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Improving **interoperability** between electric mobility and the electricity system

Towards a reference architecture for charging electrical vehicles

Allard Brand
18 September 2013

MASTER THESIS

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I hope that you will enjoy reading the current research. If you have any questions or comments, please do not hesitate to contact me.

Allard

Abstract

The current ways of energy provision will change dramatically in the coming decades. The European Union has committed to drastically reduce Europe's greenhouse gas emissions to 80-95% below 1990 levels in 2050. At the same time, electric mobility is getting significant attention in the Netherlands and many other countries.

The emergence of electric mobility introduces new threats and opportunities in relation to the electricity system, which require an increased degree of integration between the markets of electric mobility and the electricity system. The current architecture for electric mobility is inadequate, since there is no possibility to influence the charge process based on information from market parties such as the distribution system operator and/or the energy market. Charging can neither be influenced based on grid constraints nor the amount of (renewable) energy supply available. The main reason is that in the current situation, there is an absence of integration between the markets of electric mobility and the electricity system. In addition, the lack of a profitable business model can be identified. Because of the potential threats and opportunities and the impact that this could have on the business model, there is a need for further integration between the two markets.

The aim of the current research is to define a reference architecture based on the current developments and concepts from literature to help market players, such as Alliander, in making the right steps forward. The research is focused on the charging infrastructure in the public and semi-public space, concerning charge points for customers that cannot charge at home or need to charge during their travel. To structure the research, the Design Science Research Methodology (DSRM) is applied. In addition, we apply the enterprise architecture approach as proposed by Iacob et al. (2012). This approach is based on open standards; using the `Architecture Development Method' (ADM) from TOGAF, and ArchiMate as the modeling language and framework.

As main objectives, the reference architecture needs to (1) optimally integrate with the electricity system, (2) accommodate the adoption of renewable energy sources, (3) be aligned with European standardization developments and (4) have a positive impact on the current business model.

Based on a literature study, design choices and their consequences are described which form the basis of the reference architecture. The main design choices involve the concept of 'smart charging' and its implementations, and the shift of the energy contract by changing the formal end-user of electricity. Based on the literature study, a reference architecture is defined for electric mobility. To provide a path for implementation and migration, a migration architecture is established.

To validate the reference and migration architectures, a series of structured interviews have been carried out with a total of six interviewees. All interviewees acknowledged the problems in the current architecture. Overall, the interviewees acknowledged that the reference architecture would result in the objectives as stated in the current research. At the same time, some critical notes and improvements have been proposed. Based on these remarks, improved versions of the reference and migration architectures have been modeled that encompass the final artifacts of the current research.

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Acronyms

ADM	Architecture Development Method
BPM	Car and motor(ised) vehicle taxes (Dutch: 'Belasting voor personenauto's en motorvoertuigen')
BRP	Balance Responsible Party
CiMS	Chargepoint Interactive Management System
CDR	Charge Detail Record
CIR	Central Registry for Interoperability (Dutch: 'Centraal Interoperabiliteits Register')
CSO	Charge Spot Operator
CSP	Charge Service Provider
DG	Distributed Generation
DSO	Distribution System Operator
DSM	Demand Side Management
DSRM	Design Science Research Methodology
eCHS	European Clearing House System
E-REV	Extended-Range Electric Vehicle
EDF	Electricité de France
ENS	Energy Name Service
EV	Electric Vehicle
EVCOID	Electric Vehicle Contract ID
EVSE	Electric Vehicle Supply Equipment
EVSEID	Electric Vehicle Supply Equipment ID
FCEV	Fuel Cell Electric Vehicle
FEV	Full Electric Vehicle (also known as Battery Electric Vehicle)
HEV	Hybrid Electric Vehicle
IEC	International Electrotechnical Commission
M	(Electricity) Meter
NFC	Near Field Communication
OCHP	Open Clearing House Protocol
OCPP	Open Charge Point Protocol
PHEV	Plug-in Hybrid Electric Vehicle
RES	Renewable Energy Source
RFID	Radio Frequency Identification
SG-CG	Smart Grid Coordination Group
SM	Smart Meter (or 'Sub Meter' in Figure 10)
SO	System Operator
TFET-IT	Taskforce Energy Transition IT
TO	Transmission Operator
TSO	Transmission System Operator
V2G	Vehicle-2-Grid
XML	Extensible Markup Language

1 Introduction

Electric mobility is getting significant attention in the Netherlands and many other countries. Car manufacturers, consumers and grid operators show an increasing interest in the transition towards electric vehicles. Up to now, the transition has mainly focused on the development of electric vehicles and the realization of accessible charging infrastructure. However, the emergence of electric mobility introduces new threats and opportunities in relation to the electricity system, which require an increased degree of integration between the markets of electric mobility and the electricity system. The current research has as its goal to define a reference architecture with the purpose of facilitating interoperability between involved parties from the markets of electric mobility and the electricity system. In the current chapter an overview of the context and motivation behind the research will be given, as well as the adopted research method and approach. Also, an outline of the overall structure of the thesis will be given.

1.1 Context

The current ways of energy provision will change dramatically in the coming decades. The European Union has committed to reducing Europe's greenhouse gas emissions to 20% below 1990 levels in 2020, and by 80-95% in 2050 (European Commission, 2013). Eurelectric, the association of the electricity industry in Europe, even aims for carbon-neutral power in Europe by 2050 (Eurelectric, 2011). In order to make this happen, it is expected that renewable and sustainable energy sources will replace non-renewable energy sources such as coal. This process is widely regarded as the energy transition. Some visionaries even argue that we are at the beginning of the third industrial revolution, where internet technology and renewable energy will merge into a powerful "internet of energy", and people produce their own green energy in their homes, offices, and factories, and share it with each other just like we now create and share information online (Rifkin, 2011). Whether or not this revolution will occur, the general consent is that the increasing amount of distributed generation will relatively reduce the volume of demand for centralized production (Netbeheer Nederland, 2011).

Another development that is clearly evident is the increase of information flows within the energy market. Intelligent sensors are deployed in various parts of the energy distribution architecture (Enexis, 2010), and smart meters to digitally measure and communicate energy consumption are deployed to replace the current meters (Rijksoverheid, 2012). Worldwide, the concept of smart grids gets a lot of attention, both from the leading market players and academic community. According to the European Technology Platform Smart Grids, a smart grid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies (European Technology Platform Smart Grids, 2010). The European Commission acknowledged the essential role of smart grids in achieving Europe's objectives of reducing greenhouse gas emissions, and laid down a standardization mandate in 2011 to support the smart grid deployment througout Europe (European Commission, 2011).

An important element within the smart grid development and the energy transition itself is the emergence of electric mobility. On an international level, various governments establish targets, policies and plans for the deployment of electric vehicles (Foley, Winning, & Gallachóir, 2010). Electric mobility is not only considered as one of the key triggers of the energy transition, but also as a key facilitator of it. The main reasons are its significant impact on the electricity system and the relative convenient options to shift charge transactions in time. A smart or intelligent integration of electric mobility within the electricity network can illustrate the potential of balancing supply and demand, and therefore serve as an example for the transition towards 'smart' households and devices in the future (Hoekstra, 2010). Balancing supply and demand is important since decentralized production is subject to major peaks that often do not coincide with the demand for electricity (Netbeheer Nederland, 2011). Currently, the market for electric mobility runs separate from the electricity network to a large extent; there is no communication about charge transactions between both markets; electric vehicles are charged instantly and at a constant amount of power when plugged into a (public) charge point. Charging can neither be influenced based on grid constraints nor the amount of (renewable) energy supply available.

To support the transition towards electric mobility, the requisite infrastructure for charging electric vehicles is being realized throughout the Netherlands (E-laad, 2013). Figure 1 shows the travel movements associated with the use of public charging stations of December (left) and over the full year (right). A 'dot' represents a charge transaction of a specific car, and a 'line between dots' is the movement of the car between two consecutive charge transactions.

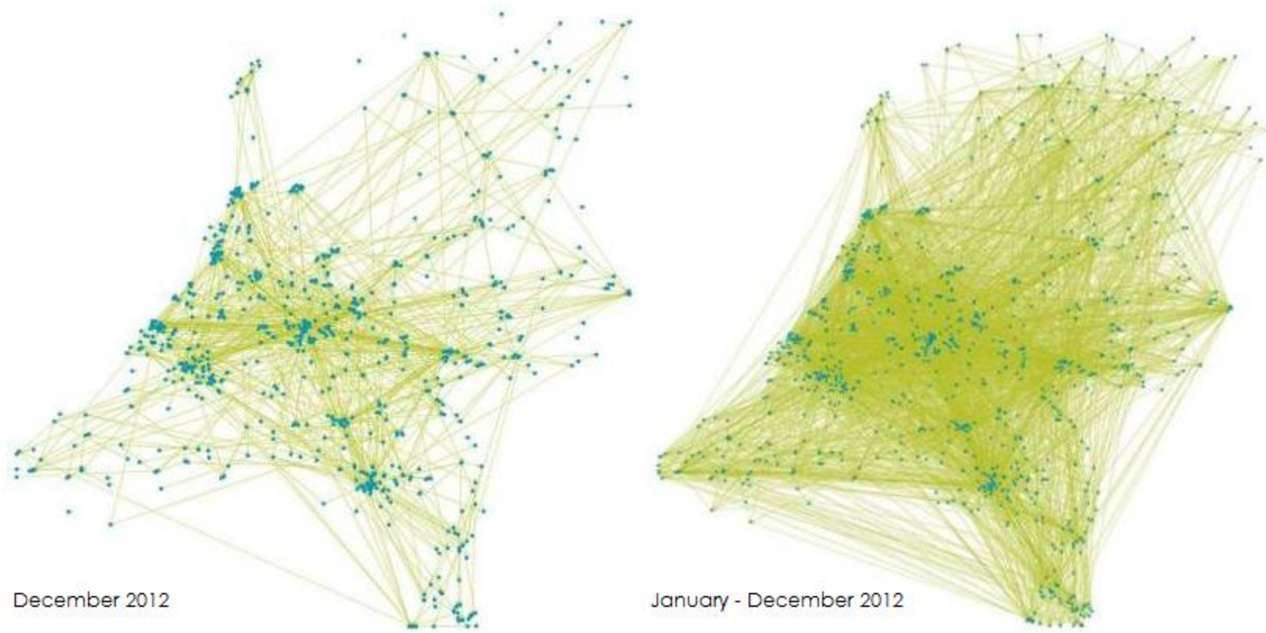


Figure 1: Public charging of electric vehicles spreads through the Netherlands (E-laad, 2013)

Although there is a widespread interest in electric mobility, many uncertainties are still present. The market for electric mobility is still immature and the allocation of market roles unclear. The (expected) developments in the electricity system increase this uncertainty. The aim of this research is therefore to clarify and propose structure for the market for electric mobility, with the purpose of facilitating interoperability between involved parties and a smart integration with the electricity grid. Based on the current developments and concepts from literature, a reference architecture will be defined in order to help market players in making the right steps forward.

1.2 Research setting

The current research is undertaken at the taskforce 'Energy Transition IT' within Alliander, an unlisted public limited utility company operating the electricity and gas networks in a large part of the Netherlands. Alliander transports electricity and gas to 3.3 million customers in the Netherlands (Alliander N.V., 2013).

The mission and vision of Alliander is to create a better society by creating sustainable energy systems. Alliander has a significant interest in the energy transition and is actively participating in order to realize this transition by conducting pilot projects. In order to shape the business and operational technology that is needed to enable the transition, the taskforce 'Energy Transition IT' (TF ET-IT) has been established. The taskforce has four strategic themes, which can be defined as follows:

1. **Electric Vehicles**
   The future of electric mobility is difficult to predict. At the same time, the potential impact on the electricity system is large. Alliander does research for future technologies in electric mobility and its impact on the electricity system. Together with the industry it aims at facilitating the development of a safe and customer-oriented charging infrastructure, in order to bring the market for electric vehicles into motion (Geerts & Groosman, 2013).

2. **Local Demand/Supply in Energy Management**
   The traditional energy system generation is characterized by large-scale, one-way flows of energy and demand management. In contrast, the energy system of the future is characterized by volatile decentralized input and therefore bi-directional energy flow. These are difficult to predict, causing the balancing to become more difficult, which in turn can decrease reliability of supply. By deploying local demand/supply concepts, (near) real-time balancing within the lowest level in the network is possible. Based on information from multiple points in the network, demand and supply can be controlled through incentives, such as price (Hagemans, Fens, Bollen, Schoot Uiterkamp, & Venekamp, 2013).

3. **Smart Buildings and Home Energy Management**
   In the energy system of the future, increased flexibility is needed in order to cope with fluctuations in energy supply. Household appliances will play a significant role in this by acting as buffer or offering the possibility to shift its use in time. Other goals are to help customers with the understanding of their energy consumption and encourage the (market) development of cleaner, more affordable energy applications (Schoot Uiterkamp, Venekamp, Geerts, Groosman, & Bollen, 2012)

4. **Dynamic Asset and Grid Management**
   Assets are all tangible operating equipment with a former, actual or planned deployment in the electricity, gas or telecommunications network owned or managed by Liander. The main focus is twofold: increasing reliability and availability of the assets and grid on one side, and reducing its costs and risks on the other side (Giesberts, Hagemans, Klein, Boon, Roling, & Bakker, 2012).

The current research focuses on the theme of electric vehicles, but has significant overlap with the theme of local demand/supply in energy management as well. The taskforce is interested in the development of a reference architecture because of the potential impact of electric mobility on its core business; operating the electricity grid.

1.3 Objectives

As explained in the introduction, the aim of this research is to clarify and propose structure for the market for electric mobility, with the purpose of achieving interoperability between involved parties from the markets of electric mobility and the electricity system. Based on actual developments and concepts from literature, a reference architecture will be defined in order to help market players, such as Alliander, in making the right steps forward.

1.3.1 The concept of a reference architecture

The concept of architecture has been defined as the fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution (IEEE, 2000). A reference architecture captures the essence of existing architectures, and the vision of future needs and evolution to provide guidance to assist in developing new system architectures (Cloutier, Muller, Verma, Nilchiani, Hole, & Bone, 2010).

1.3.2 The concept of interoperability

Generally speaking, interoperability is the ability of two systems to understand one another and/or use one another's functionality. In the context of networked enterprises, interoperability refers to the ability of interactions (exchange of information and services) between enterprise systems (Chen, Doumeingts, & Vernadat, 2008).

1.3.3 Main objective

The main objective of the current research can be translated into:

"To define a reference architecture for electric mobility with the purpose of facilitating interoperability between involved parties from the markets of electric mobility and the electricity system, in order to realize a smart integration of electric vehicles within the electricity system"

We define a "smart integration of electric vehicles within the electricity system" as the ability of controlling the charging process of electric vehicles by intelligence, influencing the transfer of electricity based on customer preferences, (near) real-time information on electricity demand and supply, and capacity constraints from the electricity grid.

1.4 Research questions

In order to achieve the main research objective that is presented in the previous section, the following central research question is defined:

"How to define a reference architecture for electric mobility that facilitates interoperability between involved parties from the markets of electric mobility and the electricity system, and realizes a smart integration of electric vehicles in the electricity system?"

In order to answer the central research question, a decomposition of the main problem is applied. This decomposition identifies the components or sub questions that assist towards answering the central research question. The following sub questions are defined:

1. **What is electric mobility?**
   In order to understand the current architecture for electric mobility, a clear definition of electric mobility is desirable. In this sub question electric mobility will be defined and its history and background reviewed.

    a. What is the definition of electric mobility?
    b. What is the history and background in the developments of electric mobility?
    c. What is the state of the art in the infrastructure for charging electric vehicles?

2. **What is the current architecture for electric mobility?**
   In order to work towards a reference architecture, the first step is a thorough analysis of the current situation. Therefore, the markets of both electric mobility and electricity will be analyzed and synthesized into an architectural overview.

    a. What must be stated in a model of the electric mobility market?
    b. What must be stated in a model of the electricity market?
    c. How do the market roles of the electricity and electric mobility markets relate to each other?
    d. What are the main concepts and processes in the current architecture?

3. **What is the motivation behind a reference architecture for electric mobility?**
   In this sub question the objectives for the reference architecture will be defined on basis of the main problems and limitations in the current situation.

    a. What are the main problems and limitations of the current situation?
    b. Which objectives can be defined to serve as a basis for the reference architecture?
    c. What are possible solutions to the problems and limitations, taking the objectives into account?

4. **What must be stated in a reference architecture for electric mobility?**
   This sub question will result in a reference architecture for electric mobility, based on the objectives and motivation as identified in the previous research question.

    a. What is a reference architecture and what is its use?
    b. How can we structure the reference architecture in order to enhance its understandability and effectiveness?

c. What are the gaps between the reference architecture and the current situation?

5. **What is the evaluation of the reference architecture?**
   We want to evaluate whether the proposed reference architecture fulfills the goals stated as part of the main objective (facilitate interoperability and realize smart integration). For the evaluation we want to draw on the expertise of external stakeholders.

   a. How can we evaluate and validate the reference architecture?
   b. What is the evaluation of the reference architecture?

1.5 Research methodology

To structure the current research, the Design Science Research Methodology (DSRM) as defined by Peffers, Tuunamen, Rothenberger, & Chatterjee (2007) will be applied. Figure 2 shows a general overview of the DSRM:

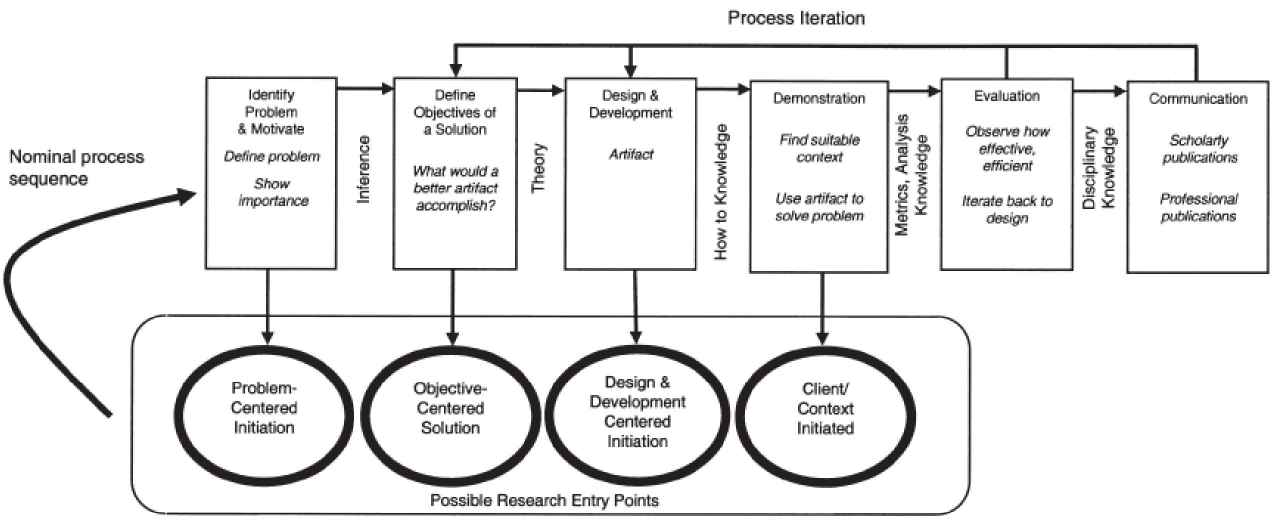


Figure 2: Overview of the DSRM (Peffers, Tuunamen, Rothenberger, & Chatterjee, 2007)

Based on the DSRM, the following phases have been distinguished in the current research:

1. **Problem identification and motivation**
   During this initial phase, the specific research problem is identified and defined, and the research is motivated by showing its importance.

2. **Defining the objectives for a solution**
   In the second phase the objectives for the solution will be defined; which includes a definition of how the reference architecture is expected to support solutions to the problems addressed in the previous phase. Resources include knowledge of state of problems and current solutions.

3. **Design and development**
   This phase involves the design and development of the reference architecture, describing the to-be situation of the market for electric mobility.

4. **Demonstration and evaluation**
   In the DSRM, the phases of 'Demonstration' and 'Evaluation' are two separate phases. A thorough demonstration and evaluation would however go far beyond what is possible in a master project. In the current research, the phases of demonstration and evaluation are therefore adopted into a single phase. In

this phase, the reference architecture is presented to experts and validated by means of a structured interview in order to measure how well the reference architecture has been defined and helps in further developments.

5. **Communication**
   The current research will be presented in a colloquium that is part of the examination of the master project. In addition, the main results of the current research will be processed into a scholarly publication.

1.6 Thesis structure and reading guide

The current research has been structured as follows. In the first chapter the research is introduced and motivated. The second chapter introduces the reader into the field of electric mobility, covers its history and background and describes the state of the art in charging infrastructure. In this chapter we will work towards a model for electric mobility. Chapter three introduces the reader to the electricity system. In the fourth chapter a problem analysis is performed, based on the information from the previous chapters. In chapter five, our approach towards enterprise architecture is described and the objectives for the reference architecture are defined. In chapter six, the models for electric mobility and the electricity market are synthesized into a model reflecting the current architecture. Based on the objectives for the reference architecture, it will be made clear that the current architecture is insufficient. In chapter seven the first steps towards the design of the reference architecture will be made; on basis of a literature study the various choices to be made are analyzed. Chapter eight will introduce the reference architecture. In chapter nine, a migration architecture will be presented as a migration path towards the reference architecture. What follows in chapter ten is the validation of the reference architecture. Based on the feedback during from the validation with experts, an improved reference architecture is presented in chapter eleven. Chapter twelve is the final chapter of the current research, and presents the conclusions and answers to the research questions. In this chapter, a reflection is given on the work done and possibilities for future work are proposed.

