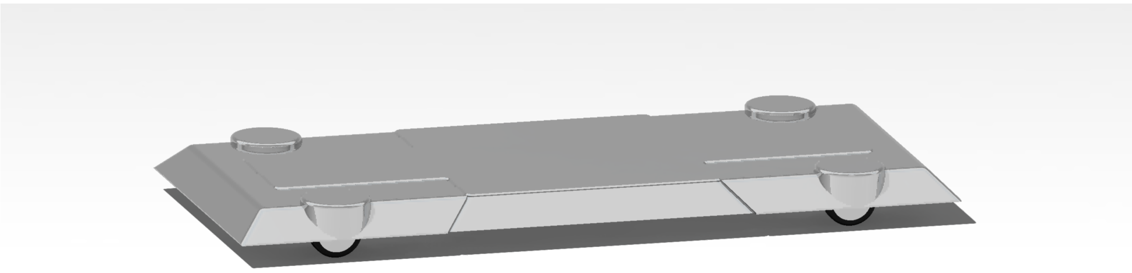


Figure 4.19: The complete/assembled chargerbot (consisting of the chargerbot modules and the private parking station module).

The wheels of the chargerbot modules may rotate and be vertically adjust - in order to drive to EVs and aligned correctly.
Furthermore, the chargerbot may be installed on for instance a parking field or in a (multiple parking) garage. The function of the chargerbot is that it will drive to the EVs that needs to be charged and charge them through the standard charging interface. The fundamental principle of the chargerbot is much like robotic lawn mowers, it covers an area. All cars within the chargerbots operational area is charged from the inbuilt ES of the chargerbot. In turn, the chargerbot charges via its home station, which also has an internal ES. The usage of ES in the home station enables a lower burden on the electricity grid and also a possible faster charging of the chargerbot (which increases the system utilisation). Should the ES of the home station and chargerbot be based on redox-flow battery, the energy liquid may be charged in the home station and then be exchanged with the chargerbot energy liquid, which is depleted of electrical load due to have charged an EV. The technology is relative cheap and enables a fast recharging of the chargerbot. As an alternative solution (or combined) lithium-ion battery could be used in the chargerbot - the final ES system for the parking hub station is yet to be defined.
Finally, to the solution should be added some kind of foldable pole with a pennant on. In order to make it easier to detect by the surrounding, which in other case may be a problem due to the chargerbots low height.

4.10 Assessments

The assessments of this project were brief, but aimed to give an basic assessment of the solution regarding how environmental and convenient it was.

4.10.1 Environmental

The sustainable and environmentally aspects is have not only been part of the project, but the problem to solve in itself enables a increased sustainability and positive environmental impact. There are several environmental advantages and positive aspects in securing and encouraging an increased EV (BEV and PHEV) share in the car market.

It is however hard to fully assess the suggested system solution. Partly due to to little testing and detail in solution. However, what may be stated is that the solution should enable a more stable and better utilised electricity production and grid usage. Thought, the solution components alone could be analysed negative, due to increased energy losses when storing energy and transfer energy from the storage to the car battery. The fact that the design requires a robust and metal design increases the negative environmental aspects. Using WPT also results in increased losses compared to a cord/wire connection. However, the functionality of the solution decreases the losses due to WPT and also (as already mentioned) the electricity productions negative environmental impact. The decreased demands in electricity production (due to a more high efficient WPT) and grids is even more important in countries with fossil-based generation.

The solution's chargers will probably have a high degree of aluminium, which is a material of large negative environmental impact to produce. However if the proportion of recycled aluminium is large enough the aluminium could be regarded as relatively environmental friendly material choice. Aluminium is easy to recycle (to a high degree) and have beneficial properties making it to a good material choice in applications requiring metal properties, especially in corrosion environments.

The energy transfer rate for the charging system, as well as the availability, affects the required amount of battery capacity of an EV. Many sorts of batteries (used in EVs) have a large negative impact on the environment. Minimising the total amount of battery cells (the storage within a battery) will lead to reduced environmental impact and lower cost of vehicle.

The presented system solution enables a transitions towards both EVs and AV, and should also be used (through symbiotic development) with AD. Autonomous vehicle (AV) and driving have many large positive importance for the development of sustainability (both social and environmental), primary in cities. To fully utilise all the benefits that the AD technology could bring, EVs (if not BEVs) could be necessary. The solution of a chargerbot in the charging system proposes benefits of shared and higher utilisation of the charging system, while still enable a highly convenient charging system solution.

4.10.2 Convenience

It was found that to enable a more convenient charging system, which could support the effort of decreasing the negative perception of EVs, the charging system must have a good strategy for convenience. The system solution tries to target the different dimensions overall as good as possible. Below follows a brief convenience assessment.
The dimension of time is targeted with the usage of ESS, an sophisticated control & monitor system (through an app), and a system that enables a high performance and high availability of charging. Thus, the user may perceive convenience regarding 'when', 'how long', and 'minimal user waste time'.
The place dimension focus on the need of convenience at different places. The availability charger may be seen as the base solution, always enabling a security for where to charge, though with low power and therefor sacrifices a bit of the time dimension. The chargerbot functionality should enable good impact on the place dimension (as well as the time), as it may be shared between many cars and does not need specific EV parking bay (which is a problem in Oslo, due to the free parking for BEVs on parking bays for charging). The high utilisation rate of the solution could result in a lower cost per car (at destination), and could also be low enough for co-operative ownerships, as well as company service for their employees. This sharing aspect partly targets the acquisition dimension as well.
The chargerbot could allow for shared ownership, or to target the acquisition dimension, the car manufacturer could provide leasing deals for co-operatives or even have chargerbot 'pools' (in a similar way as Volvo cars is part of the carpool company Sunfleet).
The dimension of use is targeted with the automatically alignment for all standard charging and a convenient mobile app, which keeps the user notified but only at a level of what the user needs and possibly want to know. The difference between an EV with this standard charging solution and a traditional combustion internal engine vehicle, is the absence of the procedure of refuel/recharge. The user will perceive the EV as a mean of botherless transportation, always ready and moves optimal back and forth over geographical distances.
The system solution currently targets the execution dimension through supporting the introduction of AD. Or rather, the system solution should be used with AD, through a symbiotic development of EVs (especially BEVs) and AD. To cannibalise on traditional car market, the system solution should aim to be configured for total convenience.

5
Discussion

The initial title and scope of this master' thesis project was wireless charging of electric cars. However, with increased problem understanding, performed research and discussion with supervisor at the company, the planning report were titled as 'future charging system for electric cars'. The 'future charging system for electric cars' demanded a much wider scope than previous title. Therefor, during the project work some redefining in the scope had to be done, in order to create a slightly more narrow scope, which could be more easily handled. This new and also final title was 'convenient charging system for electric cars'. Afterwards, both the scope and ambition in the project have been found to be to large, especially in combination with to few delimitation's. It was due to the well planned project process and trust in it, that the quality throughout the whole project were secured. A more narrow scope, more delimitation's, and a less extensive project ambition could have created additional value and quality in this project (and result), but it could also be argued about if this wide scope, few delimitation's, and extensive project ambition have been able to identify and create overall more qualitative value.
Nevertheless, efforts have been made in executing the method and process in a good and qualitative way. The decisions and results have also been based on acquired knowledge through extensive research.
The areas within the scope and topic that have been found to be most important to discuss in this thesis regards the areas of:

- Methodology & project work.
- Convenience.
- BEV versus PHEV.
- Capability for EVs.
- Transition towards sustainability.
- The proposed concept solution.

5.1 Methodology & project work

The methodology & project work regards how the project was executed, and if the methodology and process used was suitable and resulted in qualitative outcomes.
The project was initiated with a through planning report. The structure, content, and ShareLaTeX- (online LaTeX service, with integrated editor and pdf-publisher) template would be the foundation for this final thesis. Furthermore, the planning report described the methodology and process to be used, and was the results of the chosen methodology's initial phase. In addition to the defined methodology and

process, the result of the planning report was also plans (overall and detailed) and a project mission statement.
Both the overall gantt-chart and the detailed process plans were thoroughly considered during the creation. It became clear towards the end of the master thesis work that the plans held good quality, as only minor changes had to be made.
The mission statement table was not to be of any major importance in itself, but the process and work in compiling it was good and important for the whole project and thus the final outcome.
The interpretation of the product development methodology is afterwards regarded to have been successful. However, more considerations should have been made regarding the quality of using methods and tools when only being one person. Methods and tools like for instance brainstorming, affinity diagram, concept selection, weightings and concept scoring have all been challenging. This challenge was tackled by (despite the plans) perform continued research along the whole project. It was time-consuming, but to research 'others' opinions and suggestions, wider perspective and deeper understanding were acquired.
The creativeness of this project have been limited to one minds creation, with minor support from the process in itself. With present retrospective understanding and knowledge the methodology and process used should perhaps have been complimented (or replaced) with other methodologies and tools. Furthermore, much more interaction work with others should have been performed in order to stir creativeness.
Therefore, it is suggested that research enables quality in process, while collective group work increase the quality in creativeness.
Furthermore, the survey had to little responses to be of any greater statistically quality. Nevertheless, its result gave important aspects and understanding, enough to draw some important conclusions. The interviews on the other hand were perceived as highly qualitative data. However, what could be argued about is that they were performed with early project assumptions. It could have been interesting and of great value to perform an additional set of interviews later in the project, when the assumptions had been developed (through an increased problem understanding). Furthermore, the final product specifications could, and should perhaps, be more comprehensive.

5.2 Convenience

Despite being relative old, the article that the convenience theory was based on was considered to be relevant and important yet today. The described five dimensions of convenience and convenience strategy have been found to be important for satisfying needs in consumer markets. The five dimensions of time, place, acquisition, use and execution, identifies what now have been understood to be fundamental categories of all needs a stakeholder may have towards a product or service.
However, the theory about convenience was unfortunately found after the identification and defining of needs and values, and had therefor minimal part in the data collection and need identification process. Its usage would instead be to understand if and why concepts, ideas and solutions might be good or bad.

The whole system were supposed to be thoroughly evaluated in relation to the theory of convenience. But yet again, due to lack in time this could not be done properly. The convenience assessment was made too brief to give a qualitative answer regarding how the system solution is convenient, and to what extent.
The reason why convenience was found to be of highest importance for a future charging system of especially BEVs, is the hesitant market. Customers have problem in understanding the technology, and do for instance not see the true total cost of ownership, values, or advantages (compared to traditional products on the car market). It is possible that the technology still lacks some possible technological merging (innovation) or break-trough's. However, one possible merging technology that greatly could increase the convenience if merged with electric cars is AD. These two technologies merged will probably make customers perceive their offering values as products with dominant convenience (given no other disruptive technology have an cannibalisation effect on the possible market). A combined BEV and AD product would eventually beat the traditional car products. In order to speed up the growing convenience (which is due to user perceptions) the two technologies should also take use of ES technologies. These three technologies, when fully integrated with each other, and with the use of a charging system like the suggested solution, would probably lead to outstanding convenience in all five dimensions. They could for instance target and create the following convenience for each respective dimension:

- ***Time:*** *Product may be provided at a time that is most convenient for the customer* - the charging is performed efficiently and without creating waste-time for the user.
- ***Place:*** *Product may be provided in a place that is more convenient for the consumer* - the car drives itself to where you desire.
- ***Acquisition:*** *Firms may make it easier for the customer, financially and otherwise, to purchase their products* - by self-driven car sharing services.
- ***Use:*** *Products may be made more convenient for the customer to use* - it decreases the demands of the user while performing what earlier was demanded better.
- ***Execution:*** *Having someone else provide the product for the consumer* - the car may on its own drive away to do errands, like driving to grocer stores and having someone (or something) put in the ordered/bought food into the trunk.