The following table gives an overview of the research structure, and maps each of the chapters to the applicable phase of the DSRM methodology and research question(s) that are covered:

Chapter	Applicable DSRM phase	Research Questions
1. Introduction	Problem identification & motivation	-
2. Introducing electric mobility	Problem identification & motivation	RQ 1 RQ 2a
3. Introducing the electricity system	Problem identification & motivation	RQ 2b
4. Problem analysis	Problem identification & motivation Define objectives of a solution	RQ 2c – 2d RQ 3a,b
5. Approach	Define objectives of a solution	RQ 4a, b
6. Current architecture	Problem identification & motivation	RQ 2
7. Design alternatives	Design & development	RQ 3c
8. Reference architecture	Design & development	RQ 4
9. Migration architecture	Design & development	RQ 4
10. Validation	Demonstration Evaluation	RQ 5
11. Improved architectures	Design & development	RQ 4
12. Conclusions	Communication	*All research questions*

Table 1: Thesis structure and traceability matrix

Figure 3 shows a graphical representation of the research structure as described above. Each of the green blocks represents a chapter of the current research. The gray blocks map each of the chapters to the applicable phase of the DSRM methodology.

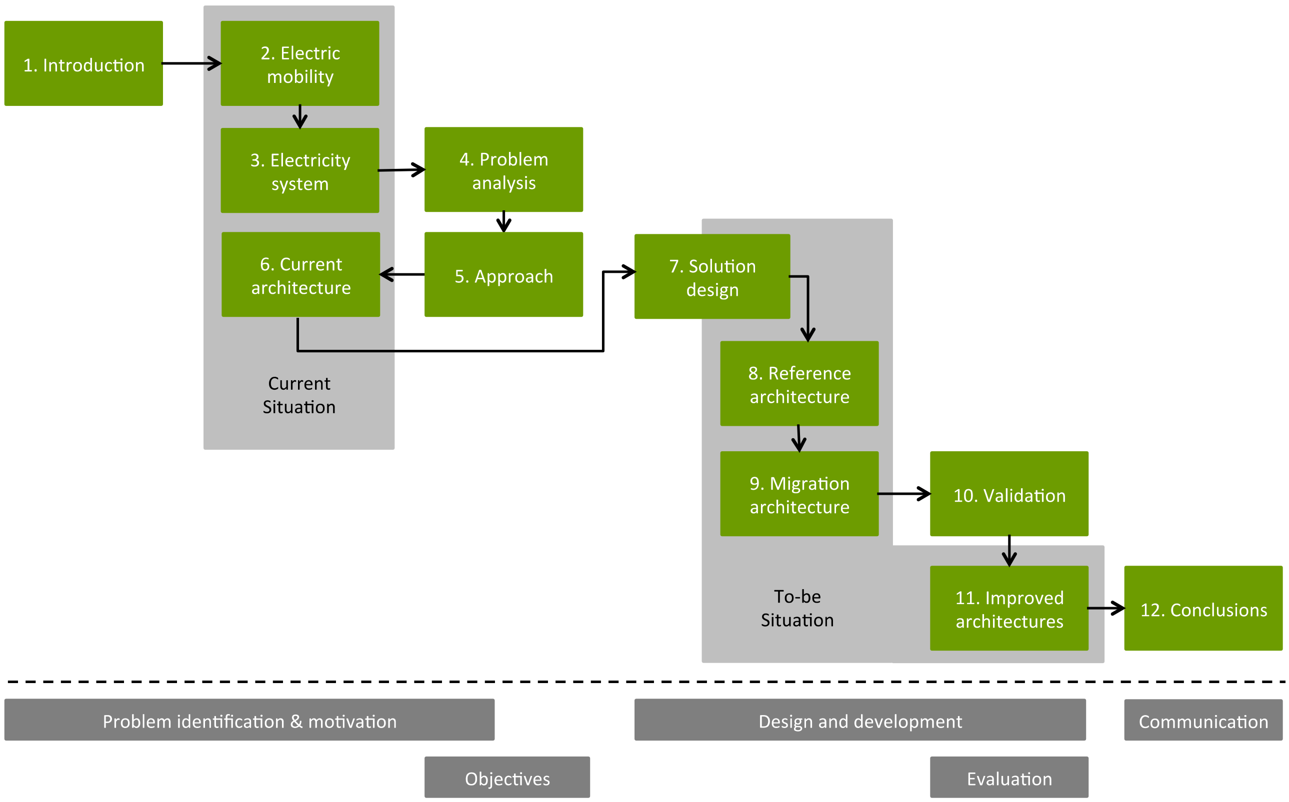


Figure 3: Research structure

1.7 Practical and scientific relevance

The current research is relevant in two ways:

1. **Practical relevance**
   As mentioned in the previous sections, the market for electric mobility is still immature and in full motion. The reference architecture as defined in the current research aims to help market players, such as Alliander, in making the right steps forward by providing a solid and comprehensive framework for further work. Insight is given into the current and desirable situation for electric mobility.

2. **Scientific relevance**
   The current research works towards a reference architecture and is built upon concepts from enterprise architecture (TOGAF, ArchiMate) and business modeling (e3value). The concepts of these fields are applied in a concrete case, showing its relevance and validating its use. The main results of the current research will be processed into a scholarly publication, disclosing the acquired knowledge during this research.

1.8 Modeling language and notation

In the current research, various models are presented. For these models, two modeling languages are used: the ArchiMate ® language and notation for architectural models, and e3value for business modeling.

1.8.1 ArchiMate

ArchiMate is an open and independent modeling language for enterprise architecture that is supported by different tool vendors and consulting firms. ArchiMate provides instruments to enable enterprise architects to describe, analyze and visualize the relationships among business domains in an unambiguous way. ArchiMate enables modeling of the architecture domains defined by TOGAF ®, a proven enterprise architecture methodology and framework used by the world's leading organizations (The Open Group, 2013).

The ArchiMate language and notation consists of various types of concepts and relationships. Figure 4 gives an overview of the relevant concepts from the ArchiMate language and notation that are applied in the current research, including their meaning.

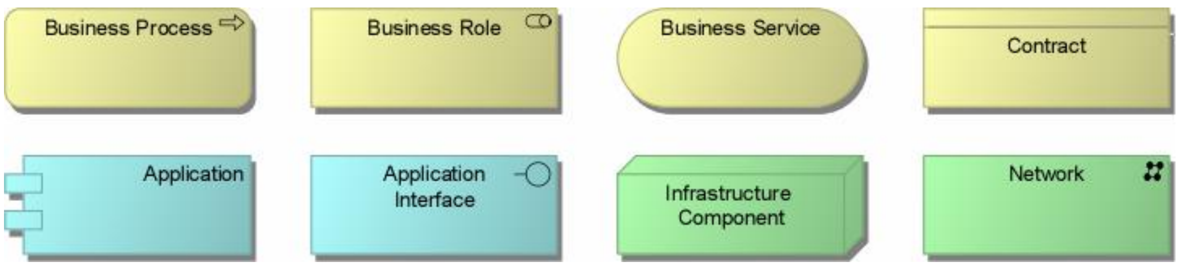


Figure 4: Applied concepts from ArchiMate ® and their meanings (The Open Group, 2012)

Table 2 and Table 3 give an overview of the structural and dynamic relationships within ArchiMate.

Relationship	Description	Notation
Association	The association relationship models a relationship between objects that is not covered by another, more specific relationship	
Access	The access relationship models the access of behavioral concepts to business or data objects	
Used by	The used by relationship models the use of services by processes, functions, or interactions and the access to interfaces by roles, components, or collaborations	
Realization	The realization relationship links a logical entity with a more concrete entity that realizes it	
Assignment	The assignment relationship links units of behavior with active elements (e.g., roles, components) that perform them, or roles with actors that fulfill them	
Aggregation	The aggregation relationship indicates that an object groups a number of other objects	
Composition	The composition relationship indicates that an object consists of a number of other objects	

Table 2: Structural relationships in ArchiMate ® (The Open Group, 2012)

Relationship	Description	Notation
Flow	The flow relationship describes the exchange or transfer of, for example, information or value between processes, function, interactions, and events	
Triggering	The triggering relationship describes the temporal or causal relations between processes, functions, interactions, and events	

Table 3: Dynamic relationships in ArchiMate ® (The Open Group, 2012)

1.8.2 e3value

In the current research, the e3-value methodology is applied to compare business models and its value exchanges. The e3-value methodology has been developed to model a value web consisting of actors who create, exchange, and consume things of economic value such as money, physical goods, services, or capabilities. It is an ontology-based methodology for modeling and designing business models for business networks incorporating concepts from requirements engineering and conceptual modeling (Gordijn, 2003). The following table gives an overview of the relevant concepts and their notation used within e3-value:

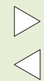
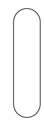
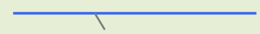
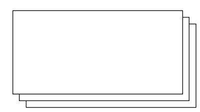
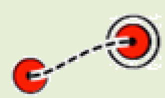
Concept	Description	Notation
Actor	An actor is (perceived by its environment as) an independent economic (and often also legal) entity	
Value Object	Actors exchange value objects, which are services, goods, money, or even consumer experiences. The important point here is that a value object is of value for one or more actors	e.g. '*money*'
Value Port	An actor uses a value port to show to its environment that it wants to provide or request value objects. The concept of ports enables us to abstract away from the internal business processes, and to focus only on how external actors and other components of the value model can be 'plugged in'	
Value Interface	Actors have one or more value interfaces. In its simplest form, a value interface consists of one offering, but in many cases, a value interface groups one or more in- and outgoing value offerings	
Value Exchange	A value exchange is used to connect two value ports with each other. It represents that two actors owning the connected ports are willing to exchange value objects with each other	 money
Market Segment	A market segment is a concept that breaks a market (consisting of actors) into segments that share common properties. Accordingly, our concept market segment shows a set of actors that for one or more of their value interfaces, value objects equally from an economic perspective	
Scenario Paths	It often occurs that, to satisfy an end-consumer need, numerous actors have to exchange objects of value with each other. Scenario paths show the value exchanges that should occur as a result of a consumer need (start stimulus). The last segment(s) of a scenario path is/are connected to a stop stimulus.	

Table 4: Definition of relevant e3-value concepts (Gordijn & Akkermans, 2003)

2 Introducing electric mobility

The field of electric mobility is relatively novel. In this chapter the history and background of developments in the area of electric mobility are reviewed, with the purpose of introducing the reader to the field.

2.1 Introducing the Electric Vehicle

Electric mobility is getting significant attention in the Netherlands and many other countries. Car manufacturers, consumers and grid operators show an increasing interest in the production of electrical vehicles. The Dutch government supports the transition to electric vehicles and promotes the use electric cars and semi-electric cars by means of an exempt from additional tax liability (fiscal surcharge), road tax and BPM. As can be seen in Table 5, one of their objectives is to have one million electric cars in the Netherlands in 2025 (Rijksoverheid, Elektrisch rijden, 2012).

Period	Market development	Expected number of electrical vehicles
2009 – 2011	Development	10 – 100's
2012 – 2015	Introduction	15.000 – 20.000
2015 – 2020	Growth	200.000
> 2020	Maturity	1.000.000 in 2025

Table 5: Objectives for growth of electric vehicles in the Netherlands (Tweede Kamer der Staten-Generaal, 2009)

On an international level, the same trend can be seen: various governments establish EV targets, policies and plans for the deployment of EVs. One of the main reasons is the commitment of the European Union to drastically reduce Europe's greenhouse gas emissions (European Commission, 2013). The following table is obtained from a study by Foley, Winning & Gallachóir (2010):

Country	Target
Austria	2020: 100,000 EVs deployed
Australia	2050: up to 65% of car stock
Canada	2018: 500.000 EVs deployed
Denmark	2020: 200.000 EVs
France	2020: 2.000.000 EVs
Germany	2020: 1.000.000 EVs
Ireland	2020: 10% EV market share
New Zealand	2040: 60% market share
Spain	2014: 1.000.000 EVs deployed
USA	2015: 1.000.000 PHEV stock

Table 6: International electric mobility targets (Foley, Winning, & Gallachóir, 2010)

2.1.1 Definition of electric mobility

Before continuing the current research, it is important to establish an unambiguous definition of electric mobility. Based on the definition from Gartner (2012), we define electric mobility as follows:

Electric mobility (or e-mobility) represents the concept of using electric technologies, in-vehicle information, and communication technologies and connected infrastructures to enable the electric propulsion of vehicles and fleets.

2.1.2 Definition of electric vehicles

Closely related to the concept of electric mobility is the concept of electric vehicles (EV). In this research the definition as formulated by the International Electrotechnical Commission (IEC), a worldwide organization for standardization will be used. This definition is worded as follows:

"Any vehicle propelled by an electric motor drawing current from a rechargeable storage battery or from other portable energy storage devices (rechargeable, using energy from a source off the vehicle such as a residential or public electric service), which is manufactured primarily for use on public streets, roads or highways." (International Electronical Commission, 2012)

2.1.3 Classification

According to the Tennessee Valley Authority, an electricity corporation owned by the U.S. government, four main types of electric vehicles can be distinguished (Tennessee Valley Authority, 2013). The four types that are identified are displayed in Figure 5. This figure itself is obtained from ICU, part of Alfen, the market leader in the Netherlands in the area of transformer substations (ICU, 2011).

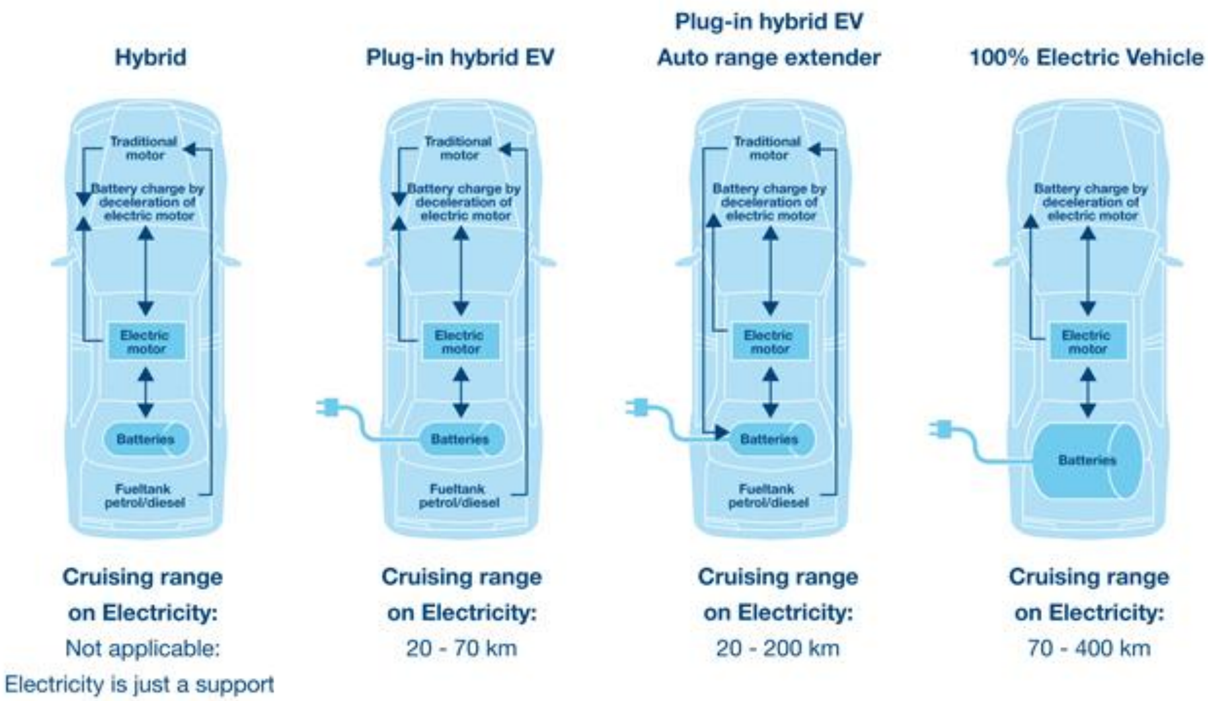


Figure 5: Types of EV (ICU, 2011)

Geerts & Groosman (2013) use the same classification, but mention a fifth type: the Fuel Cell Electric Vehicle (FCEV). This type is also an electric vehicle, but uses hydrogen instead of a battery as an energy source. The hydrogen is converted into electricity and water in a fuel cell by means of a chemical reaction. Because this type of vehicle has no electric engine we will disregard it in the remainder of this research. An example FCEV is the Audi Q5-FCEV.

Based on the sources mentioned above, we will use the following classification in the current research:

I. **Hybrid Electric Vehicle (HEV)**
This type of EV uses two or more distinct power sources in order to move. Electricity is just a support, not the main engine. The battery is charged by the deceleration of the electric engine. An example HEV is the Toyota Prius.

II. **Plug-in Hybrid Electric Vehicle (PHEV)**
This type of EV is similar to the HEV, but introduces the possibility to charge the battery by plugging the vehicle in to the electricity grid. The advantage is that this allows the EV to move a (limited) range without using the internal combustion engine at all. An example PHEV is the Chevrolet Volt.

III. **Extended-Range Electric Vehicle (E-REV)**
This type of EV has a full electric engine, supported with an auxiliary fuel engine that can charge the battery and subsequently extend the range. An example E-REV is the Opel Ampera.

IV. **Battery Electric Vehicle or Full Electric Vehicle (FEV)**
This type of EV merely has a full electric engine; no fuel engine is present. Examples of FEVs are the Nissan Leaf or the Tesla Model S.

2.2 Market overview

The market model for charging electric vehicles shows the properties of a two-sided market (TNO & Innopay, 2010). In a two-sided market there are two types of parties that interact with each other, which can be supported by one or more intermediary actors. A characteristic of a two-sided market is that each of the types of parties has its own needs. Another important characteristic is that there are network effects: the growth of one of the two types of parties has a positive effect on the growth of the other type of parties. Examples of two-sided markets can be found in the telecommunication & banking sector. When looking at the banking sector, example market models are found in electronic payment networks such as MasterCard, Visa and the Dutch iDeal model. In each of these market models, agreements are established between suppliers (banks) and buyers and sellers, which allow buyers and sellers to experience a uniform service, whilst still having competition and innovation.

Within electric mobility, the two sides of the market can be defined as follows:

1. **Customer**; the user of EV charge services
2. **Charge Provider**; providing the EV charge services

2.2.1 Concepts and services

The two sides of the electric mobility market introduced above interact with each other in various ways. Figure 6 shows the main concepts and services on a high level of abstraction.

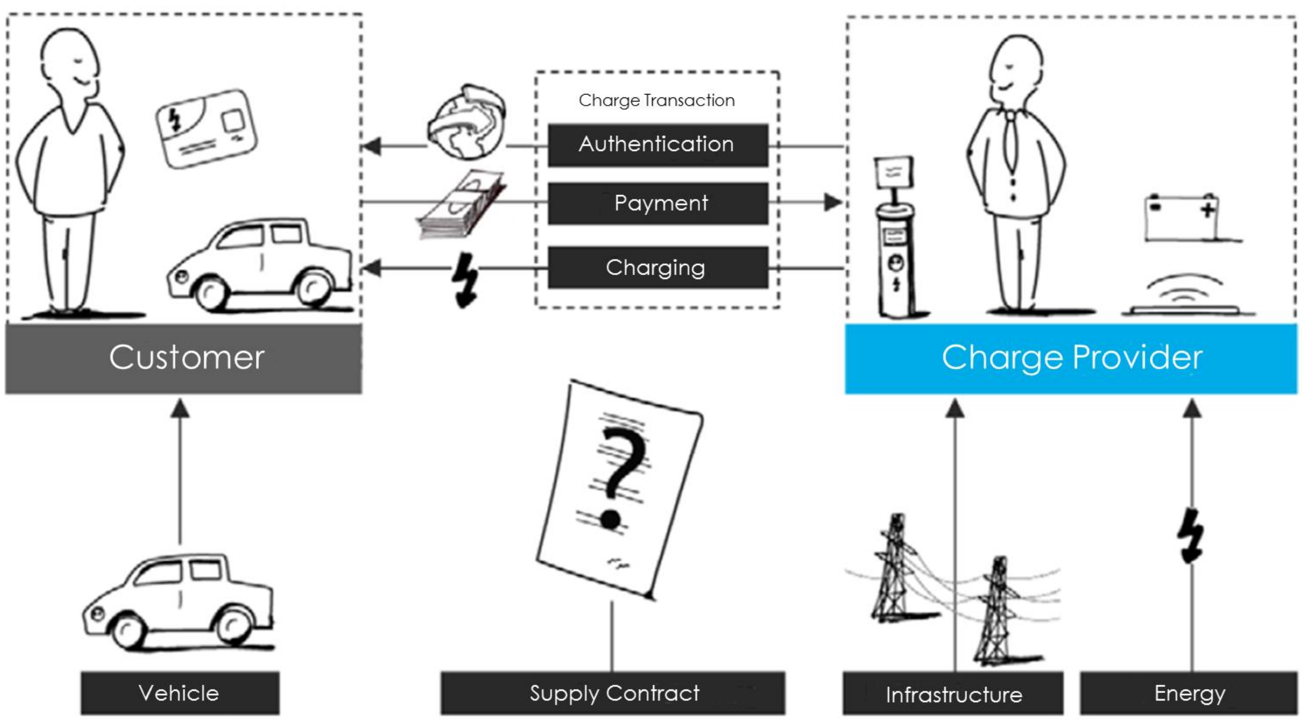


Figure 6: Concepts and services, adapted from TNO & Innopay (2010)

In the high level overview presented in Figure 6, the two sides of the market are represented as actors. The customer is related to the electric vehicle, and is responsible for charging the vehicle. The charge provider is related to the charge infrastructure, which he makes available to the customer in order to provide charge services. By means of the charge provider, energy is delivered to the electric vehicle. The delivery of energy is an element of the charge transaction. However, before this part of the charge transaction can start, the customer needs to be authenticated and arrangements about the payment need to be made. The supply contract can be fulfilled by different roles, and is therefore drawn as a separate concept (TNO & Innopay, 2010).

Another essential concept that has not been identified above is roaming. A cellular customer is roaming whenever it automatically uses mobile services in a visited network, when travelling outside the geographical coverage area of its home network. Lutz & Fluhr define e-mobility roaming as the seamless experience of an e-mobility customer to use a charging station that its standard e-mobility provider is not responsible for. Also, a roaming agreement typically contains arrangements on the financial settlement of provided services (Lutz & Fluhr, 2010).

2.2.2 The market for electric mobility

The history of the EV charging infrastructure in the Netherlands started in 2008, when Eneco introduced the first public charge point, the NRGSPOT. This charge point was part of a demonstration project in Rotterdam, and allowed customers to charge their electric vehicle for a small charge (Eneco, 2008). As the number of electric vehicles in the Netherlands increased, the Dutch network operators realized that a large-scale introduction of electric vehicles would significantly influence their electricity grids. To be able to predict and cope with these effects, cooperating network operators started the foundation 'E-laad'. One of its main goals was to realize 10.000 public charging points in the Netherlands. In October 2009, E-laad commissioned its first public charging point, located at the parking lot of the University of Tilburg (Technisch Weekblad, 2009).

In July 2009, the Dutch government published a plan of action for the development of electric mobility in the Netherlands. In this document, electric vehicles are considered as a highly promising option in order to increase sustainability, strengthen the energy position and structurally boost the economy. One of the contributions from the government was the establishment of the so-called "Formule E-team", with members from sectors regarded as essential for a successful introduction and deployment of EV. The primary task of the team was to promote the market development and removal of barriers in EV developments (Tweede Kamer der Staten-Generaal, 2009).

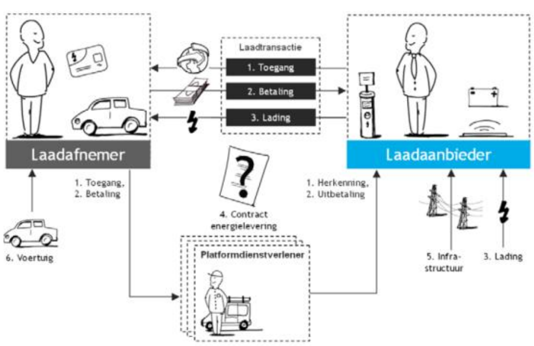


Figure 8: Provider model (TNO & Innopay, 2010)

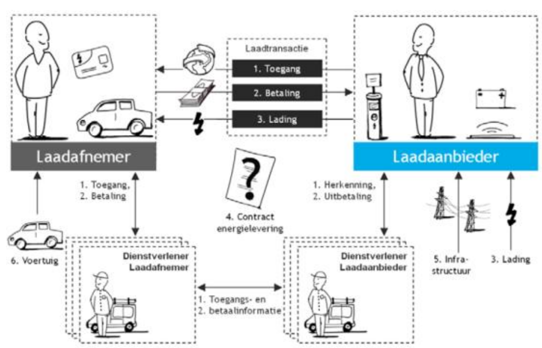


Figure 7: Network model (TNO & Innopay, 2010)

In the year that followed, EnergieNed and Netbeheer Nederland commissioned Accenture to conduct an initial study to work towards a market model for electric vehicles. In this study, market models from the telecom & banking sector have been analyzed to serve as an example. The intention of the study was to open up the dialogue between relevant market parties. The results, made public in April 2010, presents three market models and agrees on the "provider model" as the preferred model. In this model, a service provider acts as an intermediary between customer and charge point operator (EnergieNed & Netbeheer Nederland, 2010).

In a subsequent study by TNO & Innopay (2010), the provider model is further analyzed, and another model, the "network model", is introduced. In this model, the service provider is split into two service providers: one for the customer and one for the charge point operator. In the longer term, this network model is desirable to realize the most freedom of choice, innovation and a dynamic market. Following on the study by TNO & Innopay, Innopay proposed the necessary processes needed for the further development of a market model for EV charging services. Based on a consultation process in which 25 parties participated, this has led to a roadmap action for the implementation of a market model for EV charging services (Innopay, 2011). In the current situation, the market is (still) structured accordingly to the provider model.

For the purpose of readability, only a selection of developments has been described in the current section. For a complete overview of these historic developments in electric mobility, please refer to appendix E.

2.2.3 Market roles

A lot of sources define their view on the market roles that are present in the market of electric mobility. In this section the results of a literature study on market roles for electric mobility are presented; relevant market roles are identified and definitions for each of the roles are given. Various sources have been analyzed. Relevant sources include the European standardization organizations CEN, CENELEC & ETSI, the International Electrotechnical Commission (IEC), and the Green eMotion project.

In the current market for electric mobility, five main roles are evident. These roles are displayed in Figure 9. The charge spot operator (CSO) is responsible for managing and operating several charge points. The charge service provider (CSP) is the central point of contact for the customer, and provides its customers with the ability to charge at public charge points, irrespective of the charge spot operator. In order to realize this, the role of a clearing house exists, which unburdens both charge spot operators and charge service providers, making it possible to provide roaming functionality to their customers. The original equipment manufacturer (OEM) is the producer of electric vehicles and/or charge points, and provides EV related services. The remaining role is the role of electric vehicle owner and/or driver. Theoretically, this role aggregates several sub roles: the owner of the electric vehicle, the person driving the electric vehicle and influencing its charging needs, and the charge service customer, who has a contract with the charge service provider for the use of its services.

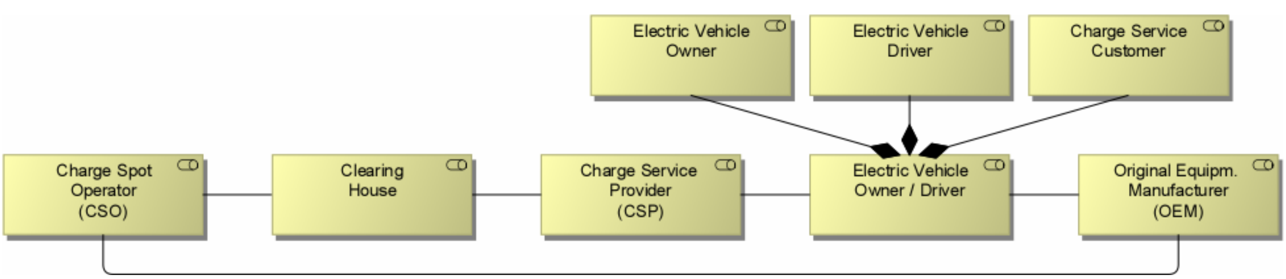


Figure 9: Overview of market roles for electric mobility

Based on the literature study, we define the market roles as follows:

- **Electric Vehicle Owner / Driver**
  Person or legal entity using the vehicle and providing information about driving needs and consequently influences charging patterns (IEC, 2012)

  Identified in: (Green eMotion, 2013), (IEC, 2012), (TNO & Innopay, 2010) and (E-clearing.net, 2012)

(list continues on the next page)

- **Charge Service Provider (CSP)**
  Operates as a contract party for the customer, and takes care of the end user authentication and billing processes (E-clearing.net, 2012)

  Identified in: (Green eMotion, 2013), (IEC, 2012), (TNO & Innopay, 2010), (E-clearing.net, 2012) and (CEN, CENELEC & ETSI, 2012)
  Other abbreviations: EVSP = Electronic Vehicle Service Provider, ESP / MSP = e-Mobility Service Provider

- **Charge Spot Operator (CSO)**
  Has a contract with energy supplier and offers access and charging services at charge points. The CSO purchases electricity from the energy supplier and will send the charge service provider an invoice for the delivered electricity (E-clearing.net, 2012) (TNO & Innopay, 2010)

  Identified in: (Green eMotion, 2013), (IEC, 2012), (TNO & Innopay, 2010), (E-clearing.net, 2012) and (CEN, CENELEC & ETSI, 2012)
  Other abbreviations: EIOP = e-Mobility Infrastructure Operator, EVSE Operator = Electric Vehicle Supply Equipment Operator

- **Original Equipment Manufacturer (OEM)**
  An entity that produces electric vehicles and provides EV services related to their own build electric vehicles (Green eMotion, 2013). Can also refer to the manufacturer of charge points.

  Identified in: (Green eMotion, 2013) and (IEC, 2012)

- **Clearing House**
  The clearing house acts as a roaming enabler. It can collect contractual data either from the marketplace, ask the involved parties by itself, or stores a subset of contract information in its own database. It forwards CDRs to the corresponding EVSP of a customer who has charged at a foreign location. The clearing house does the authentication of charging requests when it is asked by the EVSE operator (Green eMotion, 2013)

  Identified in: (Green eMotion, 2013), (IEC, 2012) and (E-clearing.net, 2012)

For a comprehensive overview of the literature study, please refer to appendix A.

2.3 Charging infrastructure

The current infrastructure for charging electric vehicles can be divided into three areas. For the municipality of Uithoorn, De Haas & Idema (2013) classified the various types and their associated costs:

1. **Loading on private property**
   This type of charge point is connected to an existing electrical installation; charging is executed 'behind the meter'. Costs related to the installation and the design on average € 1,000. The New Motion has a business model where owners of private charge points can offer their charge point to others (The New Motion, 2013).

2. **Loading in semi-public space**
   Examples are charge points at car parks of businesses and/or shopping centers. Owners of these locations often choose to offer charge services for free. This allows all electric vehicles to visit, and no complex settlement of costs is needed. For the electrical connection, existing network connections are generally used. Charge points for the semi-public space are available from approximately € 1,500.

3. **Loading in public space**
   Charge points for customers that cannot charge at home or need to charge during their travel. These charge points need to be robust, have their own network connection and need technology for authentication and communication. Total costs range between € 5,000 and € 8,000.

The current research focuses on charging infrastructure in the public and semi-public space. The main reason behind this decision is that most citizens do not have a private driveway and depend on public charging infrastructure.

Roughly speaking, there are two different approaches to the installation, operation and management of the charging infrastructure. In the first approach, these responsibilities are an extension of the regulated distribution system operator (DSO). This approach is often referred to as the "DSO model", where the DSO owns and operates the public charging infrastructure. In the second approach, the responsibilities are performed by public bodies or private undertakings, and managed within a competitive market (EDSO, 2012). In 2012, the minister of EL&I indicated that the placement and operation of the public charging infrastructure should be considered as a market task, and not as part of the public electricity grid. The second approach therefore reflects the chosen and current situation in the Netherlands, where the DSO is responsible for providing the connection towards a charging station, including the meter provided in conformance with its statutory duties. The realization, operation and management of the charging infrastructure itself are outside the scope of the DSO. For these responsibilities, a separate role of charge spot operator (CSO) is introduced, as described in section 2.2.3.

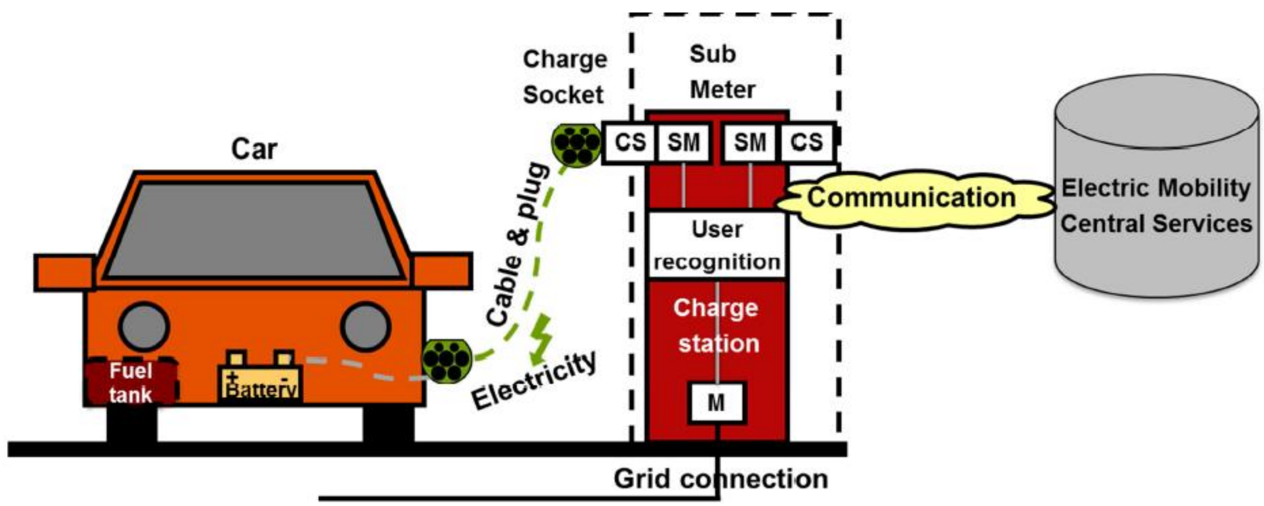


Figure 10: Overview of the current charging infrastructure (Geerts & Groosman, 2013)

In Figure 10, an overview of the current charging infrastructure is given. In this overview, the following abbreviations are used: 'CS' refers to charge socket, 'SM' to sub meter and 'M' to meter. Since the current regulation does not provide any specific directives for the realization of charge points, the connection for a charge point is currently treated in the same manner as a domestic connection. Therefore, a smart meter and safety fuse must be located on a meter board that is originally designed for households, taking up a lot of space within the charging infrastructure. In addition to the required smart meter that registers the aggregated usage of both outlets ('charge socket' in the figure), two individual meters are located to register meter readings per charge session. Also, separate safety fuses are located for each of the outlets. In essence, the smart meter and safety features are therefore redundant, taking up unnecessary space and costs (Geerts & Groosman, 2013).

In the current architecture, a public charge point has its own grid connection, and therefore needs an associated electricity contract. This situation implies that for customers, there is no possibility to choose between electricity suppliers. The energy supplier has to be the same for all users of the charging services (EDSO, 2012)

2.4 Conclusions

In the current chapter a concise introduction in the field of electric mobility is given; concepts and services are defined and an overview of the market and its history are given.

3 Introducing the electricity system

Electric vehicles need to be charged with electricity in order to function. For this reason, an important relationship exists between electric mobility and the electricity system. In the current chapter, the main concepts within the current electricity system are explored.

3.1 The electricity system and its subsystems

The electricity system can be defined as the combination of systems that produce, transport and deliver power and provide related services, including the actors and institutions that control the physical components of the system (De Vries, 2004). As illustrated in Figure 11, the electricity system consists of a technical and an economic subsystem.

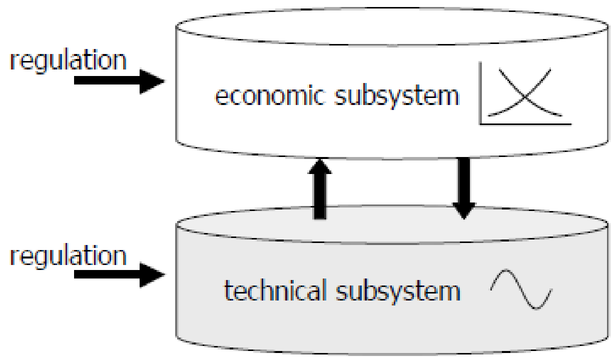


Figure 11: High-level overview of the electricity system (De Vries, 2004)

3.1.1 The technical subsystem

The technical subsystem is defined as the physical part of the electricity system, consisting of the hardware that physically produces and transports electric energy to customers, as well as the devices that use the electricity (De Vries, 2004). The purpose of the technical subsystem is to physically connect producers and consumers of electricity. The system consists of high voltage, medium voltage and low voltage networks, where high voltage is used for longer distance electricity transmission and lower voltage networks for regional distribution of electricity (Kleiwegt, 2011). Figure 12 shows an overview of the physical layer of the technical subsystem. As can be seen, electricity is transported through the national transmission network, which - in the Netherlands - mainly consists of overhead lines. Subsequently, the electricity is transported through underground cables and transformers, which convert electricity to a different voltage level with a very high efficiency (Kleiwegt, 2011).

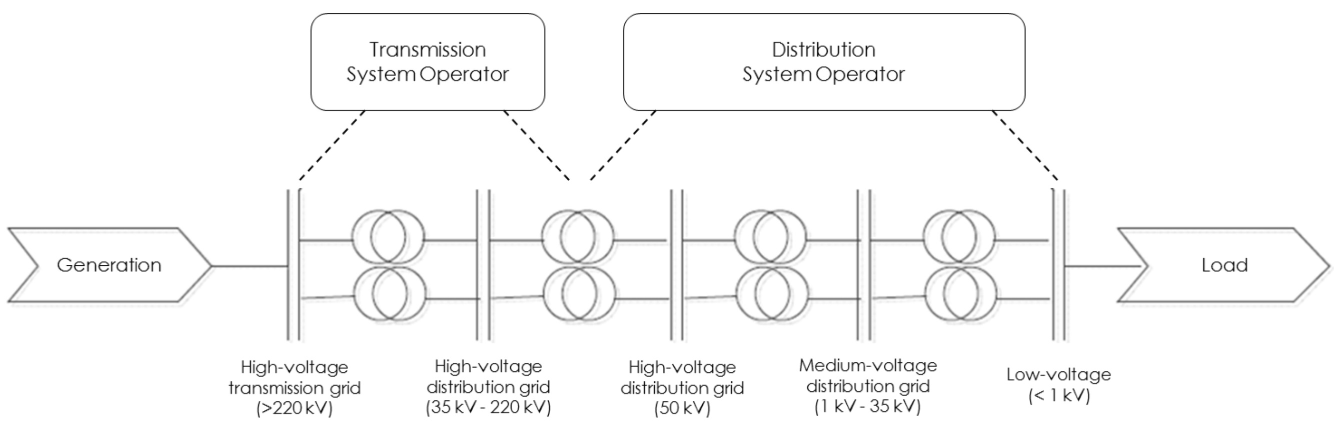


Figure 12: Physical layer of the technical subsystem; based on Kleiwegt (2011)

The characteristics of energy generation, loads and the network determine how much electricity is generated and consumed (De Vries, 2004). Two functions are needed to manage the physical transmission and distribution of electricity, namely the Transmission System Operator (TSO) and the Distribution System Operator (DSO). The TSO fulfills two roles in order to manage the transmission grid: the role of transmission operator (TO), which manages the transmission system, and system operator (SO), which maintains system stability and manages the energy balance, as the network itself cannot store electricity. Since the tasks of TO and SO are joined in one agency throughout Europe, we will refer to this role as TSO (De Vries, 2004). The DSO has a similar function, but is responsible for the regional distribution networks (Van Werven & Scheepers, 2005).

3.1.2 The economic subsystem

De Vries defines the economic subsystem as the actors that are involved in the production, trade or consumption of electricity, in supporting activities or their regulation, and their mutual relations. Two groups of actors can be distinguished: Actors operating in the economic subsystem only, and actors that also operate in the technical system. The reason for this is that the main actors in the technical system are also important actors in the economic system, although they have a different role (De Vries, 2004).

3.1.3 Synthesis of the technical and economic subsystem

In order to further comprehend the electricity system, both subsystems can be synthesized into a complete overview of the electricity system. Figure 13, which is largely based on Van Werven & Scheepers (2005), gives this overview:

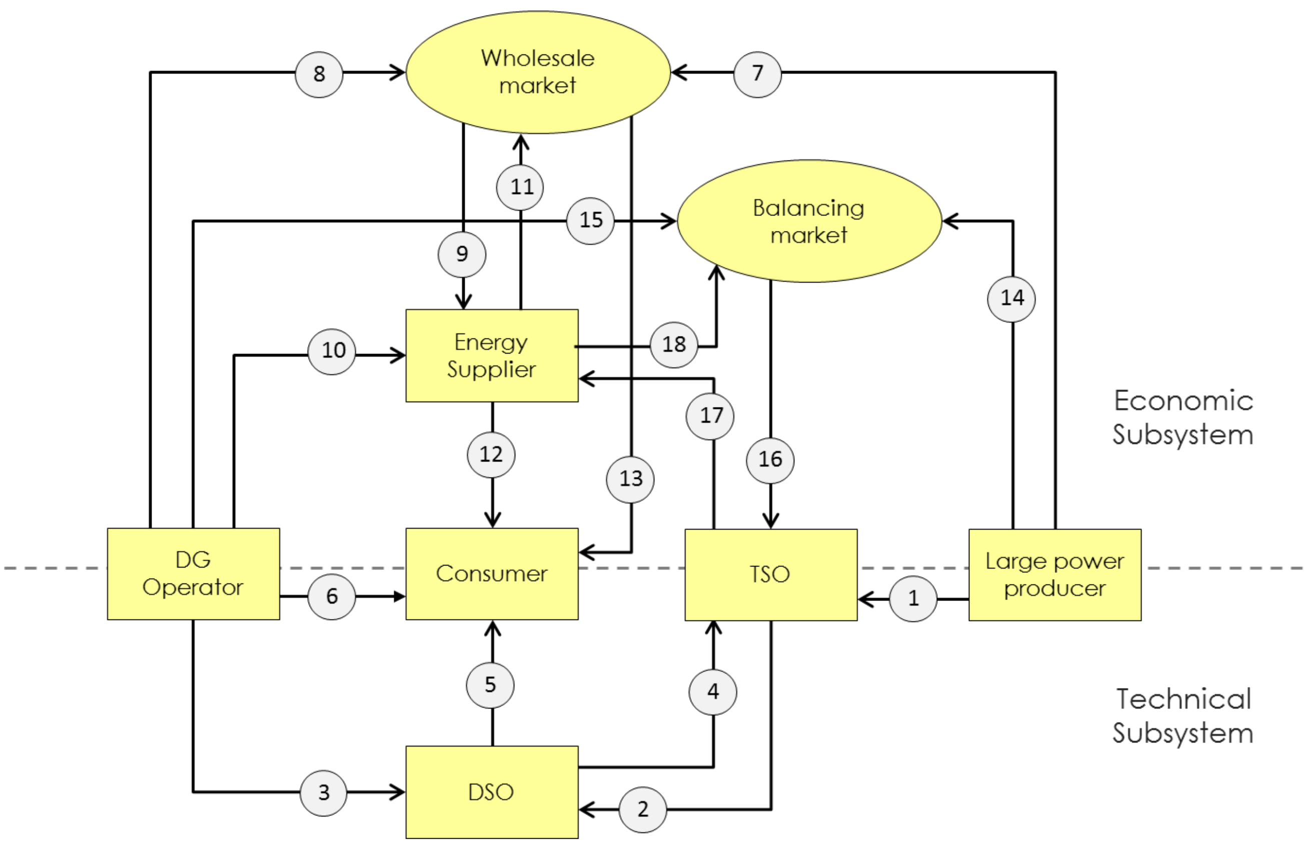


Figure 13: Overview of market and transactions within the electricity system; based on Van Werven & Scheepers (2005)

Based on this overview we will now analyze the various transactions[1] that exist between market parties within both the economic and technical subsystems. The description below refers to the transactions by using numbers that correspond with the numbers used in Figure 13. The transactions can be divided into three groups: the exchange of electricity, the transactions within the wholesale market and the transactions within the balancing market.