5.3 BEV versus PHEV

The scope of the project was to develop a concept solution for a convenient charging system for both BEVs and PHEVs. It is hard to identify if it was due to limited time or that the challenges for BEVs seemed bigger and more interesting, but the aspect of PHEVs have perhaps had too little attention. Furthermore, it was somewhat believed that a good convenient charging system for BEVs should naturally be more than sufficient for PHEVs. It can be argued if a perception like that is dangerous in product development. This mistake is probably as a result of having a too large scope and complex system, in relation to the time and resources. Despite big similarities, BEVs and PHEVs are different products that have different business models. It could probably have beneficial to do this project for each of them separately. After the two project had reach current point and delivery, as this project, they could perhaps have been merged into one project.

5.4 Capability for EVs

Few seems to worry about the capabilities for EVs, thought they should perhaps do. Neither companies (including car manufacturers), users, governments and municipals seam to have a clear picture of what growing share of EVs will bring. The insufficient common understanding of a EV-systems impact may threaten the development of EVs and thus potentially the environmental and sustainable trends.
Moreover, many countries and regions lack stability in electricity grid or sustainability in electricity production. A too rapid growth of EVs could probably in a worst case scenario result in electricity ransom's, frequent electricity black-outs, and a expanding need for fossil energy sources. It is therefor a bit surprising that the growth of EVs is pushed ahead of infrastructure developments. The usages of ES could both buy some time for infrastructure development, as well as be an important part of future electricity grid, which probably will consist of a lot of the highly fluctuating renewable energy sources.

5.5 Transition towards sustainability

President Obama said the 23rd of September 2014 - *"We are the first generation to feel the effect of climate change and the last generation who can do something about it."*. In order to do something about the climate change we need to change our behaviours and technologies used. But an abrupt change could possibly overturn the effort. It is therefore necessary to regard our demands of change in a transitional aspect. A quick but convenient transition should be the aimed approach for a sustainable future. It should be convenient in the matter of not creating a collective perception of losses in living standards. Three technologies that in this thesis have been found to, if combined, prevent such a perception are the technologies of EVs, AD, and ESS. Thus, have a great potential of become a major disruptive technology, which should have an cannibalisation effect on the traditional personal transportation market, as well as enable a sustainable transition.
As of today, the three technologies' developments have been regarded individually, but if combined the benefits should most likely be considerably more than merely the sum of each of them individually. With considerations to the hesitant market (due to lack of trust in technology) of EVs, the three technologies of EV, AD, and ESS should be merged into one new product, a new generations EV. The market must be convinced that this new generation of EVs does not have any of the weaknesses that the early EVs had. The market needs to see and most importantly be convinced that this new generations EV are a disruptive technology with many advantages, and which will lead to a sustainable future.
However, in order to not damage the car market, it is important to allow all current types of cars to co-exist in the society, until a complete transition may be completed.

This projects' result targets this transition period.

5.6 The proposed concept solution

The proposed concept solution suggests many benefits, but much further work is needed regarding assessments and testings. The availability- and fast charger solutions could be discussed regarding if they are or should even be needed. The availability charger will probably be the first to be removed in the future (if this charging system concept is brought to market). But it will probably be as a result of increased and developed infrastructure for EV charging, hence a good sign. Nevertheless, the availability charger should be considered to be important for the convenience of the system. It could well be that an growing EV market may lead to change in the standard electricity infrastructure (both public and private) for electrical devices.

Moreover, the fast charger solution does not create more convenience than traditional cars with internal combustion engine, if anything it is slightly worse due to less acquired driving range when charging the same time as a traditional car refuels. But the limitations in current technologies, regarding for instance maximal charging power, makes a expensive fast charger development illogical. Technological leaps are needed before a different fast charger (than the currently highest standard) should be developed. Until such a leap occurs focus should be put on the standard charging. However, thou the convenience of the fast charger is low, its functionality in the whole charging system is important and creates a high (necessary) degree of convenience. It is also the fast charger which will be perceived as the equal to the refuelling-process of the traditional cars (with internal combustion engines). When opportunities for development of the fast charger can be identified, it should be made totally automatic and preferably share charging interface with the standard charger or.

When regarding the standard charger solution, the most crucial question is if it will function and bring the intended values. As no real testing could be performed, it is hard to draw any conclusions. But the concept in itself could be valuable to further investigate, as it is similar but still different to existing and emerging technological solutions. Furthermore, the solution should be seen as innovative, due to that it brings the technologies of lawn-mower robots, AD, ESS, WPT, and EV-charging together into one concept solution.

The power level of the standard charger were defined to be up to 22kW. However, the new standard currently only describes 11kW. Therefore 11kW could have to be the initial development specification, but readiness for the 22kW standard should be implemented.

The chargerbot solution have a high utilisation rate, which may enable a low cost for both acquiring and maintaining it. Furthermore, the aspect of flow-battery was not developed, despite never being removed from the final first concept selection. However, the use of flow-battery for the chargerbot could enable very fast recharging. By refuelling the battery in the chargerbot, and recharge the liquid while the chargerbot is away charging an EV, the total utilisation rate of the chargerbot could be improved. There were unfortunately not enough project time to investigate this

solution further.
The amount of necessary ES capacity should be investigated through testing. The specified amount of at least 10kWh should be considered as the initial testing level. Overall, the focus of this projects' concept solution is the systems ability to create convenience. Moreover, it is important to keep in mind that the sum of convenience of all the different types and ways of charging in the system, is not as high as the convenience of the full system concept. Therefor, to test the charging systems convenience, the whole system (with all its parts) must naturally be tested.

6
Conclusion

To enable a substantial market penetration for EVs, more trust and desire must be created for EVs. The market lacks trust for EVs' (especially BEVs') driving ranges in relation to their charging times. The charging system for EVs is important for both factors, and must therefor be considered. In order to develop the charging system, a good holistic perspective is needed. It is important to see the charging system both as a part of the electric infrastructure and as the means for bringing convenience to the usage of EVs.
EVs do not only present several advantages over traditional combustion cars, but they might be a necessary part to tackle the climate change.

A fundamentally aspect of convenience in a charging system for electric cars should be that it has sufficient electric power, in order for it to function as intended. Current electric infrastructure can not handle a rapid growth of EVs, despite it being a possible or even likely development. Moreover, the amount and shares of EVs are growing, but their impacts on the electric infrastructure are not fully considered. Already today, without any mentionable EV load, some parts of the world have problem with building stable and sustainable electric infrastructure.
The needs for electricity are today increasing. It is therefore perhaps a greater risk than ever for making the world more dependent on non-sustainable energy sources.

More general and user focused aspects of convenience could be described as that convenience is the fundamental drive for all our needs. To create convenience in a consumer product it is important to target the convenience through a strategy for convenience. To create a strategy for convenience a combination of the five dimensions of time, place, acquisition, use, and execution should be made. With a good strategy for convenience and by innovation, technologies could become disruptive. By combining the technologies of AD and ESS with EV a disruptive technology could possibly be created.

In order to create convenience for the charging system for BEVs, it was found that the three different charging types of 'availability', 'fast', and 'standard' was needed. However, a convenient charging system of PHEVs only need 'availability' and 'standard' chargers. The 'availability' and 'fast' charging types brings convenience to the system by enable driving range and possibility to use system almost everywhere. The fast charger enables extended driving range when travelling far, and the availability charger may be connected to standard power grid, without any additional components or tools. The availability- and fast chargers brings convenience to the system, but what they may lack in convenience of use, the standard charger compensates

for. The standard charger is based on WPT-technology and have total convenience through a high degree of automation. For private parking stations it uses an flat all-in-one charger station, which fits under a parked car. For parking hub stations, or shared parking spaces, it uses an mobile wheel robot charger - chargerbot. The chargerbot operates around its home station (where it charges) and moves to and charges EVs in need of charging.
The standard charger could be described as:

- Self-going system that only disturbs user if necessary.
- Possibility to prepare charger with sufficient energy for improved charging performance and decreased impact on electric infrastructure.
- Removes the need of actively think about, or waste time on recharging/refuelling.
- Botherless parking with automatically aligning chargers - no change in behaviour from that of a traditional car.
- Optimal WPT performance and totally safe.
- High utilisation of the charging system.
- Compatible and beneficial for future AVs.

Furthermore, the system solution uses a wireless control system, which communicates between system components, and also to the user via a mobile app.

7
Future work

There are several aspect that should need future work, some of them regards the electric charging technologies, safety, convenience, the suggested solution, and possible future projects.

The WPT technologies will most likely develop rapidly. Even higher power levels than 22kW may be included in the future standard specifications for wireless charging. When higher power levels are to be introduced, a study of the electric infrastructure, type of EV, and possible user conveniences should be performed. Furthermore, when the charging infrastructure have reached a certain point, the availability charger will no longer be needed. Should the power levels for wireless charging reach about 100kW, the need of a wired-based fast charging solution should be reviewed.

Another thing that should be investigate thoroughly should solely regard pets (especially cats) behaviours and how to prevent them from possibly interrupt WPT charging, which is interrupted when foreign objects gets within a proximity where the electromagnetic field could be dangerous.

Convenience strategies for BEVs respective PHEVs should be developed, along with their business models.

Furthermore, a full convenience evaluation of the whole system solution should be performed, from the perspective of all defined stakeholders in the mission statement. The system concept solution should be further assessed and evaluated. The dimensions of the standard charger's case have for instant only been estimated. Work should have to be performed regarding investigating if enough ES capacity will fit, and if the ES can be charged and charge with a sufficient power level.
Moreover, a physical prototype of the charging system should be created for testing.

Three interesting future projects and what they should investigate could be:

- How an active safety system for WPT applications could function and look like.
- Investigate the fully potentials of an combined development of EV & AD.
- Development of a chargerbot prototype.

Bibliography

[1] Cevt.se, (2016). CEVT. [online] Available at: http://www.cevt.se/ [Accessed 3 Feb. 2016].

[2] Ulrich, K. and Eppinger, S. (2012). Product design and development. New York: McGraw-Hill/Irwin.

[3] Kezsbom, D.S. and Edward, K.A., 2001, The new dynamic project management: winning through the competitive advantage, 2nd edition, Wiley, New York.

[4] Wallace, S., 2015, A dictionary of education, Second edition, Oxford University Press, Oxford.

[5] Westcotte Russel, T. 2014, "13.2.2 Affinity Diagram" in , 4th ed., American Society for Quality (ASQ), pp.324.

[6] Eversheim, W., 2009, Innovation management for technical products: systematic and integrated product development and production planning, 1. Aufl. edn, Springer, Berlin. p.366.

[7] McQuarrie, E.F., 2016, The market research toolbox: a concise guide for beginners, Fourth edn, Sage Publications, Thousand Oaks, California.

[8] Brown, L.G. 1989, "The Strategic and Tactical Implications of Convenience in Consumer Product Marketing", Journal of Consumer Marketing, vol. 6, no. 3, pp. 13-19.

[9] Heinicke, M. & Wagenhaus, G. 2015, "Sustainability in the car-based mobility: the case of the electric vehicle Editha", International Journal of Energy Sector Management, vol. 9, no. 1, pp. 105-119.

[10] Yong, J.Y., Ramachandaramurthy, V.K., Tan, K.M. & Mithulananthan, N. 2015, "A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects", Renewable and Sustainable Energy Reviews, vol. 49, pp. 365-385.