[1] The overview and description of transactions are adapted from Van Werven & Scheepers (2005)

1. **Transactions concerning the exchange of electricity**
   The TSO has (regulated) agreements with large power producers, who feed their electricity directly into the transmission grid (1). The electricity is then transported from TSO to DSO (2), from where it is distributed to (small) customers (5). Electricity from distributed generation (DG), such as solar panels or windmills, is either instantly consumed on-site by a customer (6) or gets fed into the distribution network (3). Since the amount of DG is growing, the supply of energy may exceed demand, in which case the surplus electricity is fed backwards into the transmission grid (4).

2. **Transactions concerning the wholesale market**
   On the wholesale market electricity gets traded. Large power producers offer their electricity on this market (7), as well as some DG operators (8). Energy suppliers buy commodity on the wholesale market in order to serve their customers (9). In some cases, energy suppliers extract extra electricity directly via (small) DG operators (11). The energy supplier sells electricity to its customers (12). Very large electricity consumers can buy electricity directly on the wholesale market (13).

3. **Transactions concerning the balancing market**
   The liberalization of the energy market has led to the establishment of a separate balancing market in the Netherlands. This market is controlled by the TSO, who is the single buyer on this market. Since the system operator is responsible for maintaining the balance in the system, market players have to submit forecasts (or 'energy programs') in order to match supply and demand. When there is imbalance in the network, the TSO corrects this by buying the lowest priced offer in the balancing market (16). Most of the offers come from large power producers (14), however, sometimes DG operators (15) or energy suppliers (18) offer electricity as well. The TSO charges the energy supplier(s) that caused the imbalance on basis of the price that it has paid on the balancing market (17). The mechanism works the other way as well: in case of a surplus of produced electricity, the TSO accepts and receives the highest bid in the balancing market for adjusting generating units downwards.

As mentioned before, it is interesting to see that the main actors in the technical system are also important actors in the economic system, but fulfill a different role. Consider for example the case of a large power producer: in the technical subsystem its role is to provide the physical generation of electricity. Activities are expressed in terms of quality and quantity of electricity generated, transported or used. In the economic subsystem, the generating company can act as a supplier: selling electricity for a certain price (De Vries, 2004).

3.2 Market overview

As introduced in the previous section, the economic subsystem within the electricity system is focused around energy markets in which various actors' trade electricity in a variety of ways and timescales. In the current section, markets for trading electricity are identified, followed by a market role analysis in order to identify and describe the relevant market roles for the current research.

3.2.1 Power exchange

In the Netherlands, APX Power NL, part of the APX GROUP, provides the market place or power exchange. APX Power NL has been established in 1999, and provides an independent fully electronic exchange for anonymous trading of electricity. It offers its platform and services to distributors, producers, traders, brokers and industrial end-users (APX Group, 2013). This is done by the organization of two markets:

1. **Day-ahead auction**
   On the day-ahead auction, trading takes place for the delivery of electricity the next day. Orders are submitted electronically, after which supply and demand are compared and the market price is determined for each hour of the following day.

2. **Continuous markets: intraday & strips**
   The intraday market offers members the opportunity to continuously trade power products in hourly intervals as well as freely definably block orders up to 5 minutes prior to delivery. On the strips market, members can continuously trade standardized blocks of hours.

3.2.2 Market roles

Based on the electricity system as identified in the previous section, we will now describe the relevant market roles for the current research. In addition to the literature that has been covered in the previous section, literature from various other sources have been analyzed, including documentation from the European Network of Transmission System Operators for Electricity (ENTSO-E), the European standardization organizations CEN, CENELEC & ETSI, the Expert Group for Regulatory Recommendations (EG3) and the International Electrotechnical Commission (IEC). Based on these sources, an overview of the market roles in the electricity system is given in Figure 14.

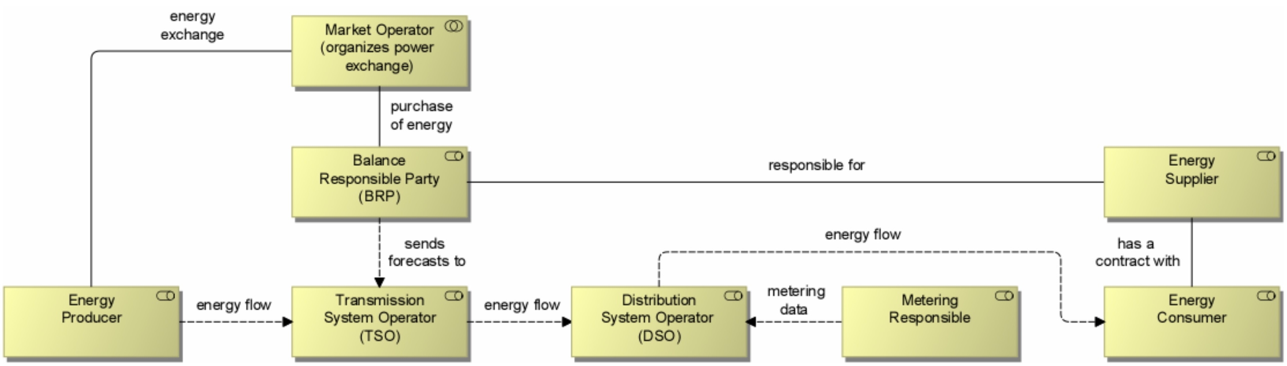


Figure 14: Overview of market roles in the electricity system

For each of the roles, the following definitions are used:

- **Transmission System Operator (TSO)**
  A party that is responsible for a stable power system operation, including the organization of physical balance, through a transmission grid in a geographical area (ENTSO-E, 2011)

  Identified in: (CEN, CENELEC & ETSI, 2012), (ENTSO-E, 2011), (EG3, 2013), (European Parliament and Council, 2003) and (De Vries, 2004)

- **Distribution System Operator (DSO)**
  Responsible for regional grid access and grid stability, integration of renewables at the distribution level and regional load balancing (EG3, 2013)

  Identified in: (Green eMotion, 2013), (IEC, 2012), (EG3, 2013) and (European Parliament and Council, 2003)

- **Energy Consumer**
  Entity or person that consumes electricity (EG3, 2013) (ENTSO-E, 2011).

  Identified in: (CEN, CENELEC & ETSI, 2012), (ENTSO-E, 2011) and (EG3, 2013)

(list continues on the next page)

- **Energy Producer**
  A party that produces electricity; a type of party connected to the grid (ENTSO-E, 2011)

  Identified in: (ENTSO-E, 2011), (EG3, 2013), (CEN, CENELEC & ETSI, 2012) and (European Parliament and Council, 2003)

- **Energy Supplier**
  Has a contractual agreement with end customer relating to the supply of electricity (EG3, 2013)

  Identified in: (ENTSO-E, 2011), (Green eMotion, 2013), (IEC, 2012), (CEN, CENELEC & ETSI, 2012), (EG3, 2013), (E-clearing.net, 2012), (De Vries, 2004) and (Van Werven & Scheepers, 2005)

- **Balance Responsible Party (BRP)**
  A party that has a contract proving financial security and identifying balance responsibility with the imbalance settlement responsible of the market balance area entitling the party to operate in the market; the only role allowing a party to buy or sell energy on a wholesale level (ENTSO-E, 2011)

  Identified in: (ENTSO-E, 2011), (EG3, 2013) and (CEN, CENELEC & ETSI, 2012)

- **Metering Responsible**
  The ENTSO-E identifies four separate roles concerning electricity metering: Meter Operator, Metered Data Collector, Metered Data Responsible and Metered Data Aggregator. In our role model, this separation is not relevant; therefore these roles are aggregated into the role of 'Metering Responsible', which we define as a party responsible for installing, maintaining, testing, certifying and decommissioning physical meters, as well as performing meter reading services and the quality control of these readings (ENTSO-E, 2011).

  Identified in: (EG3, 2013), (ENTSO-E, 2011), (CEN, CENELEC & ETSI, 2012) and (IEC, 2012)

- **Market Operator**
  The unique power exchange of trades for the actual delivery of energy that receives the bids from the Balance Responsible Parties that have a contract to bid. The Market Operator determines the market energy price after applying technical constraints from the System Operator (ENTSO-E, 2011).

  Identified in: (EG3, 2013), (ENTSO-E, 2011), (CEN, CENELEC & ETSI, 2012), (IEC, 2012), (Green eMotion, 2013) and (De Vries, 2004)

When comparing the market roles identified above (depicted in Figure 14) to the market overview as identified by Van Werven & Scheepers (depicted in Figure 13), a few differences can be noted. In our role model, the role of Balance Responsible Party (BRP) is added. Market players have to submit forecasts (or 'energy programs') in order to match supply and demand, which is the role of the BRP. Since system balance is a relevant subject in the current thesis, the role is mentioned separately from the energy supplier it represents. At the same time, the roles of 'large power producer' and 'distributed generation (DG) operator' are abstracted into a single role of 'Energy Producer'; since in essence, both have the same functionality: supplying energy into the electricity grid. Also, instead of mentioning the separate markets (wholesale and balancing market), in our model, these markets are represented by the role of 'Market Operator', abstracting away from a specific implementation. Finally, the role of 'Metering Responsible' has been added. In the Netherlands, the DSO used to be responsible for the metering processes; however, since the introduction of the 'supplier model', the energy supplier has been given this responsibility (EDSN, 2013). For the sake of understandability, the responsibility for the metering process has been stated separately in our market roles analysis. For a comprehensive overview of the literature study, please refer to appendix B.

3.3 The changing nature of electricity generation

So far, our focus has been on the present situation within the electricity system. According to Kok, Scheepers & Kamphuis (2009) from Energy Research Centre of the Netherlands (ECN), two inter-related movements can be seen in electricity generation, impacting the way the electricity system will be managed in the future. The first movement is the increase of electricity generated from sustainable energy sources in order to reduce greenhouse gas emissions. The second movement entails the decentralization of electricity generation; instead of centralized power plants with high capacity, the number of smaller electricity generating units is growing and moving closer to the load centers. In the following sections we will analyze both movements.

3.3.1 Increase of sustainable energy sources

In the Netherlands over 80% of the total electricity generation origins from fossil fuels (natural gas, oil and coal). Figure 15, adapted from the report on 'Energy in the Netherlands' (De Energiezaak, Energie-Nederland & Netbeheer Nederland, 2011) shows the various sources of electricity generation in 2009. Worldwide, a similar situation can be seen: two thirds of the electricity is still produced from fossil fuels, and approximately 15% originates from nuclear sources. Hydraulic energy is currently most significant source of sustainable electricity generation (17%). Other sustainable energy sources (wind, solar, biomass, and geothermal) contribute for only about 2% to the world wide electricity generation (Kok, Scheepers, & Kamphuis, 2009)

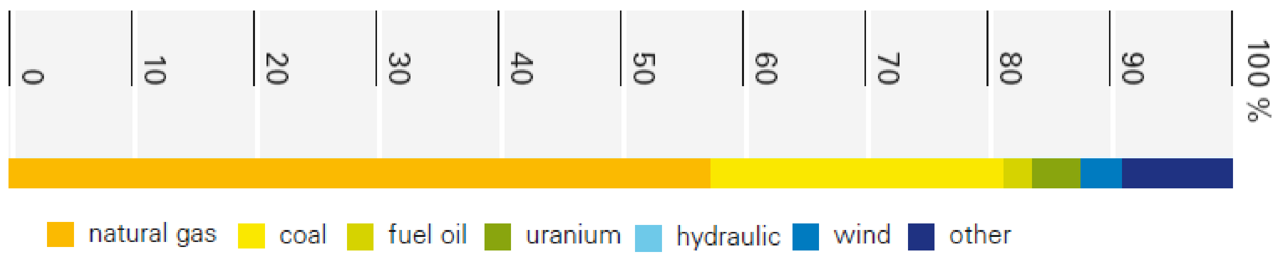


Figure 15: Sources for electricity in 2009 (De Energiezaak, Energie-Nederland & Netbeheer Nederland, 2011)

Fossil fuel usage is one of the greatest contributors to greenhouse gas emissions, leading to a significant increase in the concentration of carbon dioxide in the atmosphere (Kok, Scheepers, & Kamphuis, 2009). This introduces one of the greatest global challenges of our time: climate change (Rijksoverheid, 2007). Issues concerning climate change are high on the political agenda; as illustrated by the commiment of the European Union to reduce Europe's greenhouse gas emissions to 80-95% in 2050 (European Commission, 2013). Also, power companies representing over 70% of the European electricity production have signed a declaration in which they committed to become carbon neutral by 2050 (Eurelectric, 2011). Worldwide, energy provision is radically changing; under the influence of climate change a strong drive exists to reduce the use of fossil fuels and make the transition to renewable sources instead (TNO, Universiteit Utrecht & ECN, 2013).

A second driver for the transition to sustainable energy sources is the need for diversification in sources of energy. A significant part of the energy consumed in most western economies is imported from outside those economies; frequently from regions that are politically unstable. This introduces an undesirable external dependency, which continues to grow as the energy consumption rises. A higher share of sustainable energy will reduce this dependence (Kok, Scheepers, & Kamphuis, 2009).

3.3.2 Decentralization of electricity generation

The second movement described by Kok, Scheepers & Kamphuis (2009) concerns the decentralization of electricity generation. According to the authors, electricity generation capacity is increasingly realized in the distribution part of the electricity system; small-scale generation units are directly connected into the distribution grid. For this type of electricity generation, the authors use the term distributed generation (DG), which is defined as the production of electricity by units connected to the distribution network or to a customer site (Kok, Scheepers, & Kamphuis, 2009).

Various drivers can be identified for the decentralization of electricity generation. Pecas Lopes, Hatziargyriou, Mutale, Djapic, & Jenkins (2007) identify three groups of drivers: environmental, commercial and regulatory drivers. Environmental drivers include the reduction of green house gas emissions and the avoidance of new transmission lines and power plants. Commercial drivers include the avoidance of risk: small generation projects have lower risks, and regulatory drivers include the notion that decentralized electricity generation increases security and diversification, and that it supports competition. Another driver is introduced by Zangiabadi, Feuillet, Lesani, Hadj-Said, & Kvaløy (2011), focussing on the customer. Decentralization of electricity generation is expected to result in reliability improvements and lower costs for electricity.

The environmental drivers identified above have an impact on the increasing amount of renewable energy sources (RES) connected to the distribution grid. According to Kok, Scheepers & Kamphuis (2009), these energy sources are included in the definition of DG. However, a distinction needs to be made between based on the scale of these renewables; off-shore wind electricity generation should for example not be considered as DG since it is connected into the transmission network, instead of the distribution network.

Even though the generation capacities of individual DG units are small when comparing to centralized electricity generation by our current large-scale power plangs, the number of DG units are much higher and their growth is expected to continue (Kok, Scheepers, & Kamphuis, 2009). According to Kok, Scheepers & Kamphuis (2009), the growing share of distributed generation in the electricity system may evolve in three distinct stages:

1. **Accommodation**
   Distributed generation is accommodated in the current market. Distributed units are running free, while centralized control of the networks remains in place.

2. **Decentralization**
   The share of DG increases. Virtual utilities optimize the services of decentralized providers through the use of common ICT-systems. Central monitoring and control is still needed.

3. **Dispersal**
   Distributed power takes over the electricity market. Local low-voltage network segments provide their own supply with limited exchange of energy with the rest of the network. The central network operator operates more like a coordinating agent between separate systems rather than controller of the system.

The last stage identified above represents a scenario that is widely known as the smart-grid. Worldwide, the concept of smart grids gets a lot of attention, both from the leading market players and academic community. According to the European Technology Platform Smart Grids, a smart grid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies (European Technology Platform Smart Grids, 2010).

3.4 Conclusions

An important relationship exists between electric mobility and the electricity system. In the current chapter a concise overview of the electricity system has been given. The electricity system as we know it consists of two interrelated subsystems: a technical and economic subsystem. The electricity system however, is changing. Two interrelated movements can be seen in electricity generation, concerning the increase of sustainable energy sources in order to reduce greenhouse gas emissions, and the decentralization of electricity generation.

4 Problem analysis

Electric mobility offers both threats and opportunities to the electricity system. A clear and comprehensive definition of these threats and opportunities is needed in order to define the objectives for the reference architecture.

4.1 Introduction

Even though relationships exist between electric mobility and the electricity system, the information exchange between both markets is very low. The primary goal in the current situation has been the realization of accessible charging infrastructure to provide electricity towards drivers of electric vehicles. This situation does not require a high degree of integration between the markets of electric mobility and the electricity system. However, the emergence of electric mobility introduces new threats and opportunities in relation to the electricity system, which do require an increased degree of integration between the two markets.

4.2 Threats and opportunities

The main threat of electric mobility is the potential impact on the electricity system; the high demand for electricity can potentially lead to overloaded components in the electricity system. On the other hand, the significant demand for electricity in charging electric vehicles also introduces new opportunities when used in an intelligent manner. By matching patterns for demand and supply, both shortages and surpluses in electricity supply can be 'absorbed' in order to reduce imbalance. The same strategy can result in an increased adoption of renewable energy sources (RES) in the energy system. In addition, the battery of an electric vehicle offers capacity to store electricity that can be used for vehicle-to-grid applications. In the following sections these threats and opportunities will be analyzed.

4.2.1 Potential impact of electric mobility on the electricity system

Verzijlbergh, Lukszo, Slootweg, & Ilic (2011) investigated the impact of electric vehicle charging on residential low-voltage networks. In their analysis, a large number of low-voltage networks in the Netherlands are considered, based on data from Enexis, a large distribution system operator, operating over 35% of the Dutch distribution network. For their analysis, they used a scenario where roughly 75% of all households own an electric vehicle. This scenario is based on the expected situation in 2040, as pursued by the Dutch government. The charging needs are estimated by inspecting trips with home as their destination, and calculating two times the trip distance. Charging is extecuted with a fixed rate untill the battery is full. In the study, a yearly organic growth rate of 1% of the standard household load is assumed, to which the results are compared. Both single phase (3kW) and three-phase (10kW) scenarios have been analyzed. The results (shown in Table 7) show that a significant fraction of transformers and cables will be overloaded.

Property	Threshold value	Organic growth (1%)	3kW charging	10kW charging
Transformer	Load > 1.16	19.1%	41.2%	50.5%
Cable (overload)	Load > 1.2	2.8%	9.0%	13.1%
Cable (voltage drop)	ΔV > 20V	2.1%	4.4%	5.2%

Table 7: Overview of grid impacts in the Netherlands (Verzijlbergh, Lukszo, Slootweg, & Ilic, 2011)

The results show that in the single-phase scenario, over 40% of the transformer stations will be overloaded, and over 13% of the cables need to be replaced because of overload or voltage drops. These values are significantly higher compared to the values caused by organic growth.

In another study by Verzijlbergh, Lukszo, Veldman, Slootweg, & Ilic (2011), different scenarios have been compared for charging electric vehicles with an energy need of 6kWh, equivalent to 30 km; approximately the average Dutch daily driving distance. The authors show that in the uncontrolled scenarios, where electric vehicles start charging whenever connected to the grid, a very distinct evening peak occurs in demand. The peak is significantly higher than the current peak caused by household demand only: approximately two times higher based on a single-phase (3kW) charging scenario and even more in a three-phase (10kW) scenario.

4.2.2 Potential source of flexibility for the reduction of imbalance

In the current electricity market, production is adjusted based on the (expected) demand. As mentioned in section 3.1.3, market players have to submit forecasts (or 'energy programs') in order to match supply and demand. Since these forecasts are not perfect, an imbalance market has been realized in order to absorb the difference between actual and forecasted demand. Whenever there is imbalance in the network, the transmission system operator (TSO) corrects this by buying the lowest priced offer in the balancing market. System imbalance is however very expensive; an internal study at Alliander revealed that the total costs for system imbalance in 2011 were about 171 million euro (Hagemans, Fens, Bollen, Schoot Uiterkamp, & Venekamp, 2013). According to their analysis, the electricity system has been adjusted downwards for a total of 423 GWh over 2011, and adjusted upwards for a total of 358 GWh, both in order to 'absorb' the imbalance.

Electric mobility offers significant opportunities to help the reduction of imbalance. The main reason is that in the demand for charging electric vehicles can be shifted in time relatively easily, as long as charging is performed within the boundaries as specified by the customer. According to Brooks & Gage (2001), most personal transportation vehicles are parked more than 20 hours a day, and represent an idle asset during this period of time. An intelligent integration of electric mobility in the electricity system can potentially reduce system imbalance, and help balance responsible parties in order to reduce their costs.

4.2.3 Positive impact on the adoption of renewable energy sources

In general, renewable energy sources and distributed generation are unpredictable and introduce fluctuation in supply (Netbeheer Nederland, 2011). This unreliability of supply is considered as a negative factor in the current electricity system. However, since the demand for charging electric vehicles can generally be shifted in time quite easily, electric mobility offers significant opportunities to increase the adoption of renewable energy sources (RES). By adjusting the demand of charging electric vehicles, demand and supply can be matched in order to reduce system imbalance that is otherwise introduced by the integration of RES. This is possible, since unlike many other devices, electric vehicles offer an enormous ability to temporarily adjust their demand and 'follow' the fluctuations in supply. This removes the need for predictability and can result in a positive impact on the adoption of RES.

In a study by Richardson (2013), literature on electric mobility, the electricity grid and renewable energy integration is reviewed. Overall, the literature indicates that electric vehicles can significantly reduce the amount of excess renewable energy produced in the electricity system. More specifically, electric vehicles can absorb excess energy production that would otherwise be wasted or curtailed, which improves the economics of distributed energy generation (Richardson, 2013). An intelligent integration of electric mobility in the electricity system can therefore potentially have a positive impact on the (further) integration of renewable energy sources (RES), which can help in the commiment of the European Union to reduce Europe's greenhouse gas emissions to 80-95% in 2050 (European Commission, 2013).

4.2.4 Vehicle-to-grid opportunities

In a study about electric mobility and the energy transition, Kleiwegt (2011) affirms the notion that even though electric mobility has significant potential impact on the electricity system, it does not only form a threat. When considering in the long term, electric vehicles can also offer new opportunities such as storage capacity. Various studies analyze the so-called vehicle-to-grid (V2G) concept, where electric vehicles provide capacity to the electricity system whenever connected, by acting as a storage system. As mentioned previously, most personal transportation vehicles are parked more than 20 hours a day, and represent an idle asset during this period of time (Brooks & Gage, 2001). Electric vehicles can be utilized as power sources while parked, because these vehicles include the fundamental elements for generating AC power. Utilizing this opportunity can produce a positive net revenue stream and create a powerful economic incentive to own an electric vehicle.

Kleiwegt mentions that the Dutch car fleet owned over 7,6 million private cars in 2010, and that parked electric vehicles do not use their battery capacity most hours of the day. When connected to the electricity system, electric vehicles can therefore provide a large back-up capacity. Kleiwegt suggests that in a scenario where the full Dutch car fleet would consist of electric vehicles, the theoretical storage from these vehicles can theoretically provide up to 76 GW, which is about three times the total installed capacity of all power plants in the Netherlands (25 GW).

The study of Richardson (2013) supports the presumptions of Brooks & Gage and Kleiwegt, and concludes in addition that electric vehicles with vehicle-to-grid power would allow a further integration of distributed and/or sustainable energy resources energy into the generation mix.

4.3 Related problems

In addition to the threats and opportunities that are mentioned in the previous section, some related problems can be identified that motivate the need for a reference architecture.

4.3.1 Immaturity of the market for electric mobility

As identified in the introduction of the current research, the field of electric mobility is relatively novel and still in its infancy. The potential impact and opportunities of electric mobility in relation to the electricity system are currently unused and introduce the need for integration between the two models. This need is seen by various market players and only increases the degree of uncertainty of the future model for electric mobility. The current model implies some adverse consequences, and a final model does not yet exist. Currently, a lot of pilot projects such as (The Edison Project, 2013) , (The EV Project, 2013), (EcoGrid EU, 2013), (Green eMotion, 2013) and (MOBI.Europe, 2013) are carried out; each outlining their own view of how the division of roles for electric mobility should and/or is expected to look like in the future. A conclusion that can be made is that the current architecture does not offer a satisfying degree of interaction and influence from the involved stakeholders yet.

In the current situation, the charge spot operator (CSO) manages the charging infrastructure and is responsible for a correct provision of charging processes at their charge points. However, other parties increasingly want to influence and/or control the charging process as well, or have insight into charge point related data (such as charge point availability). Distribution system operators want to influence the charge process in order to guarantee grid stability, car manufacturers want to enhance their cars with intelligent systems that can control the charge process for their customers, charge service providers want to offer additional services, and third parties (like TomTom) want to act on the market as well, for example by providing information about charge point location and availability.

4.3.2 Lack of a solid business model

The business case for charge points has been a negative business case up to now (VNO-NCW, 2012). One of the main reasons, as mentioned in chapter 2.3, is that the public charging infrastructure is very costly, and that the current revenue model is based on small margins on top of the energy prices. According to Onoph Caron, the director at E-laad, this situation where realizing charge points involves a negative business case will stay until the market has matured (VNO-NCW, 2012).

The main cost factors of the public charging infrastructure are based on the facts that public charge points need to be robust and have their own electricity connection, involving redundant metering and safety features because of current regulation. In addition, sophisticated technology is needed for authentication and communication (including a GPRS connection). The realization of a separate market model for interoperability between market roles introduces extra costs as well, since each of the parties that are involved need to make profit in some way.

4.3.3 Technical uncertainties

Several technical choices underlie the current architecture for electric mobility; charge points are controlled and managed by a central system, identification is done via customer cards on basis of RFID, and in most cases communication between a charge point and electric vehicle consist of solely control and protection functions. However, technology develops rapidly; certificate-based authentication (Höfer, 2013), communication about charge profiles and charging needs (IEC 15118), and other authentication mechanisms such as the use of mobile phones or the on-board system within electric vehicles are emerging. The current OCPP protocol offers the possibility of remote firmware upgrade (OCPP, 2013); however, since hardware inside the charge point cannot be replaced easily, it could be argued that it would be more efficient to put technologies like authentication into other devices, such as the car itself or a mobile phone. In this way, one can go along with technology much more rapidly, and could potentially reduce the cost of a charge point.

4.4 Conclusions

Electric mobility offers both threats and opportunities to the electricity system. In the current chapter, these threats and opportunities have been identified and described, and related problems have been identified. The main conclusions that can be drawn are that in the current situation, there is an absence of integration between the markets of electric mobility and the electricity system, and a lack of a profitable business model. Because of the potential threats and opportunities and the impact that this could have on the business model, there is a need for further integration between the two markets.

5 Approach

The concept of reference architecture belongs to the field of enterprise architecture. Over the years, a number of different approaches to enterprise architecture have been proposed. In the current chapter, the approach as used in the current research will be clarified. Objectives will be defined; on which we will derive several requirements for the reference architecture.

5.1 Approach to enterprise architecture

The concept of architecture has been defined as the fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution (IEEE, 2000). By using architecture descriptions it becomes possible to efficiently and effectively document and communicate the essence of the business, the information systems and (IT) infrastructure for each of the relevant stakeholders (Iacob, Jonkers, Quartel, Franken, & Van den Berg, 2012).

A reference architecture captures the essence of existing architectures, and the vision of future needs and evolution to provide guidance to assist in developing new system architectures (Cloutier, Muller, Verma, Nilchiani, Hole, & Bone, 2010). According to CEN, CENELEC & ETSI (2012), a reference architecture describes the structure of a system with its element types and their structures, as well as their interaction types, among each other and with their environment. A reference architecture defines restrictions for an instantiation of a concrete architecture. Through abstraction from individual details, a reference architecture is universally valid within a specific domain. Further architectures with the same functional requirements can be constructed based on the reference architecture.

The motivation for the creation and utilization of reference architectures can be to have a blueprint for the development of future systems and components, providing the possibility to identify gaps between the current and future situation. It can also be used to structure a certain domain and provide a foundation for communication about it to other domains that need to interoperate. Furthermore, it can be used to document decisions which have been taken during the development process of an infrastructure (CEN, CENELEC & ETSI, 2012).

Different approaches to enterprise architecture exist, each of them covering specific parts of the enterprise architecture discipline. The Zachman framework, originally published in 1987, was one of the first frameworks proposed for enterprise architecture. Nowadays, one of the leading methodologies on enterprise architecture is TOGAF ®, which originated as a methodology for development of technical architectures but shifted its focus towards enterprise architecture over the years. When looking more closely at the approaches to enterprise architecture, it can be seen that most of them address one or at most two of the following aspects (Iacob, Jonkers, Quartel, Franken, & Van den Berg, 2012):

1. A **framework** for the subdivision of an architecture in different domains, sometimes including the relationships between these domains.

2. A **language**, defining the concepts for describing an architecture, including a (preferably graphical) representation of these concepts.

3. A **process**, or a way of working, which is in most cases a step-wise prescriptive method for developing architectural descriptions.

In the current research, we use the enterprise architecture approach as proposed by Iacob, Jonkers, Quartel, Franken, & Van den Berg (2012). The approach described by the authors is based on open standards; using the 'Architecture Development Method' (ADM) from TOGAF, and ArchiMate as the modeling language and framework. According to the authors, the combination of TOGAF (in particular the ADM) and ArchiMate offers an approach that is both operational and comprehensive.

ArchiMate is an architectural modeling language developed as part of a collaborative research project on enterprise architecture funded by the Dutch government, in which several Dutch research institutes, major corporations and governmental and financial institutions have been involved (Iacob, Jonkers, Quartel, Franken, & Van den Berg, 2012). ArchiMate is supported by different tool vendors and consulting firms, providing instruments to enable enterprise architects to describe, analyze and visualize the relationships among business domains in an unambiguous way (The Open Group, 2013). Please refer to chapter 1.8 for the modeling notation of ArchiMate.

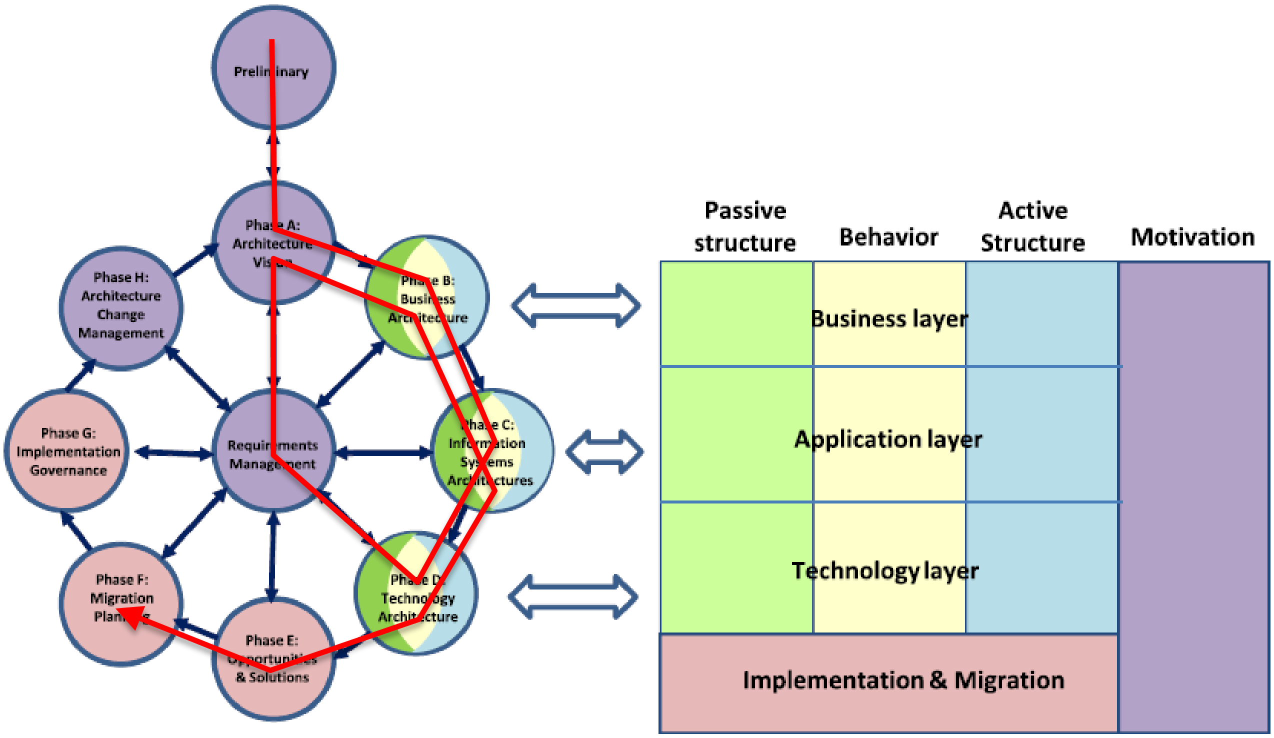


Figure 16: TOGAF ADM and ArchiMate (Iacob, Jonkers, Quartel, Franken, & Van den Berg, 2012)

With the concepts as defined in the core of ArchiMate, architectures can be created that fill in the views related to phase B, C and D of the TOGAF ADM; the phases concerned with creating the business, information systems and technology architectures. The 'Implementation and Migration' extension of ArchiMate adds concepts to support the implementation and migration phases of the ADM (phase E, F and G). The 'Motivation' extension of ArchiMate supports the remaining phases of the ADM. In Figure 16, the correspondence between ArchiMate and ADM is illustrated (Iacob, Jonkers, Quartel, Franken, & Van den Berg, 2012).

In the current research, we will describe each of the architecture layers as depicted in Figure 16. Also, for describing the implementation and migration paths, a migration architecture will be established, providing an interim solution as a first step towards the reference architecture. The motivation extension of ArchiMate is an overarching process; which is implemented in the current research by the identification and evaluation of objectives and requirements. This corresponds with the ADM, where the 'requirements management' is depicted at the center of the other steps, illustrating the overarching position of the requirements management process (The Open Group, 2013).

5.2 Objectives

Part of the motivation for the reference architecture can be expressed in terms of objectives. Therefore, to serve as a basis and assessment for the reference architecture, various objectives have been defined on basis of the problem description and analysis in the previous chapters. Each of the objectives is clarified in a separate section.

5.2.1 Optimal integration with the electricity system

As identified in the problem analysis, the charging of electric vehicle has a significant potential impact on residential low-voltage networks. This impact can be reduced by influencing the charge process, shifting demand away from (household) peaks. This way, the number of overloaded tranformers and cables can be reduced drastically. In the impact scenario based on data from Enexis, this reduction is approximately 25 % and 8% for overloaded tranformers and cables (Verzijlbergh, Lukszo, Slootweg, & Ilic, 2011). Therefore, the reference architecture should reflect and accommodate the ability to let distribution network operators (DSO) influence the charge process, with the goal of using current assets as efficient as possible and avoiding unnecessary investments in assets.

5.2.2 Accommodate the adoption of renewable energy sources

As identified in the problem analysis, a movement is expected from centralized electricity generation based on fossil fuels towards electricity generated from sustainable energy sources. The main driver for this movement is the reduction of greenhouse gas emissions (Kok, Scheepers, & Kamphuis, 2009). However, renewable energy sources and distributed generation are generally unpredictable and introduce fluctuation in supply (Netbeheer Nederland, 2011). Electric vehicles can improve the economics of distributed energy generation when integrated in an optimal manner (Richardson, 2013), and offer an enormous ability to temporarily adjust demand. Therefore, the reference architecture should reflect and accommodate the advantage offered by electric vehicles to optimally integrate renewable energy sources.

5.2.3 Alignment with European standardization developments

Standardization can be defined as "the activity of establishing, with regard to actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimum degree of order in a given context" (ISO/IEC, 1996). Standards are critical for the deployment of technologies that will have profound impacts on industrial sectors and national economies, particularly when related to information technology (Morell, 1994). Standards played an important role in the industrial revolution, for example in enabling markets to execute transactions in an equitable and efficient manner (Tassey, 1999).

According to TNO & Innopay (2010), fragmentation is expected to occur if all parties seek to achieve their own goals in isolation within a starting market. Since fragmentation can delay the adoption of electric vehicles, this is obviously not in the public interest. For the development of a reference architecture for electric mobility, it is therefore important to include alignment with standardization developments as a main objective. Standardization exists on various levels ranging from national, European to international standardization (Wettig, 2002). In the current research, the main focus will be on standardization developments on a European level. On this level, three standardization organizations are officially recognized by the European Commission: the European Committee for Standardization (CEN), CENELEC, a European regional standards organization and the European Telecommunications Standards Institute (ETSI). Together these organizations act as a European platform through which European standards are developed. CEN, CENELEC and ETSI are the regional mirror bodies to their international counterparts, i.e. ISO (the International Organization for Standardization), IEC (the International Electrotechnical Commission) and ITU-T (the International Telecommunication Union, telecommunication standardization sector) (CENELEC, 2013).

5.2.4 Optimization of the current business model

As identified in the problem analysis, several uncertainties exist in the market of electric mobility. Both market and technical uncertainties have been identified. One aspect to consider is that the business case for charge points has been a negative business case up to now. The market model as originally proposed by EnergieNed & Netbeheer Nederland (2010) has been implemented, but does not seem to succeed very well. Also, the current architecture implies a situation where the customer has no choice of energy supplier, since the energy contract is established between energy supplier and CSO. For the reference architecture, alternative solutions have to be compared to see whether other implementations could result in an improved business model.

5.3 Requirements

As indicated in Figure 16, requirements management is a central process in the ADM. As part of the motivation for the reference architecture, we have therefore identified several requirements. These requirements serve both as a basis and way of assessment for the reference architecture; and will be used in the evaluation and validation of the reference architecture. The requirements can be divided in functional and non-functional requirements.

5.3.1 Functional requirements

According to the IEEE Standard Computer Dictionary, a functional requirement is a requirement that specifies a function that a system or system component must be able to perform (IEEE, 1990). For the reference architecture for electric mobility, the functional requirements concern the alignment with the objectives stated in the previous section. Hence, we formulate:

R1. Integration of electric mobility and the energy system
The reference architecture enhances integration between electric mobility and the electricity system, and reduces the potential impact of electric mobility, when compared to the current architecture

R2. Accommodation of renewable energy sources (RES)
The reference architecture drives the adoption of renewable energy sources in the electricity system

R3. Readiness for vehicle-to-grid opportunities
The reference architecture is able to support potential vehicle-to-grid scenarios, where the electric vehicle serves as a storage facility and can supply energy back into the electricity system

R4. Support for relevant business services
The reference architecture sufficiently covers and supports the services identified for electric mobility: authentication, charging, clearing and settlement, metering and balancing

R5. Alignment with standardization developments
The reference architecture is aligned to the standardization developments, including the European Commission, CEN, CENELEC & ETSI and the IEC.

5.3.2 Non-functional requirements

In addition to the functional requirements identified above; other requirements can be identified concerning the quality of the reference architecture. Hence, we formulate:

R6. Architectural quality
In their study, Niemi & Pekkola attempt to identify the quality attributes of enterprise architecture products and services as prerequisites for enterprise architecture benefit realization (Niemi & Pekkola, 2013)

R7a. Clarity
The reference architecture provides a clear and holistic view of the particular target area, describes its various components and, basically at one glance, tells what it is all about. The architecture compresses a fairly large amount of information into a set of models, whilst at the same time maintaining clarity

R7b. Granularity
The reference architecture has the right level of granularity; it provides both a holistic view and sufficient level of detail at the same time

R7c. Uniformity
In the reference architecture, the lower layers conform to the upper layers, whilst there is no unnecessary duplication

R7d. Correctness
The reference architecture does not contain incorrect modeling assumptions

R7e. Completeness
The reference architecture covers all relevant market roles, applications and infrastructure

R7f. Usefulness
The reference architecture has a clear purpose and is appropriate to use in this context; it provides a relevant and potentially beneficial framework to the involved stakeholders

R7. Practical feasibility
The reference architecture reflects a feasible situation

5.4 Conclusions

In the current chapter, the approach towards enterprise architecture is clarified. We use the enterprise architecture approach as proposed by Iacob, Jonkers, Quartel, Franken, & Van den Berg (2012), using the 'Architecture Development Method' (ADM) from TOGAF, and ArchiMate as the modeling language and framework. Objectives and requirements have been defined that will serve as a basis for the reference architecture.

6 Current architecture

Based on the descriptions of the electricity system and the market for electric mobility, we will now synthesize both models in order to create a clear and comprehensive understanding of the concepts, services and structure in the current situation. The goal of modeling the current architecture is to further identify the inadequacy of the current situation, and to provide a basis for comparison in the evaluation of the reference architecture.

6.1 Market roles

In the first three chapters the relevant market roles for the electricity and electric mobility markets have been identified. In the current section, these market roles are synthesized into an overview reflecting the current architecture. Figure 17 depicts this overview. One important aspect to notice is that in the synthesized model reflecting the current situation, the charge spot operator (CSO) is the 'consumer' of the original electricity model, since the CSO owns the energy contract with the energy supplier.