[11] Li, C., Cao, Y., Zhang, M., Wang, J., Liu, J., Shi, H. & Geng, Y. 2015, "Hidden Benefits of Electric Vehicles for Addressing Climate Change", SCIENTIFIC REPORTS, vol. 5, pp. 9213.

[12] Musavi, F., & Eberle, W. (2014). Overview of wireless power transfer technologies for electric vehicle battery charging. Power Electronics, IET, vol.8, no. 1, pp. 60-66.

[13] SAE International, (2016). SAE International Approves TIR J2954 for PH/EV Wireless Charging. [online] Available at: http://www.sae.org/news/3391/ [Accessed 31 May 2016].

[14] Kim, J., Kim, J., Kong, S., Kim, H., Suh, I., Suh, N.P., Cho, D., Kim, J. & Ahn, S. 2013, "Coil Design and Shielding Methods for a Magnetic Resonant

Wireless Power Transfer System", Proceedings of the IEEE, vol. 101, no. 6, pp. 1332-1342.
[15] Birrell, S.A., Wilson, D., Yang, C.P., Dhadyalla, G. & Jennings, P. (2015), How driver behaviour and parking alignment affects inductive charging systems for electric vehicles, Transportation Research Part C: Emerging Technologies, vol. 58, pp. 721-731.
[16] Das Barman, S., Reza, A., Kumar, N., Karim, M. & Munir, A. 2015, "Wireless powering by magnetic resonant coupling: Recent trends in wireless power transfer system and its applications", RENEWABLE & SUSTAINABLE ENERGY REVIEWS, vol. 51, pp. 1525-1552.
[17] Skinner, R. and Bidwell, N. (2016). Making Better Places: Autonomous Vehicles and future opportunities. WSP Parsons Brinckerhoff in association with Farrells.
[18] Vattenfall AB, (2013). Energi till nytta och nöje. Produktionsbyrå Blomquist&CoCopywriter Karin Lago Nidsjö, p.33.
[19] Vattenfall AB, (2016). Välj rätt huvudsäkring - Vattenfall Eldistribution. [online] Vattenfalleldistribution.se. Available at: http://www.vattenfalleldistribution.se/sv/foretag-valj-ratt-huvudsakring.htm [Accessed 25 Feb. 2016].
[20] Vattenfall AB, (2016). ELNÄT: Säkringstariffer (Privat), OMRÅDE SÖDER, från 2016-01-01. Vattenfall Eldistribution AB.
[21] Knutfelt, M., 2015, "Charging Cost Optimization of Plug-in Hybrid Electric Vehicles", Master's thesis, Linköping: Linköping Institute of Technology.
[22] Liu, Z., 2013, Electric power and energy in China, 1st edn, Wiley, Singapore.
[23] Oberhofer, A., 2012, Energy Storage Technologies & Their Role in Renewable Integration, Global Energy Network Institute (GENI).
[24] Faria, R., Moura, P., Delgado, J. & de Almeida, A.T. 2014, Managing the Charging of Electrical Vehicles: Impacts on the Electrical Grid and on the Environment, IEEE, PISCATAWAY.
[25] Mah, D., Hills, P., Li, V.O.K. & Balme, R., 2014, Smart Grid Applications and Developments, 1;2014; edn, Springer London, London. pp.228
[26] Laddaelbilen.se, Tesla Model S | Ladda Elbilen. [online] Available at: http://www.laddaelbilen.se/elbilar/batteribilar/tesla-model-s-6378581 [Accessed 18 May 2016].
[27] Laddaelbilen.se, VW Passat GTE | Ladda Elbilen. [online] Available at: http://www.laddaelbilen.se/elbilar/laddhybrider/vw-passat-gte-29454977 [Accessed 18 May 2016].
[28] Ladestasjoner.no, Kontakttyper. [online] Available at: http://ladestasjoner.no/ladehjelpen/teknologi/26-kontakttyper#A [Accessed 15 May 2016].
[29] Elbil.no, Elbillading - Norsk elbilforening. [online] Available at: http://www.elbil.no/elbilfakta/elbillading [Accessed 15 May 2016].
[30] European Union (EU) rules on drivers' hours and working time: Simplified Guidance. (2016). Driver and Vehicle Standards Agency (UK) & Department for Transport (UK).

A
Appendix - Gantt of the overall Plan

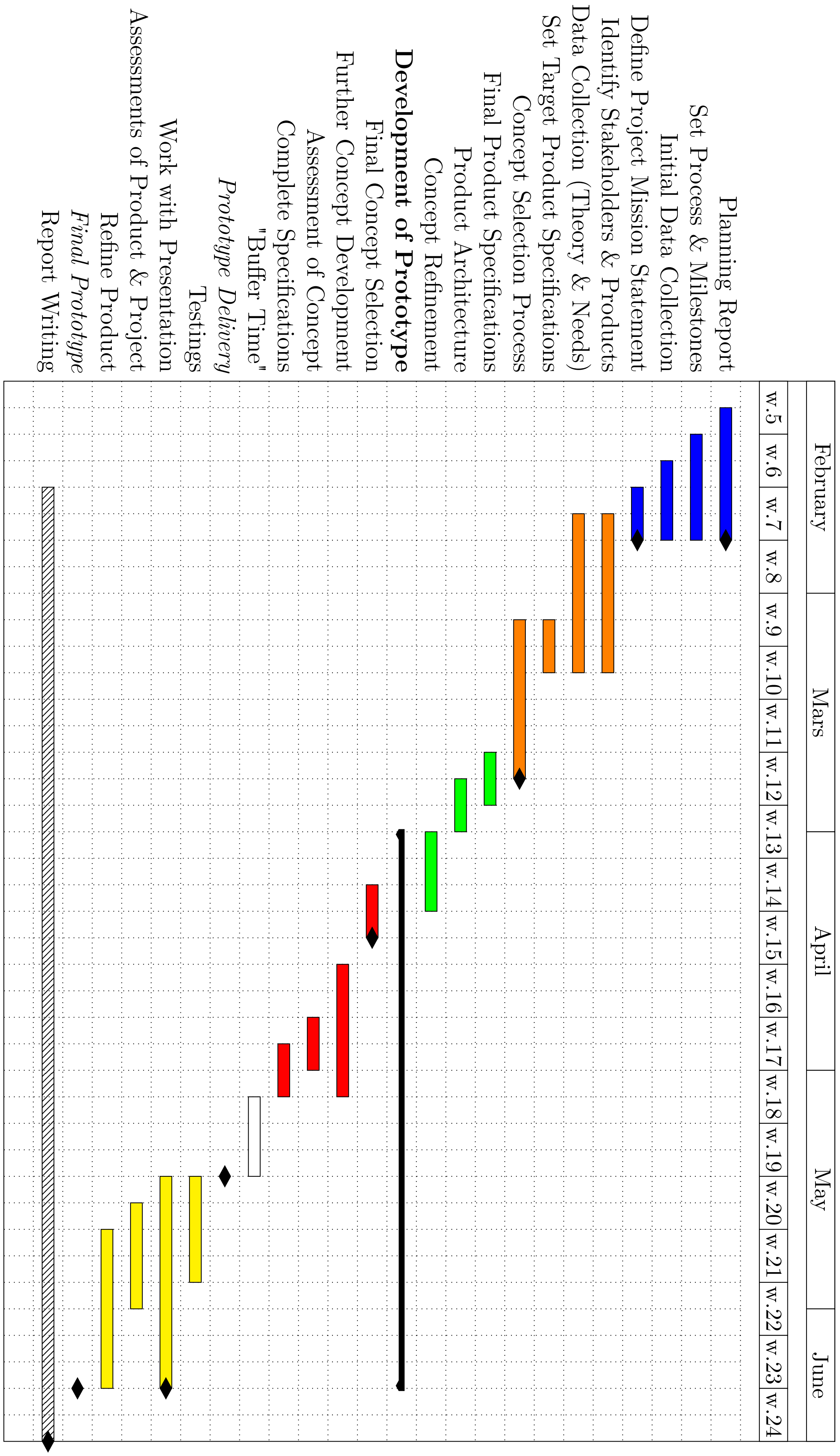
Explanation of Gantt-chart:

- Phase 0 = "Blue"
- Phase 1 = "Orange"
- Phase 2 = "Green"
- Phase 3 = "Red"
- Phase 4 = "Yellow"
- Milestones = 'Black Rombs"

Other activities & meetings:

- w.8: Initial "go/no-go" meeting with CEVT.
- w.10: Gate; support decision in concept selection by CEVT.
- w.'even': Examinator/Chalmers Supervisor meetings.
- w.12: Gate; support decision in concept selection by CEVT
- w.13: Decision regarding amount of work with 'Robust Design'.

Table A.1: Gantt-chart of the overall project plan



B
Appendix - Survey

English

Demografi & Användarsegment

Do you have a driver licens for cars?

Yes

In the process of acquiring one

No

Do you or your household own or have access to a car?

Yes

Sometimes

Not anymore

No

Thank you for your time, the rest of the questions will unfortunately not be interesting for you to answear. Have a nice day!

Are you a woman or man?

Woman Man

How old are you?

How many hours would you say that you spend traveling by car during an average...

I don't

	0 1 2 3 4 5 6 7 8 9 101112131415161718192021222324	know
...weekday?		
...weekend day?		
...holiday day?		
...long trip? (more than 100km)		

How often do you perceive that you make car journeys of the distances...

	Almost never	Rarely	Sometimes	Often
0-30 km				
30-100 km				
100-250 km				
250-500 km				
"further"				

Bränsle och tankning/laddning

What type of fuel is used in the car that you mostly use?

Diesel
Regular (Gasoline)
Ethanol (E85)
Gas (Natural-, Bio- or Hydrogen gas)
Electricity
Other

How often do you in general refuel/recharge the car?

More than 7 times/week
4-7 times/week
2-4 times/week
1-2 times/week
0-1 time/week
Never

Do you perceive it as bothersome or annoying to have to stop and refuel the car?

Yes No

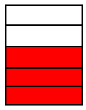
If you stop for refueling/recharging the car, how many minutes would you consider to still be acceptable for a full refueling/recharging during a...

	Minutes											More
	0	10	20	30	40	50	60	70	80	90	100	
...weekday?												
...weekend day?												
...holiday day?												
...long trip?												

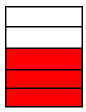
If you had an electrical or plug-in hybrid car, what could make it worth the time if you had to wait for it to recharge (ca. 30-60min)?
(N.B! Possible to give multiple answers)

Nothing would have made it worth the time	WiFi
Possible to buy something to eat	Availability of games
Possibility of shopping (clothes, hardware etc.)	People to be social with
Possible to buy groceries	Exercise or move on your body
Possible to watch a movie	Walk pets
Possible to work (workstation)	Other *(Please give example)*

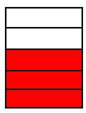
How much would you fill up the car when you stop for refueling/recharging a typical WEEKDAY?



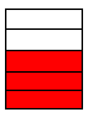
How much would you fill up the car when you stop for refueling/recharging a typical WEEKEND DAY?



How much would you fill up the car when you stop for refueling/recharging a typical HOLIDAY DAY?



How much would you fill up the car when you stop for refueling/recharging during a typical LONG TRIP?



Parkering

How easy do you perceive it would be to park in the carport?

Very easy | Easy | Difficult | Very Difficult

In what way would you park the car in the carport?

Forward parking | Reverse parking | It varies

How easy do you perceive it would be to park in following situation (parking field)?

Very Easy | Easy | Difficult | Very Difficult

In what way would you park the car in recent situation (parking field)?

Forward parking | Reverse parking | It varies

How easy do you perceive it is to parallel park?

Very Easy Easy Difficult Very Difficult

Which of the three parking situations resemble best how your car is parked at HOME?

1. "Carport"
2. "Parking field"
3. "Parallel parking"

Which of the three parking situations resemble best how your car is parked at your WORK?

1. "Carport"
2. "Parking field"
3. "Parallel parking"

Övrigt

How important is it for you that...

	Really Important!	Important	Indifferent	Not at all	Not applicable
...you never have to think about refueling/recharging the car?	○	○	○	○	○
...that the car is easy to park?	○	○	○	○	○
...that the car has many assistance systems (e.g.	○	○	○	○	○

parking assistance and driving assistance)?	○	○	○	○	○
...that you own your own car?	○	○	○	○	○
...you don't need to take pauses when traveling far?	○	○	○	○	○

Do you live in a house to which it always is possible to plug in a charging cable from the car?

Yes   No

What main fuse size do you have in your house?

16 A
20 A
25 A
35 A
50 A
63 A
Don't know

What of the following aspects would affect your eventual choice of car?

Environmentally friendly
Possible to refuel/recharge at home
Silent driving
Charging time
Range (driving)
The acceleration
Cost to buy
Running cost (fuel & service)
Horsepower
Other (please give example)

The survey that you now have answered is part of the development for future electrical and plug-in hybrid cars, with focus on the charging. Do you have any thoughts or comments concerning electrical or plug-in hybrid cars, and how they are charged?

C
Appendix - Interview Questions

Intervjufrågor

Föraren/Ägaren

Får man fråga hur gammal du är?

Ungefär hur länge har du använt och kört bil (vilken sort som helst)?

Hur bor du? (Villa, Lägenhet, Radhus, Landet, Stan etc.)

Har du familj eller husdjur?

Vad tycker du om att göra på din fritid? (Sport, hobbies etc.)

Vad har du för någon "hobby"/sysselsättning i vardagen, om du skulle få pauser/tillfällen? (T.ex. läsa bok, lösa korsord, spela spel, se på youtube eller filmer ...etc.).

Körvanor

Vilka olika sträckor kan du tänkas köra under ett år? (korta, långa, semester etc.)

Hur använder du bilen en vardag? ...helg dag? ...semesterdag?

Hur skiljer sig användningen i saker som antal och längd?

Drivmedel & Tankning

Hur många olika bilar har du använt under en längre period, och/eller ägt?

Vilka olika drivmedel har de haft?

Vad har du för elbil nu?

Vad är bra med de olika drivmedlen, vilka fördelar (respektive nackdelar) ser du med respektive drivmedel?

Om du var tvungen att stanna för att ladda under en bilfärd...
1) Hur mycket brukar du tanka, skiljer det sig åt från tillfälle och tillfälle eller dag till dag? (vardag, helg dag, semesterdag, under en längre resa)

2) Hur lång tid kan du som längst tänka dig att det får ta att tanka? Skiljer det sig åt (vardag...)

3) Vad brukar eller skulle du uppskatta att kunna göra medan bilen laddar?

Parkering och Hjälpmedel

Vilka olika sorters parkeringar brukar du parkera på? Underlag, rutade, trånga, fickparkering, uppfarter etc. (vad har du hemma och vad har du vid jobbet)?

I vilka situationer brukar du köra (framlänges) in, respektive backa in när du parkerar? Vad får dig att välja det ena framför det andra? (Tänker de på t.ex. bagageluckan och lastning?)

(Sidofråga: Det har funnits bilar med bagageutrymme där fram, hade det varit mer passande för din livsstil och körstil?)

Hur varierar det, tror du, i position mellan gångerna du parkerar på samma ställe?

Hur gör du för att hamna rätt när du parkerar?

Hur hade det kunnat skilja i variation om du parkerar i/vid en carport och ett parkeringsfält?

Har du någon form av parkeringsassistans i bilen? (Om ”***JA***”: Hur använder du den? Om ”***NEJ***”: Hur skulle din parkering förändras om du hade det? (Lättare, svårare, bättre parkering etc.)

Vilken form av assistans/hjälpmedel hade du uppskattat i en elbil?

Hur skulle automatiska hjälpmedel kunna hjälpa dig? I vilka situationer och på vilka sätt?

Vad känner du angående automatisk/självkörande parkering på bilar? Lämna ifrån bilen och se den åka iväg själv.

Hur tror du att automatisk/självkörande parkering skulle påverka hur din bil parkeras (rakare, snabbare etc.)?

Vad tror du det kan finnas för skillnader i att parkera en plugin-elbil jämfört med en vanlig bil?

Övrigt

Har du möjlighet att ansluta en plugin-elbil hemma?

Var har du tillgång till laddning och laddkabel? (Har du alltid med dig laddkabeln?)

Vad har du för storlek på huvudsäkringen hemma?

Vad var anledningen till att du skaffade en elbil? Vilka fördelar respektive nackdelar såg du innan du skaffat elbil?

Vilka fördelar respektive nackdelar upptäckte du efter att du hade skaffat elbil?

Säkerhet

Hur tänker du på säkerhet när du laddar din elbil?

Vad tror (eller vet) du att riskerna med trådlös laddning av elbilar är?

Hade du varit orolig om du fått en bil som laddades trådlöst?

Hur skulle det skilja sig i hur du tänker på säkerhet med trådlös laddning istället för trådbunden laddning?

Avslutning

Har du några övriga tankar eller idéer rörande elbilar (dess laddning eller intressanta användningsaspekter)?

Vilket sätt hade du helst som standard valt att ladda bilen på? Hemma (möjligtvis under natten) eller Snabbladdning längst vägen (upp till 80 % battericapacitet på 20-30min laddning)?

Är det viktigt för dig att äga bilen själv eller kan du tänka dig att dela bil (t.ex. elbil som förstabil och dela på en dieselbil?)

Hur skulle du se på att kunna ladda medan du kör, jämfört med stillastående laddning?

D

Appendix - Needs list

Table D.1: The needs identified through survey & interviews.

Identified needs list		
No.	**Interpreted Need**	**W/R/S**
1	The charging system solution will mainly make use of time and occasions when the user does not have to wait for the charging.	R
2	The solution has a neutral or positive effect on the future aspect of car sharing and autonomous vehicles.	R
3	The system solution have a good functionality for households with two electric cars, regarding the possible deliverable power.	W
4	The charging of the car does not have any dangerous health effect on the human body, if it would get in between.	R
5	There is no risk of damage or disabling of belongings and things, that could possibly get near while charging (for instance credit cards, mobile phones, hard-drives/memorysticks etc.)	R
6	The driver is always well informed about how far the car may drive with current charge.	R
7	The system solution have a low running cost	W
8	The system solution is perceived as cost worthy.	W
9	The system solution is environmental friendly.	R
10	The system solution allows convenient charging management, monitoring and notifications.	R

11	The system solution gives information of the positive impact that the charging and use of EV or PHEV does.	W
12	The system solution allows the car to be parked easily in a way that minimizes the risk of scratches or damages on the car (which may occur when parked)	W
13	The system solution is neutral or reduces the time to park in designated parking places (both forward, reversed & parallell)	W
14	The system solution have a solution that enables multiple charging parking places at workplaces and their parking fields.	W
15	The system solution enables sufficient driving range for 'daily', 'occasionally', and 'rarely' travels	R
16	The recharging of the car adds minimal waste of time to travels.	W
17	There is always a charger available where the car is most often charged.	S
18	The charging solution has sufficient equipment in the car for possibility to charge at unplanned occasions and places.	W
19	The system solution enables occasional range extension.	W
20	The maximum waiting time (perceived waste time) for recharging during travel is 11.5 minutes	R
21	The system solution do not require connection to high household power, but also allows low power outlet charging. Req 16A main fuse (Ĩ0A out). Wish 6A/car.	R
22	The system solution enables charging wherever there is sufficient electric power	W
23	Possible cord-charging connector is easy to understand and use, without risk of injuries but still with good performance and a light weight (not fireman hose)	R

24	The charging system solution should be designed for function in conditions as snow, and prevent itself to be damage if its plowed on the parking.	R
25	The charging solution have optimal performance for stationary (standing still) charging.	S
26	The charging solution may store energy in order to increase the daily capacity and possibly the performance of the charging, with minimum efficiency loss	R
27	The system solution makes use of low-usage time on the electricity grid.	W
28	The system solution functions optimal with different available/deliverable charging currents, with minimum demand of user input or knowledge	W
29	The charging system solution uses the available power at charging stations to best satisfy the overall customer needs and acquire highest satisfaction (prioritization aspect)	W
30	The solution will not be an obstacle on the parking lot, no matter what the ground is made of.	W
31	The charging solution charges itself and only notify the user when human assistance is assumed to be required.	W
32	Possible charging equipment is protected against stealth, as they are vital for the function of the car.	R
33	The system solution have functionality to acquire sufficient energy to continue if running out of electricity at a city-road side.	W
34	The charging system automatically measures and (if it's possible) pay for the power or notifies the user so that the user may compensate possible power supplier.	R
35	Charging stations have waiting time services, for instance 'dine', 'WiFi', 'workstation', 'grocery' or 'exercise' utilities (for charging times longer than 30 minutes).	W
36	The charging solution does not disturb while being used.	R
37	The system solution is robust.	R

38	The system solution demands minimum maintenance.	W
39	The system solution is not damaged or damage anything else if streets are flooded.	R

End of Needs list, table D.1

E

Appendix - Metrics / Target product criteria

Table E.1: The metrics created from the identified needs in table D.1.

Identified metrics list				
Metric No.	**Need No.**	**Metric**	**Imp.**	**Unit**
1	1, 27	Times for standard charging.	5	Time
2	2	Functional or integrational with future autonomous vehicles.	2	Y/N
3	3, 21	Time for full recharging.	3	h
4	4	Amount of harmful exposure levels on the human body (due to charging).	5	SAR & mT
5	5	Risk for damage of pets, devices and belongings (due to charging).	5	List
6	6	User-friendly visualization of remaining driving range.	3	Sub.
7	7,8	System cost (relatively competing systems)	4	US$
8	9	Overall system usage impact on the environment (energy and efficiency)	5	CO2 & %
9	10	Accessibility of monitoring- and control system.	4	Sub.
10	11	Information to user about climate impact (in a positive way).	2	Y/N