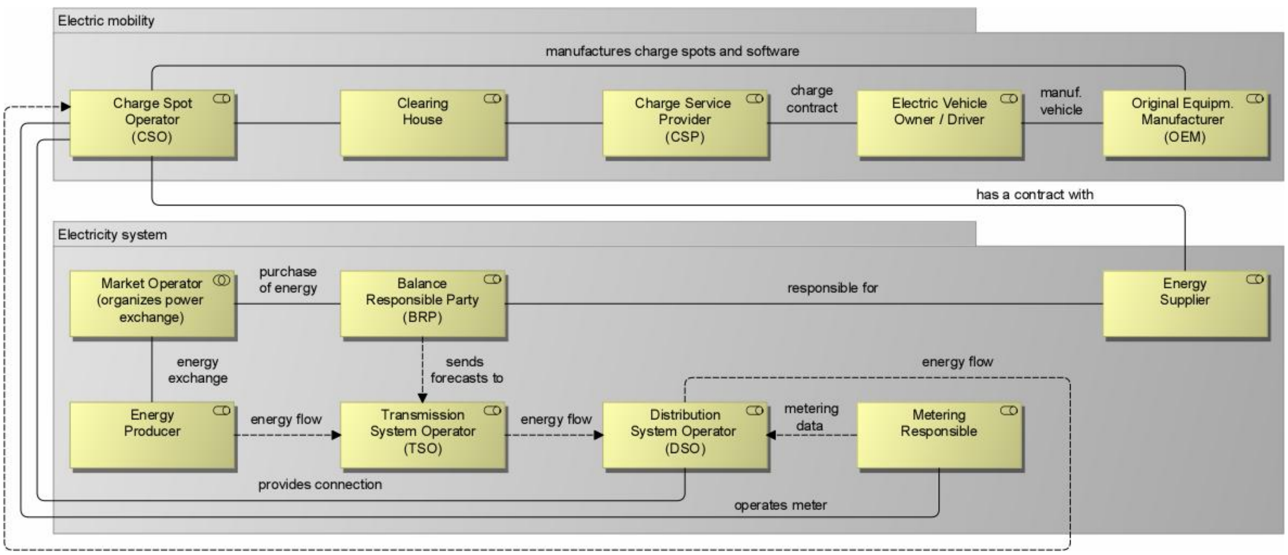


Figure 17: Roles in the current architecture

As can be seen in the figure, the degree of connectivity between the electricity system and the electric mobility layer is relatively low. The main connections between the two markets are the contractual relationship between charge spot operator (CSO) and electricity supplier, and the technical relationship between distribution system operator (DSO) and the CSO. The balancing of electricity supply and the demand of electrical vehicles lies within the responsibility of the balance responsible party.

6.2 Processes

In the current research, seven relevant processes have been identified when analyzing the current architecture. Figure 18 gives an overview of these processes, related to the roles that are related to these processes.

Since authentication is needed at most of the public charging spots, an initial process within the current architecture (as seen from a customer perspective) is customer registration. Authentication is done by means of customer RFID cards, which can be obtained at a charge service provider (E-laad, 2012). For each of the charge sessions made at a public charging spot, detailed records are stored. These records are used as a basis for the financial settlement between CSO and CSP, and are therefore exchanged between both parties (P2, 2012). The clearing house takes care of the data exchange needed for these processes of authentication, clearing and settlement (E-clearing.net, 2012). Since the customer has to pay for the charge service in the end, a billing process is needed as well.

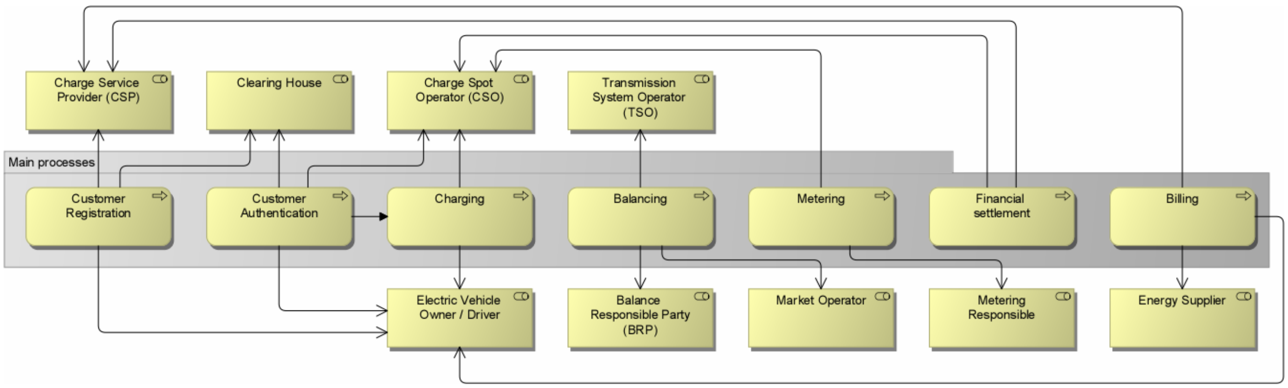


Figure 18: Processes in the current architecture

In the current architecture, balancing the electricity system is done outside the scope of electric mobility itself. The TSO is responsible for maintaining the balance in the system, and BRPs have to submit forecasts (or 'energy programs') in order to match supply and demand. When there is imbalance in the network, the TSO corrects this by buying the lowest priced offer in the balancing market, which is controlled by the TSO itself (please note that in Figure 18 the role of market operator has been mentioned separately in order to increase understandability). In the following sections, each of the processes is separately explained.

6.2.1 Customer registration

In order to be able to authenticate at a public charging spot, a customer RFID card is needed. These cards can be obtained at a charge service provider (CSP). After signing a service contract, the charge service provider will issue a customer specific ID card containing a unique authentication ID. The authentication ID is registered in the central registry (CIR), which is used by all charge spot operators (CSOs). In this way, interoperability is offered to the customer; the customer will be able to charge his vehicle at every public charging spot (P2, 2012).

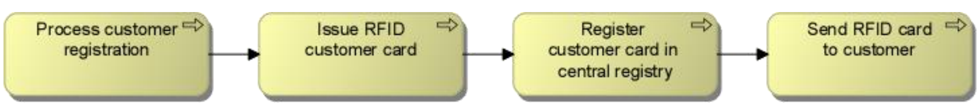


Figure 19: Overview of the customer registration process

6.2.2 Customer authentication

For the authentication of a customer at a charge point, a Near Field Communication (NFC) tag is used. In the Netherlands, a Mifare Classic 7 byte variant is used, containing a unique RFID. Charge service providers are responsible for the uniqueness of registered customer cards. Also, the authentication risk is theirs (P2, 2012). The following figure gives an overview of the customer authentication process:

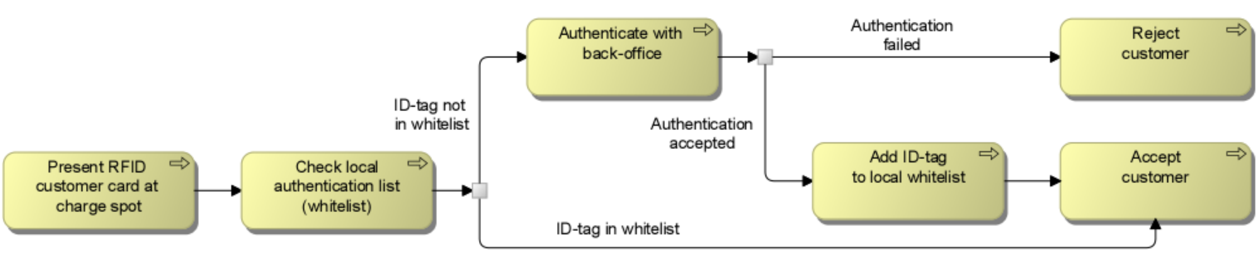


Figure 20: Overview of the customer authentication process; based on (E-laad, 2012)

As can be seen, the customer uses its customer card containing the unique RFID to authenticate at a charge point. Every charge point maintains a local database containing whitelisted RFID tags. In the case the charge point does not know a certain RFID tag, the charge point will communicate with the back-office in order to authenticate.

Whenever the authentication succeeds, the ID-tag is added to the local database. Whenever the authentication has been successful, the customer will be accepted and can plug in its connector. In case the authentication fails, the customer will be rejected and cannot start the charge process (E-laad, 2010).

6.2.3 Charging process

After a customer has been authenticated, the charging process can take place. In order to charge its vehicle, the customer has to connect the charger between charge point and electric vehicle. This has to be done within sixty seconds after authentication, or the transaction will be ended immediately. Whenever the charger has been connected at both sides, the charge process will start. The system will start a new transaction in order to keep track of the delivered electricity. The flow of electricity will continue until the vehicle has been fully charged, the charger is disconnected at the vehicle, or the customer presents its customer card to the charge point. The connector outlet on the charge point will not be unlocked until the customer has successfully authenticated itself for the second time. Whenever the charging process has finished successfully, details of the charge session will be transmitted to the central back-office system. When there is no internet connection, the charge details will be stored until the charge point gets back online (E-laad, 2010). The following figure shows an overview the charging process:

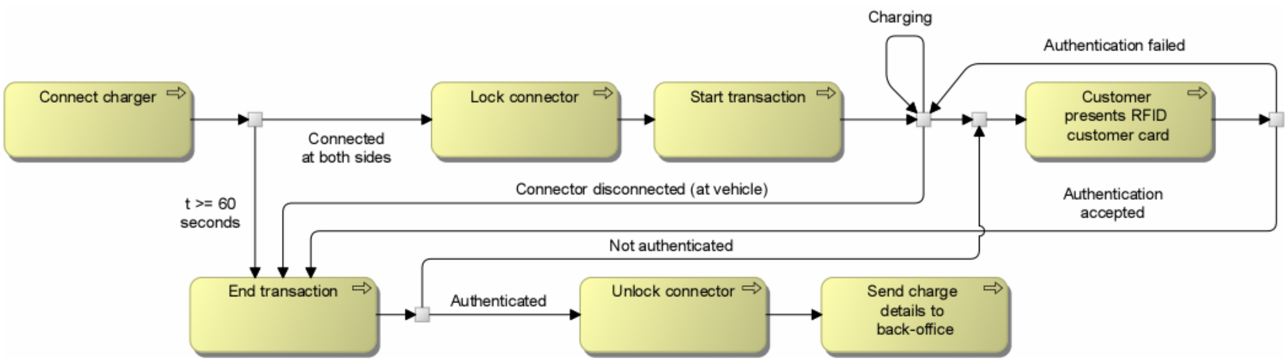


Figure 21: Overview of the charging process; based on (E-laad, 2010)

6.2.4 Financial settlement

Currently, the process of clearing and settlement is focused around the exchange of charge details between charge spot operators and charge service providers, and the financial settlement on basis of this data. In order to do so, Charge Detail Records (CDRs) are interchanged between both parties (P2, 2012). To facilitate the interchange of data, parties make use of a centralized clearing house system. Currently, two specific implementations of this type of system exist: The 'Centraal Interoperabiliteits Register' (CIR), and the European Clearing House System (eCHS).

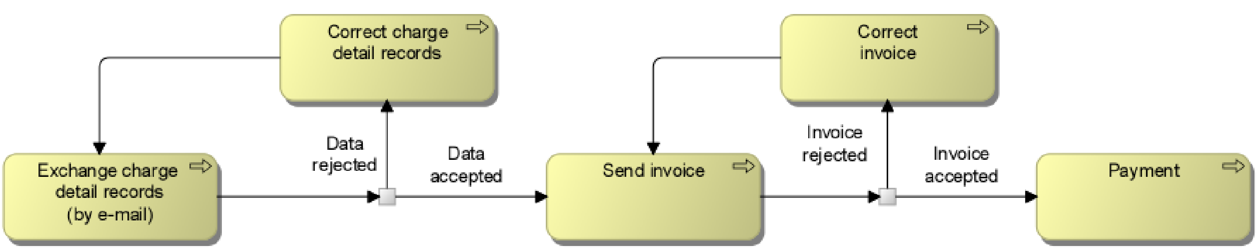


Figure 22: Overview of the settlement process; based on (P2, 2012)

The exact implementation of the CIR is not available; but according to the documentation by P2 the CDRs are sent by email. This process occurs after the last day of the month, but no later than five working days after this date. Data acceptance notices must be sent by mail within five working days of receipt. If the data is accepted an invoice will be sent within five working days after the acceptance message. If the data is rejected, the reasons are examined and the records need to be corrected. After the invoice has accepted, payment should be executed within 30 days (P2, 2012). Figure 22 shows an overview of this process.

In case of the eCHS, the system offers web services supporting the up- and download of CDRs, based on the Open Clearing House Protocol (OCHP). Currently, both systems run next to each other (E-clearing.net, 2012).

6.2.5 Metering process

In order to meter the usage of an electricity connection, meters are deployed at each connection point. In early 2007, a central 'Metering Registry' has been introduced in the Netherlands. Energy suppliers use the registry to get the metering values from the regional distribution system operators (DSOs). Based on this registry, the energy suppliers get an insight into the usage history of a connection. The functionality of the registry is limited to the provisioning of meter readings and usage via a central database, and supports processes such as the validation and calculation of meter readings. The DSO controls the access to the registry and updates the data (EDSN, 2013).

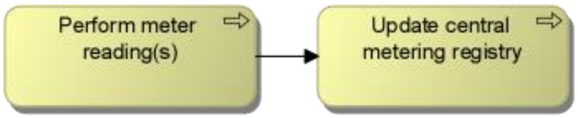


Figure 23: Overview of the metering process

6.2.6 Balancing process

In order to match the demand and supply of electricity, the current balancing process works with electricity forecasts and a separate balancing market. As introduced in chapter three, this market is controlled by the TSO, who is the single buyer on this market. Market players have to submit forecasts (or 'energy programs') in order to match supply and demand. When there is imbalance in the network, the TSO corrects this by buying the lowest priced offer in the balancing market (Van Werven & Scheepers, 2005).

In the Netherlands, TenneT fulfills the role of TSO. The obligation for market players to submit forecasts is referred to as 'program responsibility', which is defined by TenneT as the responsibility of customers (with the exception of protected customers) and license holders to draw up, or to have drawn up, programs for the production, transmission and consumption of electricity for the benefit of grid operators, and to act in accordance with these programs. Parties authorized by TenneT, so-called balance responsible parties (BRP), inform TenneT on a daily basis about the transactions with other BRPs that they have planned for the next day. The sum of all transactions entered into by each BRP is called an 'Energy Program' or E-program. TenneT checks all E-programs for consistency. The metering responsible (a role that is often fulfilled by the regional grid operators) notifies TenneT of the amount of electricity that each BRP has actually consumed and/or supplied. The difference between the amounts recorded in the E-program and the total of the actual measured values of each BRP is called the imbalance (TenneT, 2013).

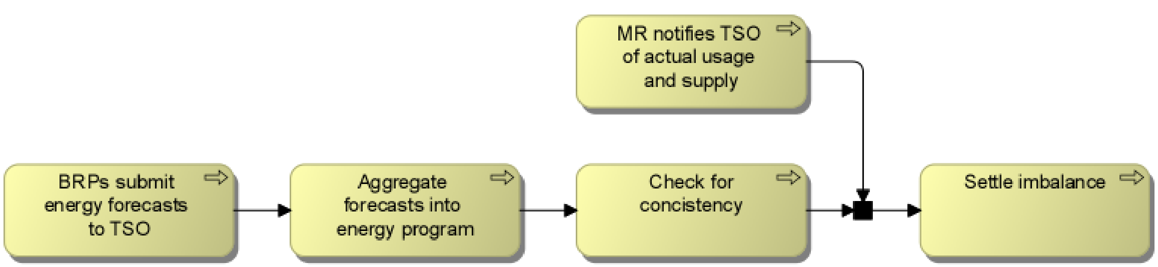


Figure 24: Overview of the balancing process; based on (TenneT, 2013)

6.3 Business layer

Based on the market roles analysis and business processes identified in the previous sections, the business layer of the current architecture can be modeled. In Figure 25 the business layer of the current architecture is depicted, which aggregates the market roles and the services realized by the business processes in the current situation. Each of the market roles is connected to one or more services that it realizes.

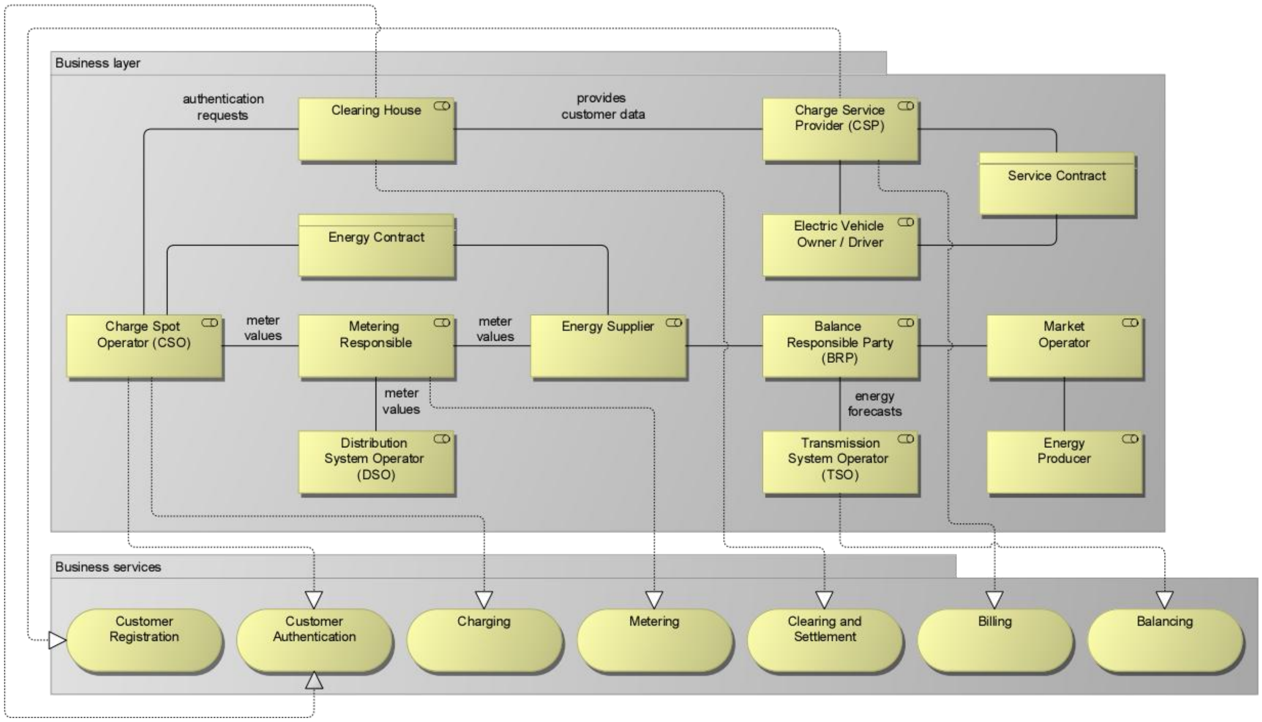


Figure 25: Business layer of the current architecture

6.3.1 Business model

Using the roles and concepts from the business layer, a business model that reflects the current situation can be constructed. As mentioned in section 1.8.2, we apply the e3-value methodology to clarify and compare business models and its value exchanges. **Figure 26** shows the business model as applicable in the current situation. For the purpose of understandability, only the relevant market roles are included; not all roles as identified in the business layers are relevant to understand the business model for electric mobility.

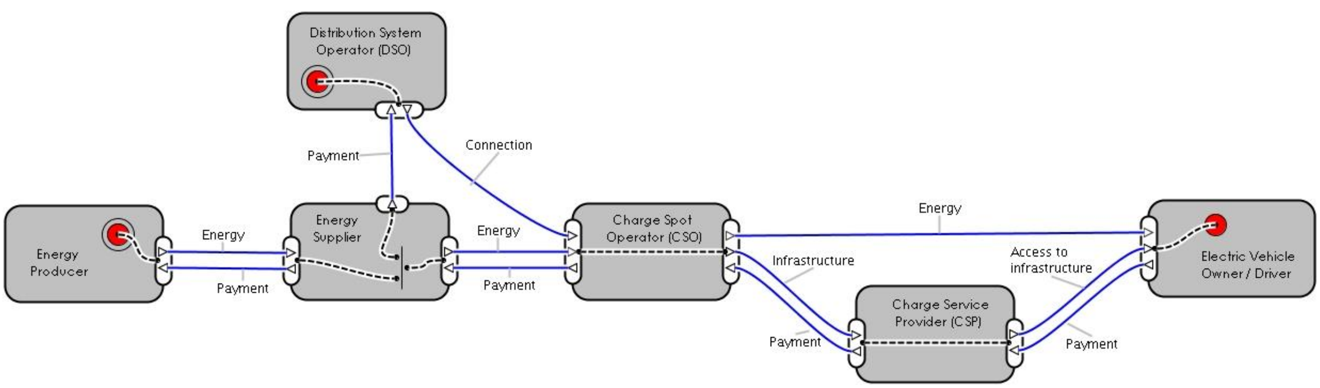


Figure 26: Value exchange in the current architecture

As can be seen in the figure, the main value that gets exchanged is the energy flow, which origins from the energy producer and ends at the electric vehicle owner / driver. Based on this model one can conclude that the business model for electric mobility is based on (small) 'margins' on top of the energy prices.

As mentioned in section 6.1, the charge spot operator (CSO) has an energy contract with the energy supplier in the current situation; therefore a value exchange exists between CSO and energy supplier. However, the CSO is not the final end-customer of the energy in reality, since the electric vehicle (i.e. the electric vehicle driver / owner) consumes the energy during the charging process. In order for the customer to compensate the CSO for the energy, the charge service provider (CSP) mediates between customer and CSO. The customer has a service contract with the CSP, which charges the customer based on the charging session duration and power. Since it is legally not allowed to resell energy, the CSP and CSO apply hourly rates (The New Motion, 2013). As defined in the "supplier model" for the energy market (EDSN, 2013), the energy supplier is the single point of contact for the energy consuming party and takes care of the settlement with the distribution system operator (DSO). The energy supplier purchases its energy from one or more energy producers on the energy market.

6.4 Application layer

The current application landscape exists of various types of systems. For the current research and architecture, five systems are of relevance, which are displayed in Figure 27. The first type is the embedded client application running inside charge points, which communicates with a charge point management system. Various implementations of these charge point management systems exist. In most cases, charge points from a specific supplier are delivered with a charge point management system from the same supplier. Communication between charge points and charge point management systems is based on the Open Charge Point Protocol (OCPP, 2013).