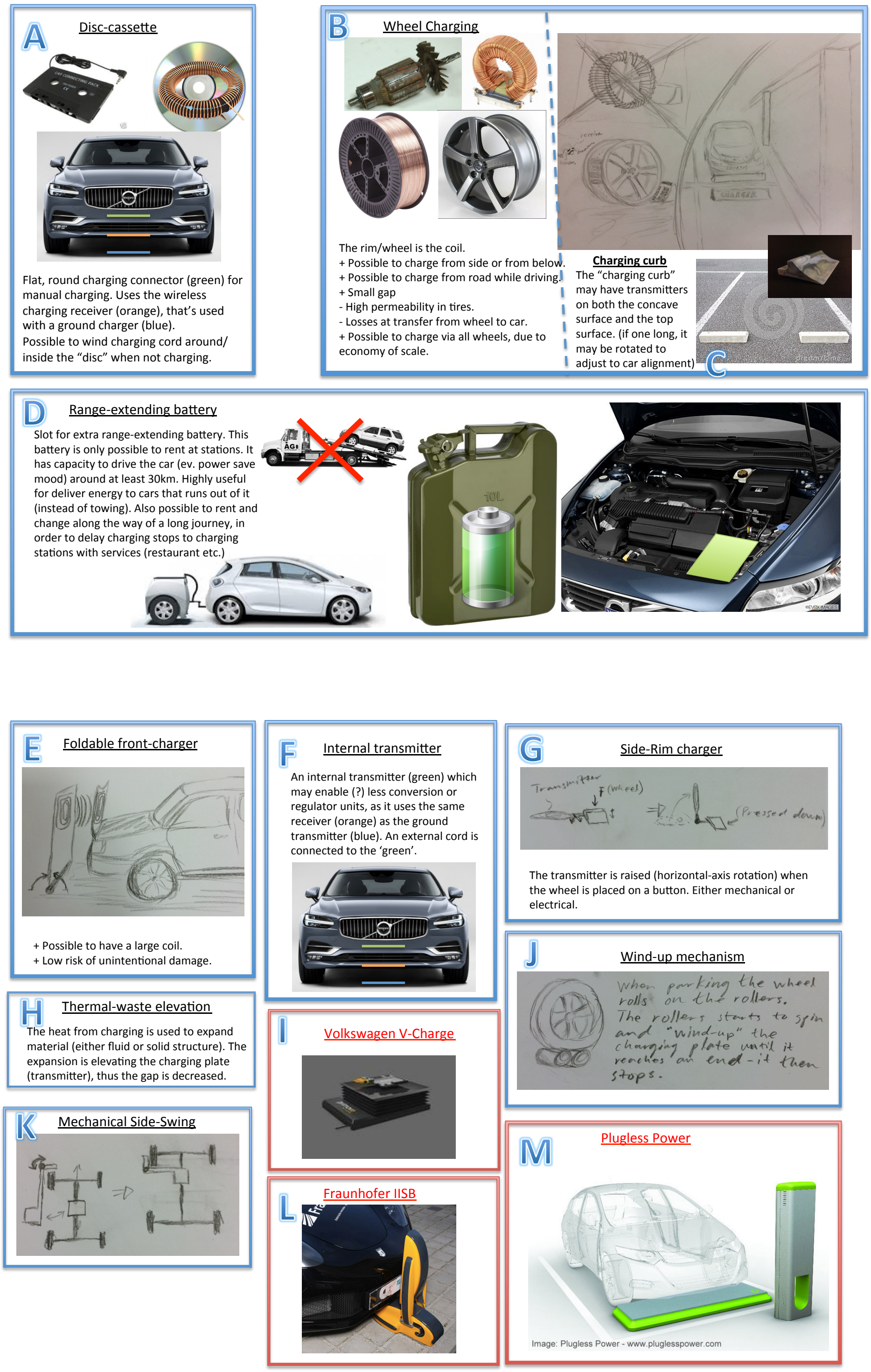
11	12	Divergence from ’optimal’ parking on parking fields (direction and alignment).	5	cm
12	13	Time to park.	2	min
13	14	Amount of electric cars that can be managed in the charging system on a workplace parking field.	4	Units
14	15	Driving range.	4	km
15	16	’Waste time’ due to charging.	3	Sub. & min
16	17	Availability (geographically) for "emergency" charging	3	Sub.
17	18	Sufficient charging equipment for "emergency" charging.	3	Y/N
18	19,20,33	Acquired extendable driving range in <11.5min	3	km
19	22,28	Connectible with different standard power sockets/outlets specifications.	4	List
20	23	Good ergonomically designed cord-connection system (form, weight, light, safety etc.)	4	Sub.
21	24	Functional for different normal seasonal weather situations.	4	List
22	25	Possible amount of deliverable energy transfer and efficiency.	5	kWh & %
23	26	Possible amount of stored energy and added losses from stored energy.	3	kWh & %
24	28	Cord-connection system is easy to understand and use with different available charge currents.	2	Sub.
25	29	Waste-waiting time at shared charging stations.	2	min

26	30	Convenient removal of possible obstacle component of the system on the parking lots.	2	Sub.
27	31	Semi-automatic operated it-system managing charging.	3	Y/N
28	32	Security system solution that prevents theft of system components.	5	Y/N
29	34	"Measurable energy charging and possibility to repay energy ""owner""."	3	Y/N
30	35	Available services in connection to charging stations.	2	List
31	36	Noise level at one meters distance.	4	dB
32	37	Amount of movable parts.	5	Units
33	38	Maintenance frequency.	4	Weeks
34	39	Flood-safe system design.	3	Sub.

End of Metrics list, table E.1

F

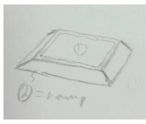
Appendix - Initial sub-system concepts


A
Disc-cassette
Flat, round charging connector (green) for manual charging. Uses the wireless charging receiver (orange), that's used with a ground charger (blue).
Possible to wind charging cord around/ inside the "disc" when not charging.
B
Wheel Charging
The rim/wheel is the coil.
+ Possible to charge from side or from below.
+ Possible to charge from road while driving.
+ Small gap
- High permeability in tires.
- Losses at transfer from wheel to car.
+ Possible to charge via all wheels, due to economy of scale.
Charging curb
The "charging curb" may have transmitters on both the concave surface and the top surface. (if one long, it may be rotated to adjust to car alignment)
C
D
Range-extending battery
Slot for extra range-extending battery. This battery is only possible to rent at stations. It has capacity to drive the car (ev. power save mood) around at least 30km. Highly useful for deliver energy to cars that runs out of it (instead of towing). Also possible to rent and change along the way of a long journey, in order to delay charging stops to charging stations with services (restaurant etc.)
E
Foldable front-charger
+ Possible to have a large coil.
+ Low risk of unintentional damage.
F
Internal transmitter
An internal transmitter (green) which may enable (?) less conversion or regulator units, as it uses the same receiver (orange) as the ground transmitter (blue). An external cord is connected to the 'green'.
G
Side-Rim charger
Transmitter
F (wheel)
(Pressed down)
The transmitter is raised (horizontal-axis rotation) when the wheel is placed on a button. Either mechanical or electrical.
H
Thermal-waste elevation
The heat from charging is used to expand material (either fluid or solid structure). The expansion is elevating the charging plate (transmitter), thus the gap is decreased.
I
Volkswagen V-Charge
J
Wind-up mechanism
When parking the wheel rolls on the rollers. The rollers starts to spin and "wind-up" the charging plate until it reaches an end - it then stops.
K
Mechanical Side-Swing
L
Fraunhofer IISB
M
Plugless Power
Image: Plugless Power - www.pluglesspower.com

N Mobile Robot Charger

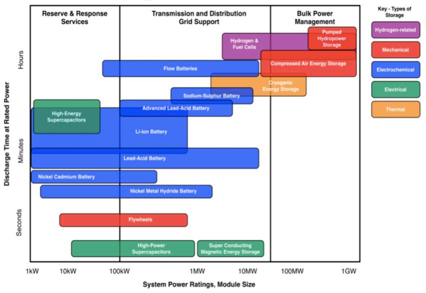
+ No specific charging spaces, the robot moves around.
+ Easier to set up and cheaper than building several charging places on a parking field(?)
# Communicates with cars (WiFi and GPS)
(?) Battery or super capacitor?
+ Perfect (?) alignment without user

O Viscoelasticity

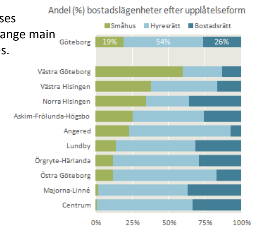


Concave holes cover with slow-viscoelasticity material, which the wheels parks on. The car will slowly slide down into the holes and thus align and decrease the gap between car underbody and charging transmitter.

P Energy storage charger

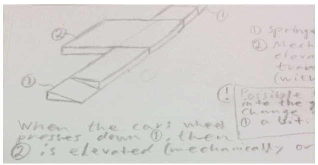


+ Possible to charge faster
+ Possible to have more than one EV.
+ Possible to own EV without having a house.
++ Creates a larger market group.
-- More energy losses
+ Don't need to change main fuse or house-wires.

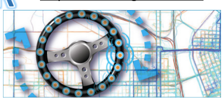


Q Mechanical elevation

The charging plate is elevated by simple and robust mechanic when the wheel presses down a "button".



R Haptic Steering Guidance



Guides the driver in alignment (both sideways and "depth" to the charging plate.

S Visual Guidance

- Possible distraction from surrounding.
+ Good view in parking direction.

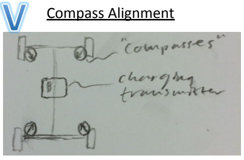
T Audio Guidance

- Stress
- Imprecise
+ Efficient when straight reversing.
+/- May use surround speaker system, but driver may have impaired hearing
+ Different sort of sound for different sensors (may be confusing)

U (1&2) Parking Beacon

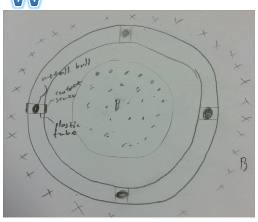
When approaching a parking, manually activate parking mode (or auto with GPS). The car will use the inbuilt comm.-device (part of VolvoCars keyless future) for sending out a beacon that activates the charging plate (and probably in the future self-parking). The charging plate will start to emit a small/weak magnetic field to which the car seeks to align to.

V Compass Alignment



Measures how the compasses are directed.

W Magnetic Alignment Ring



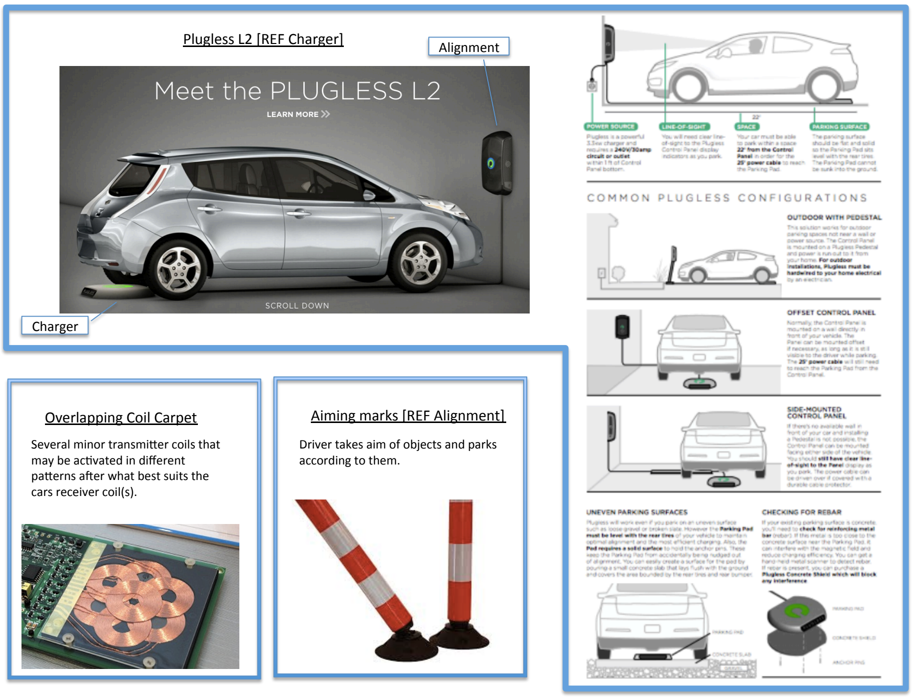
The ring isn't necessary, but the four metal balls are. Their individual alignments in small tubes are measured.