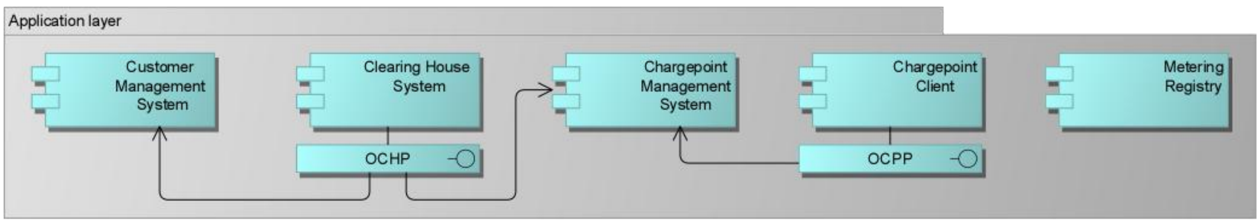


Figure 27: Application view of the current architecture

Next to the applications specifically dealing with charge points, various customer management systems exist that are managed at each of the charge service providers (CSPs). In order to provide roaming functionality for customers of service providers at the charge points of various charge spot operators, a separate system exists: the clearing house. As mentioned in the previous section, two specific implementations of this clearing house currently exist: The 'centraal interoperabiliteits register' (CIR), and the European Clearing House System (eCHS).

The interfaces between the clearing house systems and the customer management systems of the different charge service providers and charge spot operators mainly consist out of three components: the exchange of authorization data, the exchange of charge data, and in some cases the exchange of charge point information for value-added services. For the European Clearing House System, this communication is based on the Open Clearing House Protocol (OCHP) from the E-clearing.net foundation (E-clearing.net, 2012). We have no information about the interface offered by the CIR; OCHP is therefore considered as the generic interface in the current architecture.

6.5 Infrastructure layer

In the current architecture, the infrastructure consists of nodes that represent servers and databases, realizing each of the applications identified in the previous section. The infrastructure is reflected in Figure 28.

An electric vehicle is connected with a charge point via a charging plug. The type of this plug depends on the type of the charge point. For an AC charge point the charging plug conforms to IEC 62196-2 "Type 2", also known as the 'Mennekes' plug (P2, 2012). The charge points are connected with a central back-office server. Logica made a proof-of-concept of this architecture, consisting of a charge point client, an open protocol and a central management system. This architecture served as a basis for the current architecture throughout the Netherlands, and E-laad is still making use of their system (Logica, 2010). The data connection between charge point and back-office server is based on a GPRS connection. In the absence of a data connection (i.e. whenever the data connection fails), charge points stay functional to the customer (P2, 2012).

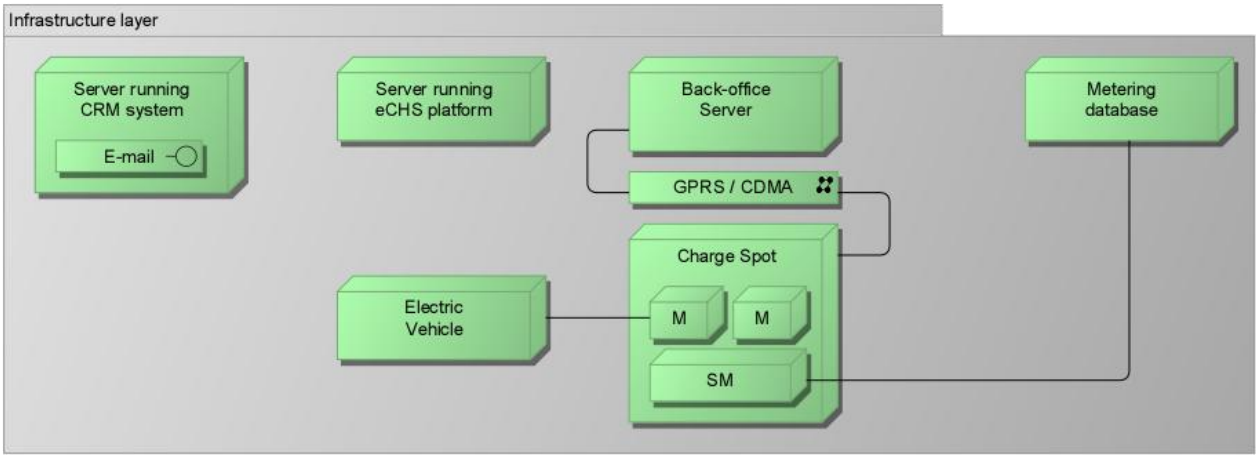


Figure 28: Infrastructure view of the current architecture

The back-office servers, clearing house databases and customer management systems are connected via the internet, either by (open) protocols or e-mail. In the current situation, the distribution system operator (DSO) is responsible for the meter readings, which are kept in a separate metering database. The exact implementation of this database and its relation to the electric mobility is out of scope for the current research.

As identified in chapter 2.3, the connection for a charge point is currently treated in the same manner as a domestic connection. Therefore, a separate smart meter (SM) is installed In addition to the meters (M) that register the usage per charge session for each of the outlets (or 'charge sockets'). An electric vehicle is connected to the outlet, and therefore in turn to a separate meter.

6.6 Overview

In order to draw a comprehensive overview of the current architecture, the three layers (business, application and infrastructure) are synthesized in a single architectural overview. This overview is shown in Figure 29. The architecture is structured according to the three layers as identified in the ArchiMate framework (Iacob, Jonkers, Quartel, Franken, & Van den Berg, 2012).

6.7 Conclusions

In the current chapter we synthesized the architectures of electric mobility and the electricity system into a total overview of current situation in electric mobility. From this overview, a number of conclusions can be drawn. The main conclusion is that the current architecture is inadequate in several ways. Based on the identified threats and opportunities in the previous chapter, there is a lack of integration between electric mobility and the electricity system, since currently, there is no possibility for influencing the charge process based on information from the distribution system operator (DSO) and the energy market. Charging can neither be influenced based on grid constraints nor the amount of (renewable) energy supply available. The main reason is that charge points can only be accessed and controlled by the charge spot operator (CSO) in the current situation. As identified in the previous chapters, the current architecture also implies a situation where the customer has no choice of energy supplier, since the energy contract is established between energy supplier and CSO.

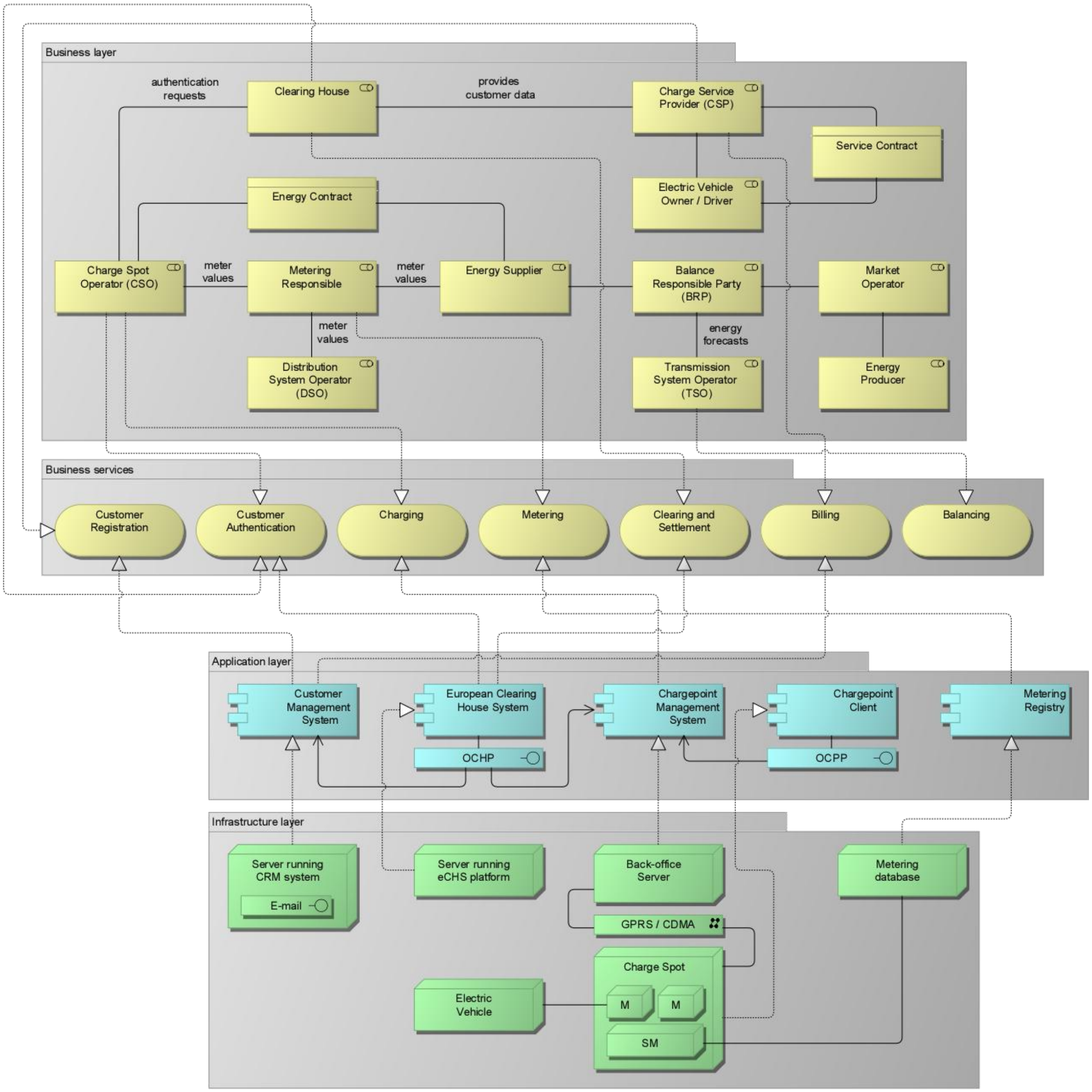


Figure 29: Overview of the current architecture

7 Solution analysis

In order to advance to the design of a reference architecture for electric mobility, knowledge on possible solutions for the problems identified in the previous chapter is acquired and analyzed in the current chapter. Based on the objectives and requirements defined in the previous chapter, solution paths are identified and compared.

7.1 Introduction

The current chapter describes the main choices that motivate the design of the reference architecture. Based on a literature study, design choices are described which form the basis of the reference architecture. The main design choices involve the concept of 'smart charging' and its implementations, and the shift of the energy contract by changing the formal end-user of electricity. The current chapter is constructed of three main parts:

1. The need for 'smart charging' and its options for implementation (chapter 7.2, 7.3 & 7.4)
2. The change in business model by shifting the energy contract (chapter 7.5)
3. The consequences and implications of these design decisions (chapter 7.6)

7.2 The need for 'smart charging'

In the current situation, no external control is involved in the charging process. This basic form of charging electric vehicles is called 'uncontrolled' or 'dumb' charging (CEN, CENELEC & ETSI, 2012). As stated in the problem analysis and objectives, integration is needed between the process of charging electric vehicles and external influences based on fluctuations in demand and supply. In an ideal situation, charging should be influenced based on grid constraints and the amount of (renewable) energy supply available. This concept is not new, and is widely regarded as 'smart charging'. Various studies have analyzed the potential opportunities for smart charging; however, the concept is still relatively new and a lot of uncertainties exist. The main reason is that the concept of smart charging requires cooperation between multiple market parties, and can be implemented in various ways. Decisions have to be made about the division of roles and responsibilities. In the current research, we work towards a reference architecture in order to reduce some of these uncertainties and propose a framework for further understanding.

7.2.1 The concept of 'smart charging'

The main idea of smart charging is that by taking control of the charging process, the use of the grid and available energy can be optimized to minimize additional investments and facilitate the integration and storage of renewable energy (CEN, CENELEC & ETSI, 2012). Movares defines smart charging as a method of charging electric vehicles optimized to the available grid capacity and/or fluctuations in the supply of (sustainable) energy (Movares, 2013).

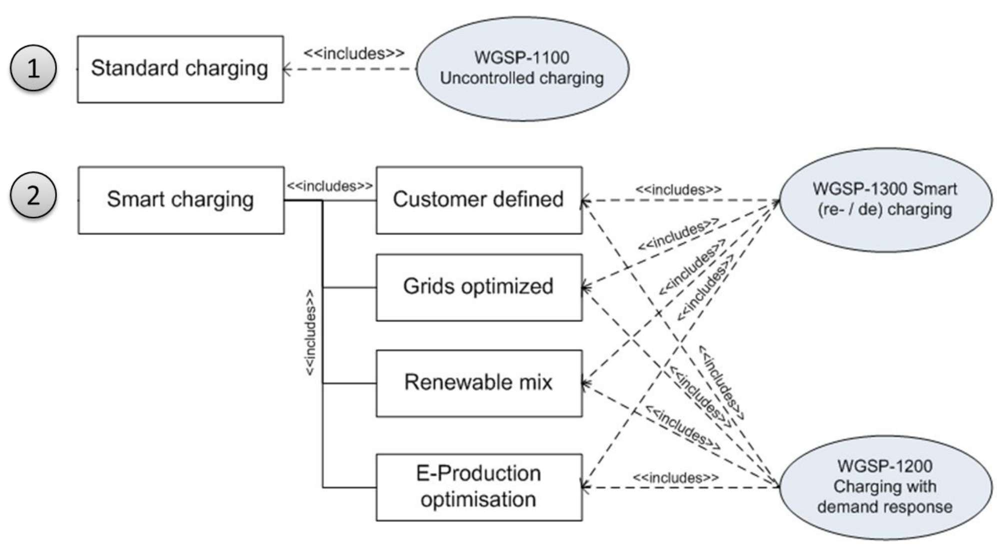


Figure 30: Use cases for charging electric vehicles (CEN, CENELEC & ETSI, 2012)

As mentioned in the previous section, the concept of smart charging requires cooperation between multiple market parties. In a report by CEN, CENELEC & ETSI, use cases have been collected from a diverse range of stakeholders concerning the charging of electric vehicles. These use cases have been grouped and generic use cases have been suggested to reflect the needs of interested stakeholders. This resulted in the identification of four relevant factors that should ideally influence the charging process: the customer, the electricity grid, the amount of renewable energy available and the production profile of electricity. In the report, the four factors are aggregated into two use cases: smart charging based on control signals (WGSP-1300) and charging with demand response (WGSP-1200). Figure 30 shows the relationships between the four factors and the two resulting generic use cases. The concept of smart charging is positioned as an alternative to 'standard' or uncontrolled charging (CEN, CENELEC & ETSI, 2012). The two generic use cases serve as a basis to further realize smart charging; they are essentially two ways to 'implement' the smart charging concept. In the following sections, each of the four factors that constitute the basis behind the concept of smart charging is clarified further.

7.2.2 Customer-defined charging

The ability to charge an electric vehicle at a public charge point should be considered as a service that is offered to customers. Consequently, customer needs and requirements should be the starting point of each transaction. Smart charging has to be performed within the boundaries as specified by the customer. According to ISO/IEC 15118, the main customer need is that the charging process will be completed at a predetermined point in time, or in the case of any exceptional circumstances, a specified error reporting procedure should occur (IEC, 2011)

7.2.3 Grid optimized charging

The electricity system, also known as the electricity grid, has limited capacity and can have voltage constraints. As mentioned in the problem description (please refer to section 4.2.1 for more information), the charging of electric vehicle potentially can have significant impacts on the residential low-voltage networks. The process of charging electrical vehicles should therefore be optimized to meet grid constraints for two inter-related reasons: in order to use the electricity grid in an efficient manner and avoid unnecessary upgrades, but also to prevent power quality issues. The prevention of overloaded cables and tranformers is also known as congestion management.

7.2.4 E-production optimized charging

This objective concerns the optimization of electricity production, with the aim of avoiding unnecessary investments in production capacity. The current production capacity is largely based on peak loads. In the case of uncontrolled charging these peaks will only increase, resulting in an increasing need for production capacity. As mentioned in the problem analysis, flexible production capacity is very expensive, and an increase in peaks is undesirable. The use of storage and load control can reduce this need and results in peak shaving. This also includes the concept of vehicle-to-grid implementations. As identified in the problem analysis, most personal transportation vehicles represent an idle asset while parking, which can be utilized for power storage (Brooks & Gage, 2001). By using the battery system of electrical vehicles, storage capacity can be offered.

7.2.5 Renewable mix charging

The objective of 'renewable mix charging' is concerned with charging based on the supply and availability of renewable energy sources (RES). This form of charging is related to all other forms of smart charging (customer defined, grid optimized and E-production optimized) (CEN, CENELEC & ETSI, 2012).

7.3 Options for smart charging

As described in the previous section, the main idea of smart charging consists of influencing the charging process based on external factors. This is a form of demand side management (DSM) or load management, which can be defined as a process that is intended to influence the quantity or patterns of use of electric energy consumed by end-use customers (CEN, CENELEC & ETSI, 2012).

In general, two options exist in performing demand side management; it is either system led or market led. In the system led scenario, the system operator or a service aggregator or agent sends 'control signals' to the demand-side customers, indicating that there is a requirement for load reduction or shifting. In the market led scenario, the customer responds directly to market pricing signals, causing behavioral or systematic consumption change based on market mechanisms (International Energy Agency, 2003). These two scenarios are reflected in the use cases identified in Figure 30. The use case 'charging with demand response' (WGSP-1200) describes the market led scenario, where price signals or other incentives are used to influence the customer. In this scenario, the customer should be able to respond in some way. The use case 'smart charging' (WGSP-1300) describes the system led scenario, providing a more controlled way of performing demand side management based on technical signals and scheduling for load control.

In the next sections, we will describe each of the options for smart charging or demand side management. Since the title of the second use case (WGSP-1300, 'smart charging') is slightly confusing, we will refer to this type of charging as 'controlled charging'. Also, a third option for smart charging will be introduced which combines concepts from both the controlled as the demand-response scenarios.

7.3.1 Controlled charging

The use case of controlled charging is a realization of smart charging based on flexible contracts and technical signals for load control (CEN, CENELEC & ETSI, 2012). Control signals can be sent to either the charging station or the electric vehicle. These control signals can range from simply switching between on and off, charging with a specific rate or can involve communication about sophisticated charge schedules. An example of such a charging schedule can be seen in Figure 31. This figure is obtained from the IEC 15118 standard, describing communication between charge points and electric vehicles. Part of the communication as described in this standard involves activities such as target setting, charging schedule selection, charging control and re-scheduling. In the example as shown in Figure 31, the electric vehicle provides several types of information: the maximal power (3680 W in this example), the minimum reasonable charging power (1000 W in this example), and the maximum delay before the vehicle needs to be charged at full power (3 hours and 15 minutes in this example). Based on this information, a charging schedule is determined (IEC, 2011).

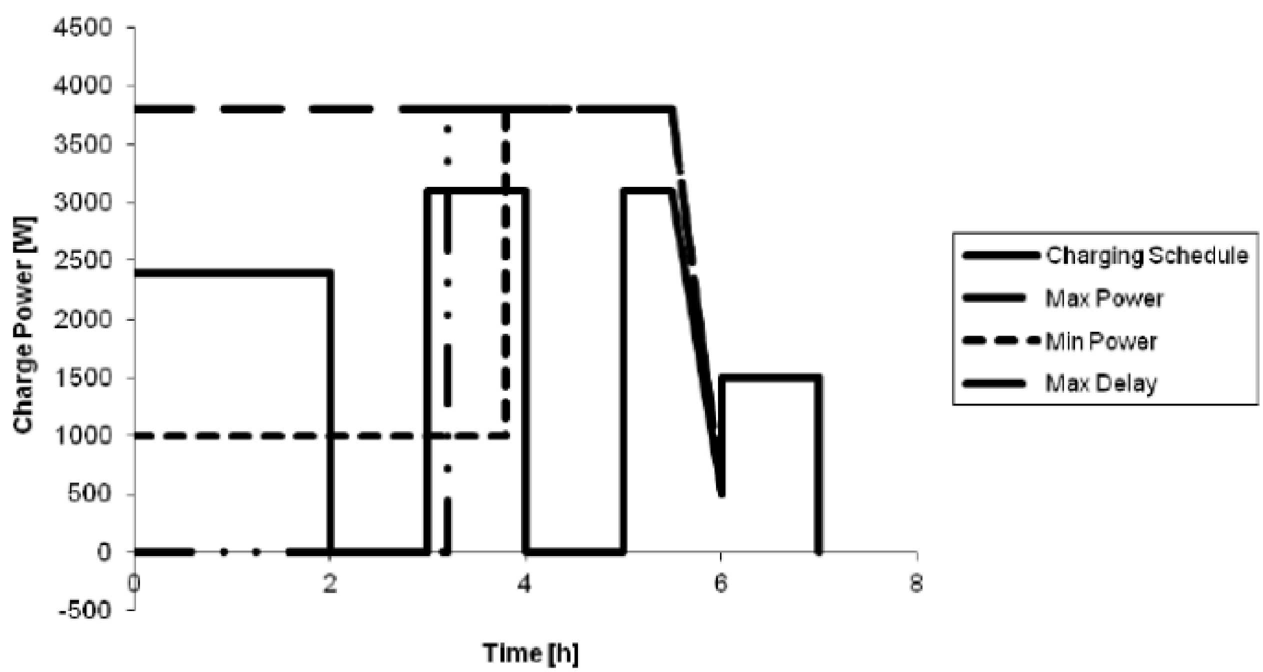


Figure 31: Example of a charging schedule (IEC, 2011)

An example project demonstrating the controlled charging scenario is the ‘Smart Charging’ project by Better Place, Enexis and Oranjewoud. The project involves a pilot to realize a working demonstration for smart charging (Better Place, Enexis & Oranjewoud, 2010). In order to do so, centrally controlled charge points are being used, and each consumer has a charge service provider (CSP). This situation reflects the current situation in the Netherlands. The main goal of the pilot is to demonstrate a situation where the needs from the distribution system operator (DSO) are balanced with the demand-driven needs from the customer. When an electric vehicle arrives at a charge point, it uses its CSP to request the charge process. In order to do so, the driver has to provide information like charge point identification, the current state of charge, the amount of energy need and the time of departure. Based on this information, the CSP will create a charge schedule for the electric vehicle and will submit this to the DSO for approval. Whenever the charge schedule fits within the local grid constraints, it is executed. If not, the schedule is denied and a forecast of the local grid capacity is returned. The CSP can then either alter the current charging schedule, or could alter the set of active charging schedules under his control. The project successfully demonstrated the feasibility of controlled charging, based on local grid constraints from the DSO. However, several issues still have to be solved. One example is that the pilot is based on a single CSP. In the current situation, multiple CSPs exist; which raises the question of how the available capacity should be divided between these CSPs. Also, only control signals from the DSO are currently included, however, in an ideal situation, control signals based on the actual supply of (renewable) energy should be integrated as well (Better Place, Enexis & Oranjewoud, 2010).