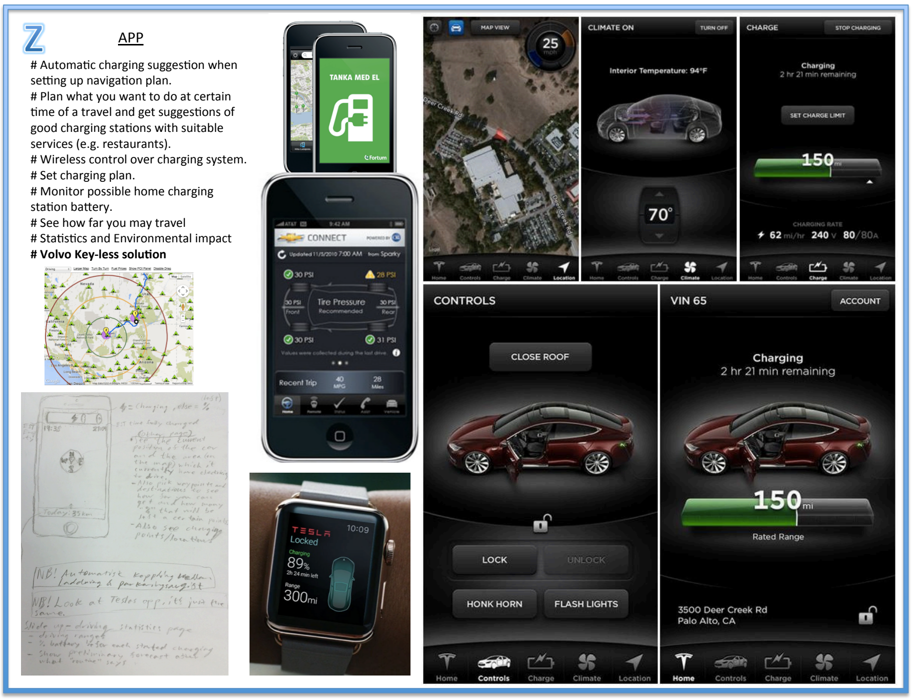
X Floating Self-Alignment

The Receiver (and/or possibly also the transmitter) "floats" in a liquid. The magnetic field will automatically align the receiver (/transmitter) to where the magnetic flux is "best".

Y Suspension Self-Alignment

The Receiver (and/or possibly also the transmitter) is mechanically suspended by some kind of feathers. The magnetic field will automatically align the receiver (/transmitter) to where the magnetic flux is "best".


Plugless L2 [REF Charger]
Alignment
Meet the PLUGLESS L2
LEARN MORE
SCROLL DOWN
Charger
COMMON PLUGLESS CONFIGURATIONS
OUTDOOR WITH PEDESTAL
OFFSET CONTROL PANEL
SIDE-MOUNTED CONTROL PANEL
UNEVEN PARKING SURFACES
CHECKING FOR REBAR
Overlapping Coil Carpet
Several minor transmitter coils that may be activated in different patterns after what best suits the cars receiver coil(s).
Aiming marks [REF Alignment]
Driver takes aim of objects and parks according to them.


APP
Automatic charging suggestion when setting up navigation plan.
Plan what you want to do at certain time of a travel and get suggestions of good charging stations with suitable services (e.g. restaurants).
Wireless control over charging system.
Set charging plan.
Monitor possible home charging station battery.
See how far you may travel
Statistics and Environmental impact
Volvo Key-less solution
CONNECT
Tire Pressure
CLIMATE ON
CHARGE
CONTROLS
CLOSE ROOF
LOCK
UNLOCK
HONK HORN
FLASH LIGHTS
VIN 65
ACCOUNT
Charging
2 hr 21 min remaining
150 mi
Rated Range
3500 Deer Creek Rd
Palo Alto, CA
TESLA
Locked
89%
300mi

G

Appendix - Concept selection matrices

Table G.1: First full-system concept selection matrix of "Charger".

Charger concepts	Plugless L2 [REF]	A - Disc-cassette	B - Wheel Charging	C - Charging Curb	E - Foldable front-charger	F - Internal Transmitter	G - Side-Rim Charger
Selection Criterias	Charger	Charger	Charger	Charger	Charger	Charger	Charger
Ease of handling (hold)	0	-	+	+	0	-	-
Ease of use (control)	0	-	+	+	0	-	0
Secure (Stealth)	0	0	0	0	0	+	0
Secure (Health)	0	0	-	0	-	+	-
Charging Efficiency	0	-	-	-	+	-	-
Durability	0	-	-	-	-	0	-
Ease of manufacture	0	-	-	-	-	-	-
Availability	0	+	+	0	0	0	0
Sum +'s	0	1	3	2	1	2	0
Sum 0's	8	2	1	3	4	2	3
Sum -'s	0	5	4	3	3	4	5
Net Score	0	-4	-1	-1	-2	-2	-5
Rank	1	12	5	5	7	7	13
Continue?	Ref, develop	0	0	0	0	0	0
Alignment Concepts	*I - Wolksvagen V-Charge*	*K - Mechanical Side-swing*	*L - IISB (Fraunhofer)*	*M - (Pluglesspower)*	*N - Mobile Robot Charger*	*Overlapping Coil Carpet*	
Selection Criterias	*Charger*	*Charger*	*Charger*	*Charger*	*Charger*	*Charger*	
Ease of handling (hold)	-	-	+	+	+	0	
Ease of use (control)	-	-	+	0	+	0	
Secure (Stealth)	0	0	0	0	-	0	
Secure (Health)	+	0	-	-	+	0	
Charging Efficiency	0	+	-	0	-	0	
Durability	-	-	-	0	-	0	
Ease of manufacture	-	-	-	0	-	0	
Availability	0	0	0	0	+	0	
Sum +'s	1	1	2	1	4	0	
Sum 0's	3	3	2	6	0	8	
Sum -'s	4	4	4	1	4	0	
Net Score	-3	-3	-2	0	0	0	
Rank	10	10	7	1	1	1	
Continue?	0	0	0	Not develop, similar to reference	Develop	Develop	

Table G.2: First full-system concept selection matrix of "Alignment".

Alignment Concepts	Aiming marks [REF]	H - Thermal-waste elevation	J - Wind-up mechanism	O - Viscoelasticity	Q - Mechanical elevation	R - Haptic Steering Guidance	S - Visual Guidance	T - Audio Guidance
Selection Criterias	Alignment	Alignment	Alignment	Alignment	Alignment	Alignment	Alignment	Alignment
Ease of handling (hold)	0	+	0	+	+	+	-	+
Ease of use (control)	0	+	-	+	0	+	+	+
Secure (Stealth)	0	-	-	-	-	0	0	0
Secure (Health)	0	0	0	+	+	+	+	+
Charging Efficiency	0	+	+	+	+	+	+	+
Durability	0	-	-	0	-	0	0	0
Ease of manufacture	0	-	-	-	-	-	-	-
Availability	0	-	-	-	-	+	+	+
Sum +'s	0	3	1	4	3	5	4	5
Sum 0's	8	1	2	1	1	2	2	2
Sum -'s	0	4	5	3	4	1	2	1
Net Score	0	-1	-4	1	-1	4	2	4
Rank	9	12	14	7	12	1	4	1
Continue?	Ref	Not develop	Not develop	Interesting, not develop but save	Not develop	Develop	Not develop	Develop

Other concepts	U1 - Manual Parking Beacon	U2 - Auto Parking Beacon	V - Compass Alignment	W - Magnetic Alignment Ring	X - Floating Self-Alignment	Y - Suspension Self-Alignment	Pluggless L2
Selection Criterias	Alignment	Alignment	Alignment	Alignment	Alignment	Alignment	Alignment
Ease of handling (hold)	0	+	+	+	+	+	+
Ease of use (control)	+	+	+	+	+	+	-
Secure (Stealth)	0	0	0	0	0	0	0
Secure (Health)	+	+	+	+	+	+	0
Charging Efficiency	+	+	+	+	-	-	+
Durability	-	-	+	-	-	-	0
Ease of manufacture	-	-	-	-	-	-	-
Availability	0	0	0	0	0	0	0
Sum +'s	3	4	5	4	3	3	3
Sum 0's	3	2	2	2	2	2	3
Sum -'s	2	2	1	2	3	3	2
Net Score	1	2	4	2	0	0	1
Rank	7	4	1	4	9	9	7
Continue?	Not develop	Develop/Combine	Develop	Not dev. Thou V better	Not develop, but continue with self-alignment	Not develop, but continue with self-alignment	Not develop

Table G.3: First full-system concept selection matrix of "Other".

Other concepts	*Complete Charging system*	*Emergency range*	*Energy Utilization*	*APP*
Selection Criterias	***Plugless L2 complete system [ref***	***D - Range-extending battery***	***P - Energy Storage Charger***	***Z - App***
Ease of handling (hold)	0	+	0	+
Ease of use (control)	0	+	+	+
Secure (Stealth)	0	+	-	+
Secure (Health)	0	+	0	0
Charging Efficiency	0	+	+	0
Durability	0	+	-	0
Ease of manufacture	0	-	-	-
Availability	0	+	+	+
Sum +'s	0	7	3	4
Sum 0's	8	0	2	3
Sum -'s	0	1	3	1
Net Score	0	6	0	3
Rank	3	1	3	2
Continue?	Ref	Develop	Develop	Develop

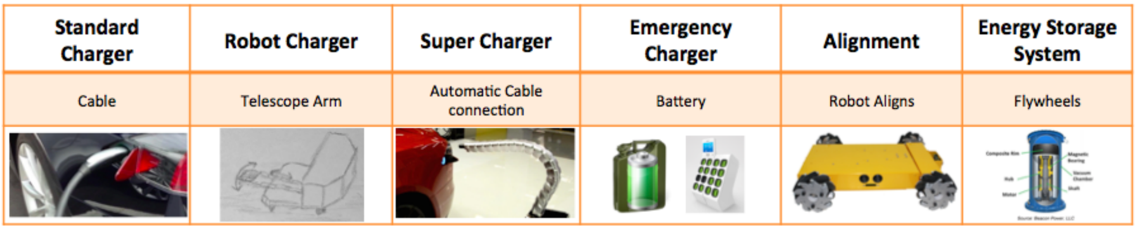
H

Appendix - Full-system concepts

For the first screening iteration:

The seven generated full-system concepts.

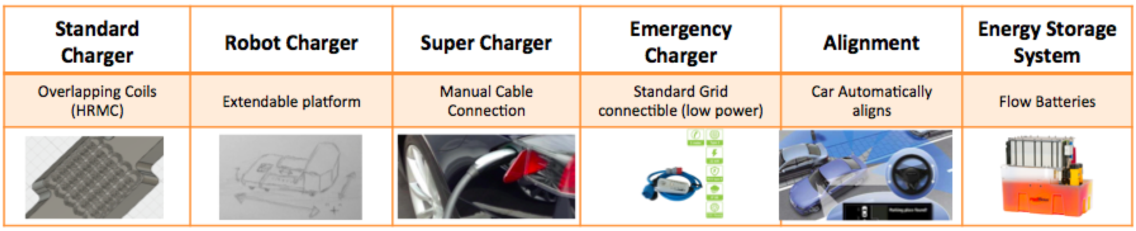
Robotic Cable



Standard Charger	Robot Charger	Super Charger	Emergency Charger	Alignment	Energy Storage System
Cable	Telescope Arm	Automatic Cable connection	Battery	Robot Aligns	Flywheels

Figure H.1: .

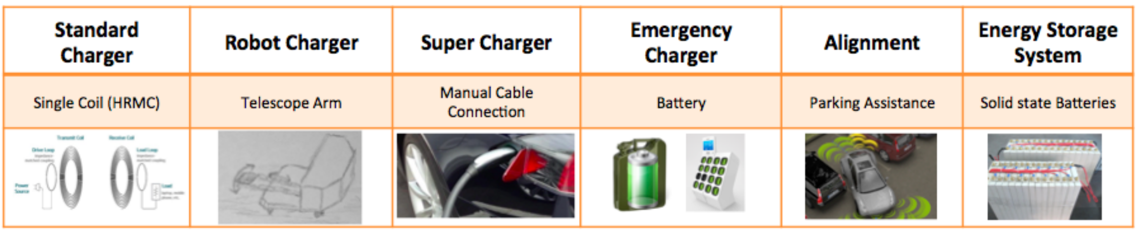
Overlapped Coils



Standard Charger	Robot Charger	Super Charger	Emergency Charger	Alignment	Energy Storage System
Overlapping Coils (HRMC)	Extendable platform	Manual Cable Connection	Standard Grid connectible (low power)	Car Automatically aligns	Flow Batteries

Figure H.2: .

Standard +2



Standard Charger	Robot Charger	Super Charger	Emergency Charger	Alignment	Energy Storage System
Single Coil (HRMC)	Telescope Arm	Manual Cable Connection	Battery	Parking Assistance	Solid state Batteries

Figure H.3: .

All wireless

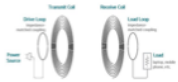
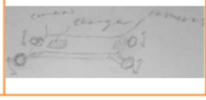
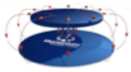
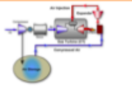
Standard Charger	Robot Charger	Super Charger	Emergency Charger	Alignment	Energy Storage System
Single Coil (HRMC)	Flat & individual wheel control	Wireless	Standard Grid connectible (low power)	Charger Aligns	CAES
					

Figure H.4: .

Simple-fast tow

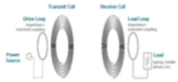
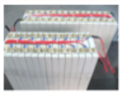
Standard Charger	Robot Charger	Super Charger	Emergency Charger	Alignment	Energy Storage System
Single Coil (HRMC)	Foldable arm	Automatic Cable connection	Towing	Charger Aligns	Solid state Batteries
					

Figure H.5: .

Capacitive Wireless

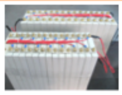
Standard Charger	Robot Charger	Super Charger	Emergency Charger	Alignment	Energy Storage System
Capacitive Wireless Coupling	Telescope Arm	Automatic Cable connection	Towing	Robot Aligns	Solid state Batteries
					

Figure H.6: .

Go the extra mile

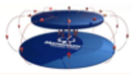
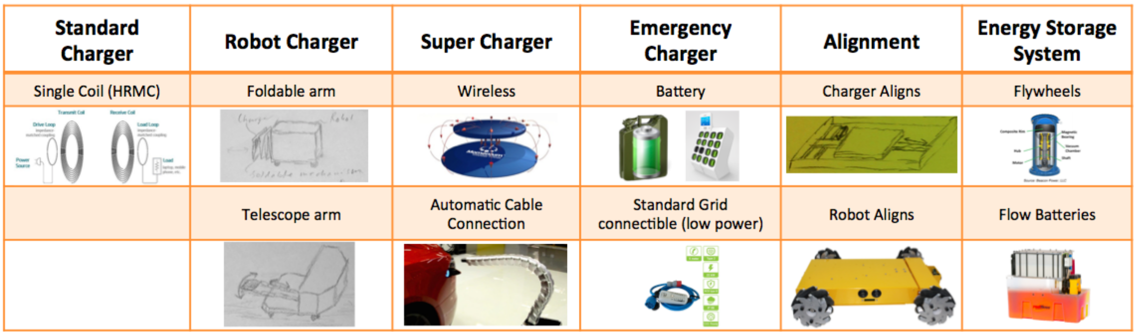
Standard Charger	Robot Charger	Super Charger	Emergency Charger	Alignment	Energy Storage System
Single Coil (HRMC)	Foldable arm	Wireless	Battery	Charger Aligns	Flow Batteries
					
	Telescope Arm		Standard Grid connectible (low power)		Capacitors
					

Figure H.7: .

For the final screening iteration:

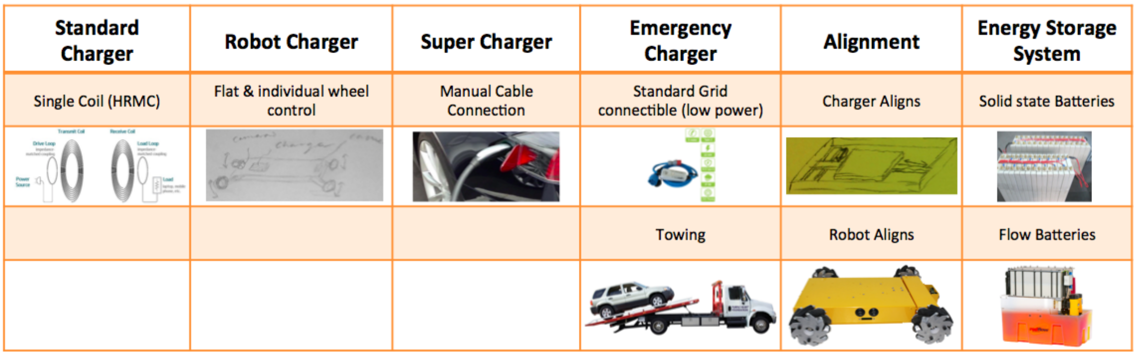
The 'last iterated' concept



Standard Charger	Robot Charger	Super Charger	Emergency Charger	Alignment	Energy Storage System
Single Coil (HRMC)	Foldable arm	Wireless	Battery	Charger Aligns	Flywheels
	Telescope arm	Automatic Cable Connection	Standard Grid connectible (low power)	Robot Aligns	Flow Batteries

Figure H.8: .

The 'reviewed' concept



Standard Charger	Robot Charger	Super Charger	Emergency Charger	Alignment	Energy Storage System
Single Coil (HRMC)	Flat & individual wheel control	Manual Cable Connection	Standard Grid connectible (low power)	Charger Aligns	Solid state Batteries
			Towing	Robot Aligns	Flow Batteries

Figure H.9: .

I

Appendix - Findings from Oslo & Kraftforum

The findings from the field-trip to Oslo and the participation at Kraftforum were written in a separate document, which is presented in this appendix.

Norway field trip & Kraftforum (GBG)

Norway field trip: *9th-10th of May 2016*
Kraftforum (Gbg): *11th of May 2016*

The field trip to Norway was a two-day trip in a PHEV VW Passat. The aim was to find out what the key factors for the high and increasing sale market of BEVs are.
The first day began with traveling from Gothenburg (GBG) to Oslo, after which visits to one Nissan Leaf respectively Tesla resellers were made. The second day began with a visit to the municipal of Oslo and a meeting with Sture Portvik – responsible for the charging poles of Oslo. The second day continued with a visit to The Norwegian EV Association (Norsk Elbilforening) and a meeting with Petter Haugneland. The travel back to Gothenburg was eventless, except for discussion between us who made the field trip (Johan Hellsing, Jesper Persson and Alexander Berggren).

The day after the field trip to Norway the Kraftforum day took place on Lindholmen Gothenburg – a one day seminar and network event.

Summarization of this document

- Smart electrical driving plan for PHEV.
- PHEV could successively move towards BEV, in order to change the negative perceptions of BEVs.
- Decrease amount/length of cable and fool-safe use of different outlets/connectors.
- Increase and improve utilization of charging points.
- Clean usage for user (no dirt).
- Increased car-climate efficiency.
- Inbuilt battery temperature cooling/heating system.
- Decrease power but increase energy utilization from electrical grid. (*There is no energy problem in the grid, but a power problem).*
- Great challenge in availability of charging points and delivery of sufficient power for EV owners living in apartment buildings.
- Infrastructure development (charging stations) is the bottleneck for a growing market (EU directive formulates the need of a charging point every 100km).
- Target price for building/placing a public charging point should be preferably less than 6500 EUR.
- Preconception and user perception (worries and skepticism) is the greatest barrier for BEV market growth. PHEV with successive transformation to BEV could be the key.
- Adaptable charging power (at least three level, low-mid-high).
- Wireless connectivity will likely be desired in the future.
- The need for charging is (only) about 10kWh/occasion, a regular day.

Travel in PHEV VW Passat: GBG-Oslo

Observations and thoughts from traveling in the PHEV VW Passat were made:

- A PHEV should plan its battery usage (electrical drive) if a set destination and navigation is entered in the inbuilt navigator. If not, the battery may be drained before reaching a city destination were the electrical drive may be of more importance.
- The car had two cables, one three-phase (400V) and one one-phase (230V). The cables had the same connection to the car but different in the wall end. Thoughts were made why not use the same cable and attach an adapter in the other wall end?
- When the battery is almost depleted the car automatically don't lower the engine to less than about 2000 RPM (most effective power point for engine?), but instead starts to diverge power to the charging of the battery.
- At destination (in the evening after visits to the EV resellers) it was hard to identify what kind of power outlet connector there was in the garage, where we parked. It was also some hesitations at first regarding what power the outlets allowed for. Only the one-phase could be used. The charging should take four hours and end about 22:30. As no other car could park and charge in the garage thoughts were first made if we should come back and move the vehicle, but it was decided to be to bothersome (not convenient). Especially if we should happen to desire a glass of alcoholic beverage. We occupied the charging point (as they call it in Norway) for about 14h of which we only charged 4h – less than 30% charging point utilization.
- Furthermore, the cables became a mess while straighten them out in order to charge. When a cable should be put back into the car it was to bothersome to wire it or order it in any way, it was therefor just 'thrown' into the back of the car.
- The floor of the garage was also dirty, so the cables became a bit dirty which made the procedure of handling it a bit more complicated (in order to avoid get dirt on the clothes).

Reseller visits

The reseller visits were somewhat spontaneous and unplanned. Interesting findings were made and the feeling afterwards was that Tesla had built a very good BEV, while Nissan Leaf felt as a good and 'sufficient' BEV. Some observations and findings were:

- The range of the car is highly affected by the temperature and climate – both concerning the change in battery properties, and the users' needs to adjust in-car climate. Solutions are to include a heating/cooling system for batteries respectively change focus from car coupe climate to car passenger climate. Example of passenger climate focus is a steering wheel heater, which could decrease the needed heating of the whole car during cold days.
- Incentives were also understood to be highly important for increasing the BEV market shares. See heading "Important Incentives".

Oslo municipal visit

The findings were:

- The BEV market has grown faster than the municipal has capacity (economy) to build charging stations. Relies on private (non cost-free for users) actors/companies.
- Only standard (low power) charging stations are built by the municipal, hence non-standard (higher power) charging is not cost-free for users.
- Problem of utilization of charging point parking's. BEVs that doesn't need to charge (or is already done with charging) occupy parking place needed by BEV's that need to charge.
- Needs to build more free parking places without charging point (but still near charging points) for BEVs, in order to solve the utility problem of charging points.
- There have started to become a power delivery problem for charging stations and smart grid parking places is now built (without ESS/Energy Storage System). The charging power of cars is varied and prioritized after clusters of cars in parking lots. This reduces the high power demands by distribute it over time (same energy but lower power). Ergo, there is not lack of electrical energy but electrical power.
- To build one new charging point (one car connection) cost roughly about 60 000 NOK (Norwegian currency), but it varies a lot.
- Problem with installing charging points in apartment buildings. It's too expensive to supply sufficient power. The municipal installs them on the streets instead.
- None or little problems with stealth or sabotage of charging equipment's, thou some problems with cars that may drive into the poles.
- The Type 2 connection is to prefer. Schuko is expensive and less EV's will probably really on it in the future.
- Emerging smart charging stations (with multiple charging points). That will prioritize and diverge power to charging of duty vehicles (by a booking system).
- The municipal pays 60% of the cost for installation on company parking lots, if the public will be allowed to use them.
- It should not be cheaper to buy and use a EV than taking the buss. There is a trade-off between emission and traffic queue.
- Diesel vehicles may soon be banned from entering certain city zones some days of the year (when it's cold), due to local negative environmental impact (caused by SOx, NOx etc.).
- Will soon construct micro grids in the city for prioritizing power usage and possibly transfer stored energy between the micro grids.

The Norwegian EV Association visit

- They function as an overall technical support center, and thus lowers the demand of the same service by resellers and car manufacturers.
- They have found that for every new EV owner, three more will come.
- Problem with damage on connectors at fast charging stations, due to drop accidents when charging cable is not safely re-fastened after usage.
- They said that they would prefer to not have cables at charging stations.
- Tesla's connector is the best so far. Though, it will no be sufficient for the future charging powers.
- Larger battery packs (as Teslas) could perhaps hold its power for longer time, hence give the car less decreased range (due to outside temperature).
- There is a EU directive of at least one charging point per 100km (Norway aims for every 50km).
- Batteries should preferably have the same product life as the whole car.
- There is a need for a middle power alternative (between standard and fast/hurtig). This would be useful at shopping centers and restaurants etc.
- Wireless charging would be were interesting for the future.
- In a cold country as Norway in the winters, too much energy is used for secondary systems and personal climate (heating). The air condition is also to energy demanding in conventional cars.
- The once who dares to buy EVs are mostly engineers, who have already read a lot of specifications and information about the technologies before buying.
- There is a great need of increased charging infrastructure for apartment buildings.
- BEV owners living in apartments typically only charge 10%, of the needed daily energy, at home.
- The overall environmental and sustainability awareness (before buying an EV to after have owned an EV for a while) is shown to go from about 20% to 62% among the EV buyers.

Kraftforum

During the Kraftforum a lot of interesting knowledge and aspects were presented. One of the most interesting presenting companies was Chargestorm.
Chargestorm is a manufacturer of charging stations and some interesting facts that they claimed were:

- In average an EV in Sweden charges 6-7 kWh/night.
- Average charging is just below 10 kWh/occasion.
- There is a problem to provide sufficient current (power) into apartment buildings.
    - For instance, one apartment cooperative in Stochholm wanted to prepare for EV charging stations and desired 1000A input to the building. The power company answered that they could only provide 400A. To be noted is that the heating system of the building demanded 250A. This gives only 150A to the charging of EV's.

One other topic during the Kraftforum were if and how the electrical grid could support the load of EV charging.

Important Incentives

The important incentives identified during the field trip to Norway are:

- Convenience in Economic
  - No purchase taxes
  - Exemption from 25% VAT (Value-Added Tax/Mervärdesskatt) on purchase.
  - No charges on toll roads (a lot of toll roads over the whole country).
  - Free charging at municipal charging points.
- Convenience in Usage
  - Free municipal parking.
  - Free access to bus lanes.
  - High charging infrastructure – standard, semi-fast (semi-hurtig), and fast charging (hurtig).
- Convenience in Service
  - Possibility to get up to five free rents of cars with conventional fuels, in order to be able to do rare long trips.
  - Free road assistance (first year) by car producer – less worries about "what if my battery gets depleted while on the road".

The **economical incentives** result in BEVs with acquiring cost the same (if not less) than conventional cars. Also, the usage cost is highly decreased, and is almost insignificant (compared to conventional cars).
The **usage incentives** result in easier to drive and park in Oslo.
The **service incentives** seemed to be less important and used, but could possibly be important for some customers.

J

Appendix - Full-system concept scoring matrices

The first iterations full-system concept scoring matrix is shown in figure J.1.

The final first full-system concept scoring matrix is shown in figure J.2 and includes both the last iterated concept (before the concept review, described in chapter 4.5.9) and the reviewed concept.

Table J.1: The matrix for the first iteration of the full-system concept scoring.

		Concepts															
		A (Ref.) Plugless L2		B Robotic Cable		C Overlapped Coils		D Standard + 2		E All wireless		F Simple-Fast-Tow		G Capacitive Wireless		H Go the extra mile	
Selection Criteria	Weight [%]	Rated	Weighted Score	Rated	Weighted Score	Rated	Weighted Score	Rated	Weighted Score	Rated	Weighted Score	Rated	Weighted Score	Rated	Weighted Score	Rated	Weighted Score
The systems capacity allows high driving range	4	3	0,12	4	0,16	2	0,08	4	0,16	2	0,08	2	0,08	3	0,12	5	0,2
Possibility to charge without bother the user (time)	6	3	0,18	5	0,3	4	0,24	1	0,06	5	0,3	5	0,3	4	0,24	5	0,3
Quiet charging	5	5	0,25	2	0,1	5	0,25	5	0,25	3	0,15	5	0,25	5	0,25	3	0,15
Fast standard charging (home)	3	2	0,06	4	0,12	1	0,03	3	0,09	3	0,09	4	0,12	5	0,15	4	0,12
System charging capacity at parking fields (work)	4	2	0,08	4	0,16	4	0,16	4	0,16	4	0,16	4	0,16	4	0,16	4	0,16
Amount of stored energy and efficiency of charging with it	4	0	0	2	0,08	2	0,08	3	0,12	4	0,16	4	0,16	4	0,16	4	0,16
Shared charging station capacity (work & supercharge)	5	0	0	5	0,25	4	0,2	3	0,15	3	0,15	4	0,2	4	0,2	4	0,2
Adaptability to different standard electrical standards (sockets and power)	4	3	0,12	4	0,16	2	0,08	2	0,08	3	0,12	2	0,08	3	0,12	4	0,16
Ergonomical cord-charging solution	2	2	0,04	5	0,1	3	0,06	3	0,06	4	0,08	4	0,08	5	0,1	3	0,06
Cord charging solution is user friendly and adaptible to different charge currents	2	2	0,04	5	0,1	4	0,08	2	0,04	4	0,08	4	0,08	5	0,1	3	0,06
Low system cost	2	4	0,08	2	0,04	1	0,02	2	0,04	3	0,06	2	0,04	3	0,06	2	0,04
Environmental friendly	4	4	0,16	4	0,16	3	0,12	2	0,08	3	0,12	2	0,08	3	0,12	3	0,12
Charging Efficiency	5	2	0,1	4	0,2	2	0,1	3	0,15	2	0,1	3	0,15	4	0,2	3	0,15
Low levels of possible harmfull energy fields (human, pets, garage-stuffs)	6	4	0,24	5	0,3	3	0,18	4	0,24	1	0,06	4	0,24	3	0,18	1	0,06
Minimum and easy maintenance (possibly Self maintenance)	4	4	0,16	2	0,08	4	0,16	2	0,08	2	0,08	3	0,12	3	0,12	3	0,12
Robust design	6	4	0,24	2	0,12	4	0,24	3	0,18	4	0,24	2	0,12	2	0,12	4	0,24
Adaptability towards autonomous vehicles	3	3	0,09	5	0,15	5	0,15	2	0,06	5	0,15	5	0,15	5	0,15	5	0,15
Precision in parking (alignment to charger)	6	3	0,18	5	0,3	4	0,24	1	0,06	5	0,3	5	0,3	5	0,3	5	0,3
Minimum time for user to park	2	3	0,06	5	0,1	4	0,08	3	0,06	5	0,1	5	0,1	5	0,1	5	0,1
Easy to emergency recharge wherever you are	6	1	0,06	4	0,24	2	0,12	4	0,24	3	0,18	1	0,06	1	0,06	5	0,3
Acquired driving range in <11,5min	5	2	0,1	4	0,2	2	0,1	3	0,15	3	0,15	4	0,2	4	0,2	3	0,15
Steal safe	3	3	0,09	1	0,03	2	0,06	3	0,09	3	0,09	3	0,09	1	0,03	2	0,06
Fully functional for all normal seasonal weather	6	3	0,18	2	0,12	2	0,12	2	0,12	2	0,12	2	0,12	2	0,12	2	0,12
Safe for unexpected floodings or lightning strikes	3	3	0,09	2	0,06	3	0,09	3	0,09	3	0,09	3	0,09	2	0,06	3	0,09
	Total Score	2,72		3,63		3,04		2,81		3,21		3,37		3,42		3,57	
	Rank	8		1		6		7		5		4		3		2	
	Continue?	Don't develop		Combine with H		Don't develop		Don't develop		Don't develop		Analyze, don't develop		Analyze, don't develop		Combine with B	

Table J.2: The final first full-system concept scoring matrix, where the last iterated concept is labeled X1 and the reviewed concept X2.

		Concepts					
		A (Ref.) Plugless L2		X1 From B&H		X2 F&G and Oslo	
Selection Criteria	**Weight [%]**	**Rated**	**Weighted Score**	**Rated**	**Weighted Score**	**Rated**	**Weighted Score**
The systems capacity allows high driving range	4	3	0,12	5	0,2	5	0,2
Possibility to charge without bother the user (time)	6	3	0,18	5	0,3	5	0,3
Quiet charging	5	5	0,25	3	0,15	4	0,2
Fast standard charging (home)	3	2	0,06	5	0,15	5	0,15
System charging capacity at parking fields (work)	4	2	0,08	4	0,16	5	0,2
Amount of stored energy and efficiency of charging with it	4	0	0	4	0,16	5	0,2
Shared charging station capacity (work & supercharge)	5	0	0	4	0,2	4	0,2
Adaptability to different standard electrical standards (sockets and power)	4	3	0,12	4	0,16	5	0,2
Ergonomical cord-charging solution	2	2	0,04	5	0,1	3	0,06
Cord charging solution is user friendly and adaptible to different charge currents	2	2	0,04	5	0,1	5	0,1
Low system cost	2	4	0,08	1	0,02	3	0,06
Environmental friendly	4	4	0,16	3	0,12	4	0,16
Charging Efficiency	5	2	0,1	4	0,2	4	0,2
Low levels of possible harmfull energy fields (human, pets, garage-stuffs)	6	4	0,24	2	0,12	3	0,18
Minimum and easy maintenance (possibly Self maintenance)	4	4	0,16	2	0,08	3	0,12
Robust design	6	4	0,24	3	0,18	3	0,18
Adaptability towards autonomous vehicles	3	3	0,09	5	0,15	5	0,15
Precision in parking (alignment to charger)	6	3	0,18	5	0,3	5	0,3
Minimum time for user to park	2	3	0,06	5	0,1	5	0,1
Easy to emergency recharge wherever you are	6	1	0,06	5	0,3	5	0,3
Acquired driving range in <11,5min	5	2	0,1	3	0,15	5	0,25
Steal safe	3	3	0,09	2	0,06	2	0,06
Fully functional for all normal seasonal weather	6	3	0,18	2	0,12	2	0,12
Safe for unexpected floodings or lightning strikes	3	3	0,09	2	0,06	2	0,06
	Total Score	2,72		3,64		4,05	
	Rank	3		2		1	