As a closing remark, controlled charging should be seen as a “top-down” approach in demand-side management, where measures are taken by market roles in order to control the electricity demand (CEN, CENELEC & ETSI, 2012). In other words, market roles (such as utilities) decide to implement measures on the demand side to increase the efficiency of the energy system. This is the approach that has been used by the vast majority of the power industry over the last thirty years (Eurelectric, 2011).

7.3.2 Demand-response charging

The use case for demand-response charging involves extra communication that makes it possible to receive price signals or other incentives, providing the possibility for a customer to respond (CEN, CENELEC & ETSI, 2012). In contrary to the controlled charging approach, the concept of demand-response implies a “bottom-up” approach, where customers become active in adapting their consumption patterns (Eurelectric, 2011). According to the International Energy Agency, demand response refers to a set of strategies which can be used in competitive electricity markets to increase the participation of the demand-side, or end-use customers, in setting prices and clearing the market (International Energy Agency, 2003). Demand response can be seen as a concept describing an incentivizing of customers in order to initiate a change in their consumption or feed-in pattern (CEN, CENELEC & ETSI, 2012).

In a demand-response approach, customers are exposed to (near) real-time prices or other incentives, to which they may respond in two ways (International Energy Agency, 2003):

1. Shift their demand in time to an off-peak period
2. Reduce their total or peak demand (either by energy efficiency measures, or self-generation)

Of course, customers are free to choose to not respond and pay the market price instead. This approach is not new; a similar form of demand-side management can be seen in public transportation: travelling in peak hours is more expensive, in such a way to encourage travelers to shift their travel to off-peak hours. However, even though the concept of demand-response is well known, demand-response has typically been low in existing energy markets. According to the International Energy Agency, this is caused by lack of the incentive and means to respond for market participants. “Regulated retail prices, outdated metering technologies, a lack of real-time price information reaching consumers, system operators focused on supply-side resources and a historical legacy in which demand response was not considered important – all of these factors combine to produce the low levels of demand response seen in electricity markets today” (International Energy Agency, 2003).

According to the International Energy Agency, significant economic gains can be achieved with relatively small amounts of response. In their report, they describe that in some scenarios, the wholesale prices could be reduced with up to 50%, whilst having a demand-response capability of just 5% (International Energy Agency, 2003).

Demand-response can be implemented in two ways, based on the method in which customers can respond to the price signals. The first option is a manual implementation: customers get price information, for example on a display, and based on this information they decide whether or not to shift their consumption. The second option considers an automated implementation: customers shift their consumption automatically, based on technical signals and some kind of an energy management system. For instance, the system could set-up the system in such a way that (part of) their consumption is shifted when prices are at a certain level (Eurelectric, 2011).

An early example of the 'manual' option can be seen in France, where Electricité de France (EDF) works with a pricing program called 'Tempo'. In this program, the price of electricity varies depending on the days and hours of the day; there are blue, red and white days, and peak and off-peaks hours. In total, six different price-periods exist, which are communicated to the customers by simple signals. In 2008, the program had attracted 450,000 customers. The result of the program is a substantial reduction of demand on both white (15%) and red (45%) days. On average, the customers reduced their annual electricity bill by 10%. A survey of the customers revealed that 90% of the customers were satisfied with the program (European Parliament, 2012).

'11 – '12	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
September			S	D						S	D						S	D						S	D						
October	S	D						S	D						S	D						S	D						S	D	
November					S	D						S	D						S	D						S	D				
December			S	D						S	D						S	D						S	D						S
January	D						S	D						S	D						S	D						S	D		
February				S	D						S	D						S	D						S	D					
March			S	D						S	D						S	D						S	D						S
April	D						S	D						S	D						S	D						S	D		
May					S	D						S	D						S	D						S	D				
June		S	D						S	D						S	D						S	D						S	
July	D						S	D						S	D						S	D						S	D		
August				S	D						S	D						S	D						S	D					

Figure 32: EDF's Tempo Program (S = Saturday, D = Sunday) (EDF, 2012)

For the option of 'automated' demand-response, currently several developments can be seen. Two examples of automated demand-response are the OpenADR and PowerMatcher technologies. The Open Automated Demand Response (OpenADR) is an open and standardized way for electricity providers and system operators, providing a common language to communicate about demand-response signals over any existing IP-based communications network, such as the internet (OpenADR, 2013). The PowerMatcher is a general purpose coordination mechanism for balancing demand and supply, based on concepts from multi-agent systems (Kok, Scheepers, & Kamphuis, 2009).

7.3.3 Application

In order to increase our understanding on the concepts as introduced in the previous sections, the options for smart charging are applied in the current chapter. The main question is how to relate the relevant stakeholders to the charging process; how can the role specific objectives be translated into either price or control signals (such as start charging, stop charging, and charge at a specific level).

For the scenario of controlled charging, a promising option is to introduce the role of the 'aggregator' (also referred to as 'flexibility operator'), which is a "generic role that links the role customer and its possibility to provide flexibilities to the roles market and grid" (CEN, CENELEC & ETSI, 2012).

The aggregator is responsible for summing up flexibilities from several customers, and actively participates in energy markets or other commercial transactions to market these flexibilities (ADDRESS, 2009). The aggregator is active in the energy and/or imbalance market in order to market the flexibility offered by the resources under its control. For the relationship with the distribution system operator (DSO), three scenarios are possible. In the current situation, where there is no market for grid capacity, the aggregator can receive direct control signals from the DSO. In the situation as described in the European conceptual model of Smart Grids (please refer to Figure 39), the control between DSO and aggregator can also be implemented in a demand-response approach, where the aggregator makes decisions solely on price signals. Of course, a combined situation is possible as well. In all cases, the aggregator works on basis of customers who sign a 'flexible load contract' with the aggregator. The scenario of controlled charging has been depicted in Figure 33.

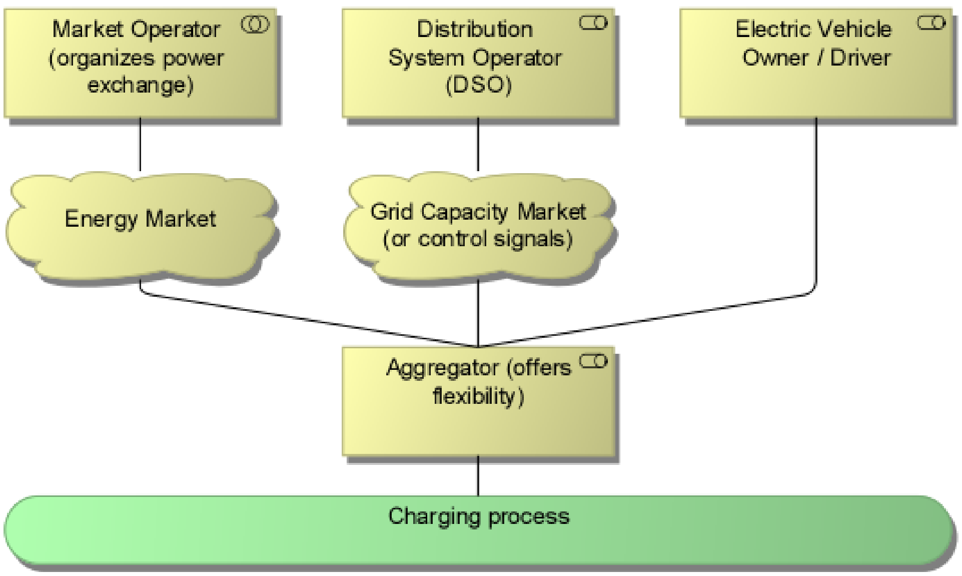


Figure 33: Aggregator influencing the charge process

The aggregator is a central concept in the ADDRESS ('Active Distribution networks with full integration of Demand and distributed energy RESourceS') project. This is a four-year large-scale R&D European project launched in June 2008, coordinated by ENEL and a consortium consisting of 25 partners from 11 European countries spanning the entire electricity supply chain. In the project, the aggregators are the key mediators between the consumers on one side and the markets and the other power system participants on the other side. The aggregator gathers the "flexibilities" provided by customers, and offer them to the different power system participants through various markets. According to the project report, it should be emphasized that the role of aggregator is about marketing modifications in demand, rather than energy profiles itself. In other words, aggregators sell a deviation from the forecasted level of demand and not a specific level of demand (ADDRESS, 2009) (Eurelectric, 2011).

In contrast to the scenario of controlled charging, the external control of the charging process could also be fully automated based on a demand-response energy management system (EMS). This EMS acts as a software agent that represents the customer. The EMS communicates about demand-response price signals over some sort of communications network, such as the internet (OpenADR, 2013). Based on the price signals, the EMS can adjust the charging process automatically. The idea of using multi-agent systems for demand-response energy management is central in the dissertation of Kok (2013) and the PowerMatcher technology (PowerMatcher, 2013).

In his dissertation, Kok (2013) presents the 'smart energy management matrix', which categorizes various types of energy management into four general classes. Two of these classes can be related towards demand-response charging. In the first approach, which is called 'price reaction', communication is based on a one-way signaling of dynamic prices to end-customers and/or his systems. The 'Tempo' program from EDF is an example of the price reaction approach (please refer to the previous section and/or Figure 32). At certain time intervals, a new electricity price (or price profile over the coming hours) is sent to the end-customer. This price is either displayed for the end-customer to react to, or used by an energy management system to switch devices automatically. In the second approach, which is called 'market integration', devices engage in an automated market trade with each other. Communications are two-way, based on energy prices and volumes. In essence, this scenario equals to the 'price reaction', with the addition that devices communicate their available flexibility together with their preferences and conditions to an electronic market. Because of these communications, the reaction of the full response pool can be known beforehand. In order to apply demand-response charging, it is therefore important to apply two-way communication.

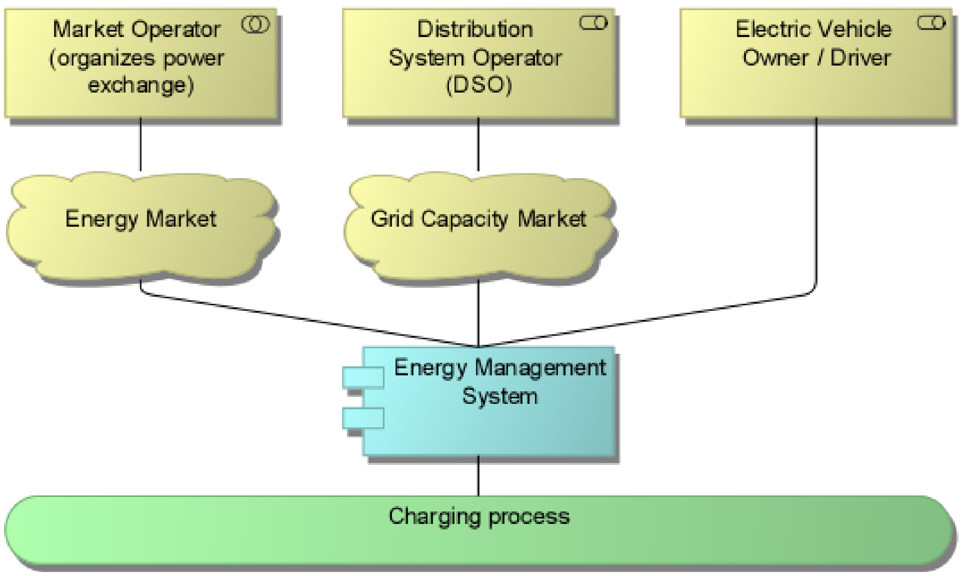


Figure 34: Energy management system influencing the charge process

7.3.4 Comparison

As identified in section 7.3, two options for smart charging are available in order to implement flexibility and intelligence in the charging process: controlled charging and demand-response charging. In the current section we will compare these options, which we define as follows:

- **Controlled charging (top-down approach)**
  Intelligent way of charging, based on flexible contracts and technical signals for load control (CEN, CENELEC & ETSI, 2012). Control signals are sent by a third party (fulfilling the role of 'aggregator', also referred to as 'flexibility operator'), and can be sent to either the charging station or the electric vehicle. These control signals can range from simply switching between on and off, charging with a specific rate or can involve communication about sophisticated charge schedules.

- **Demand-response charging (bottom-up approach)**
  Intelligent way of charging, where price signals or other incentives are sent to the customer, providing the possibility for the customer to respond (CEN, CENELEC & ETSI, 2012). At certain time intervals, a new electricity price (or price profile over the coming hours) is sent to the end-customer and/or systems, on which demand can be adjusted. Devices communicate their available flexibility together with their preferences and conditions to an electronic market (Kok, 2013). Price signals can be sent to either the charging station or the electric vehicle.

In Table 8 the advantages and disadvantages are listed for each of the identified options. The main considerations are about privacy autonomy, system reaction and the required changes and effort. According to Kok (2013), one of the issues in the controlled charging scenarios is the issue of consumer autonomy; customers have problems with an outside authority directly influencing their charging behavior. Other advantages and disadvantages concern the required changes for the customer and other roles involved in the current architecture.

Scenario	Advantages	Disadvantages
Controlled charging	1. Relatively easy to integrate with the current situation 2. Simple for the customer to understand (separation of energy and flexibility) 3. System reaction can be known beforehand	1. Partial use of response potential 2. Uncertain system reaction 3. Privacy and autonomy issues 4. Additional layer of control (requires 'Aggregator' role) 5. Requires a new type of contract for the provision of flexibility 6. Requires CSOs to provide ability for control to aggregator
Demand-response charging *(using two-way communication)*	1. Full use of response potential 2. No privacy issues 3. Enables distributed control, with full power and responsibility at the customer 4. System reaction can be known beforehand	1. Requires new energy contracts with 'flexible' prices 2. Requires a (near) real-time marketplace for energy and grid capacity 3. Requires a new way of thinking from a customer perspective 4. Requires control and intelligence at a lower level

Table 8: Advantages and disadvantages for each of the smart charging scenarios

When analyzing Table 8, we draw the same conclusion as Kok; based on the identified scenarios, the demand-response approach using two-way communication is the most favorable scenario. According to Kok, this scenario forms the hot spot in his 'smart energy management matrix' and therefore forms the basis of the PowerMatcher technology (Kok, 2013).

7.4 The traffic light concept

The traffic light concept is a framework that is often referred to in the discussions concerning smart charging, and combines the approaches of demand-response (the "bottom-up" approach) and controlled (the "top-down" approach) charging. On one hand it is a concept that describes the relationship between the use of flexibilities on the grid side (red/orange phase) and the market side (green phase); the yellow phase should be considered as the transitional period from market to grid. On the other hand, the traffic light concept describes a use case that evaluates the grid status (red, yellow, green) and provides the information towards the relevant market roles (CEN, CENELEC & ETSI, 2012). An overview of the traffic light concept is displayed in Figure 35.

In the green situation, which should be seen as the 'normal operating state', the market operates freely; this could either reflect a situation with fixed electricity prices, or variable prices based on demand-response. In this situation, the distribution system operator (DSO) may or may not apply incentives to coordinate and influence actors in their demand. The yellow state indicates that the DSO will start to actively engage with the market in order to keep the system from becoming unstable. This could be by stepping in to procure in real time at market prices ("bottom-up" approach), or by executing pre-agreed flexibility contracts ("top-down" approach). The yellow state is a temporary state preventing the grid from entering the red state. In the orange/red state the DSO needs to take control of market interactions in a certain area where the constraint has occurred. In this situation, the DSO will execute dedicated emergency actions through flexibility operators, or execute direct controls over generation or demand in order to re-stabilize the system as far as a contract or regulation and legislation allows doing so. This can thus be considered as a full “top-down” approach. In the red situation, which should be avoided at all times, the fuses in the distribution grid will blow and the transmission of electricity is stopped (CEN, CENELEC & ETSI, 2012).

Figure 35: Traffic light concept; adapted from CEN, CENELEC & ETSI (2012)

7.5 Shift of the energy contract

In addition to the integration of smart charging, another important design decision that motivates the reference architecture is the shift of the contractual relationship for the provision of energy. As mentioned in section 6.1, the charge spot operator (CSO) has an energy contract with the energy supplier in the current situation. The CSO is however not the final end-customer of the energy in reality, since the electric vehicle (i.e. the electric vehicle driver and/or owner) consumes the energy during the charging process. In order for the customer to compensate the CSO for the energy, the charge service provider (CSP) mediates between customer and CSO. The customer has a service contract with the CSP, which charges the customer based on the charging session duration and power. Since it is legally not allowed to resell energy, the CSP and CSO apply hourly rates (The New Motion, 2013). The model in Figure 26 reflects this situation (located in the chapter concerning the current architecture).

We argue that the current model is inadequate in several ways. One could argue that the current model is rather oblique, since even though electricity is legally not being resold, this is essentially still the case. In addition, the customers have no ability to choose their own energy supplier when charging. As a result, the current situation implies a relative long chain of cash flows, resulting in several cost locations for the end customer.

In the current research, the energy contract is assigned to the customer itself, which introduces a contractual relationship between energy supplier and customer, instead of the charge spot operator (CSO). This aligns charging scenarios for electric vehicles with the current situation for household energy. The direct assignment of the energy contract to the customer can however be implemented in different ways. In a scenario where the charge point is owned and operated by the CSO, a logical option would be to separate between energy provisioning and the charging service itself. The service contract relates to the ability to use charge points from various CSOs with one single customer card. The energy contract relates to the provision of energy. This would introduce two separate scenario paths for the value exchange, as depicted in Figure 36.

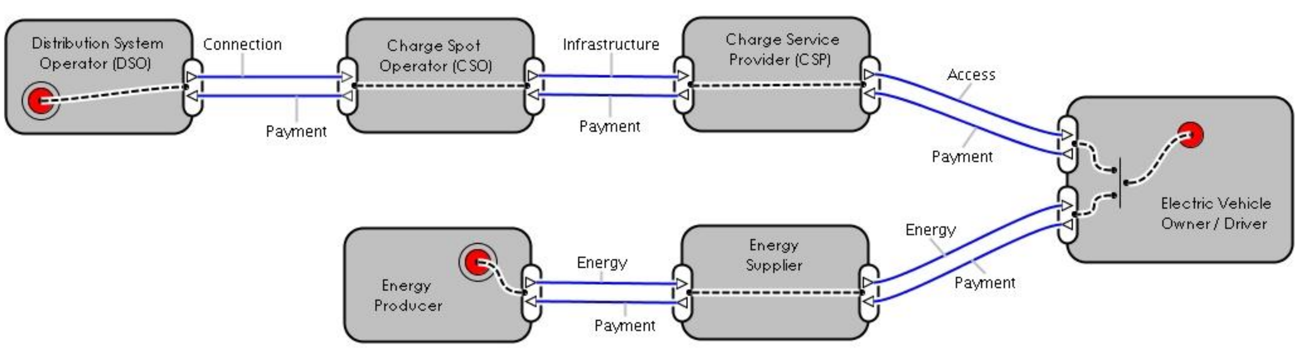


Figure 36: Separate scenario paths for energy and service

Even though the scenario as identified above might be promising, some arguments need to be taken into consideration. One of the main arguments against the separate paths for value exchange is that there is no single point of contact for the customer any longer. The customer needs two separate contracts to be able to charge, which is obviously not an ideal situation. An alternative scenario would therefore be to let the CSP manage the energy contracts for its customers, so that the customer will still get a single invoice when using the public charging infrastructure. This scenario is depicted in Figure 37.

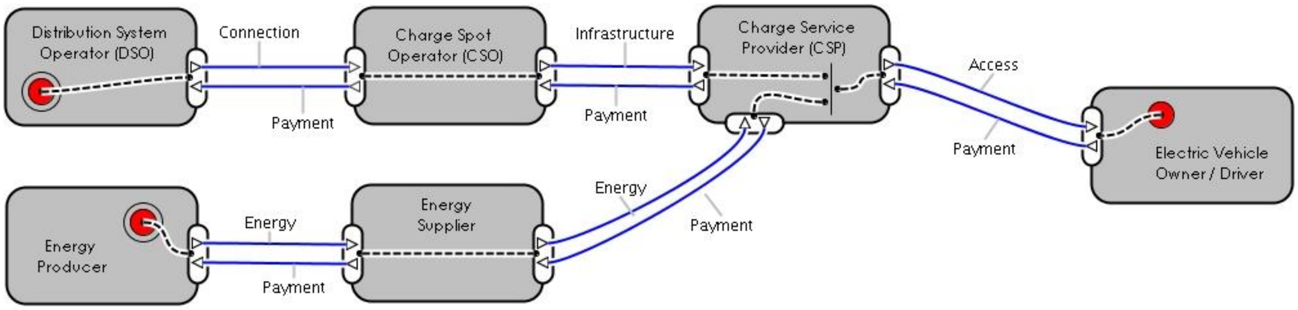


Figure 37: Value exchange when the charge service provider (CSP) owns the energy contract

Continuing on this reasoning, an interesting possibility emerges when the roles of CSP and energy supplier are merged into a single role, where the energy supplier acts as a service provider towards the customer. In this case, the energy supplier provides energy contracts for electric mobility, and at the same time provides customer cards that the customer can use to charge at every charge point. In addition to financial settlement with the energy producer and DSO, the energy supplier now has an additional responsibility to compensate the CSO for the use of its charge points. This scenario is depicted in Figure 38.

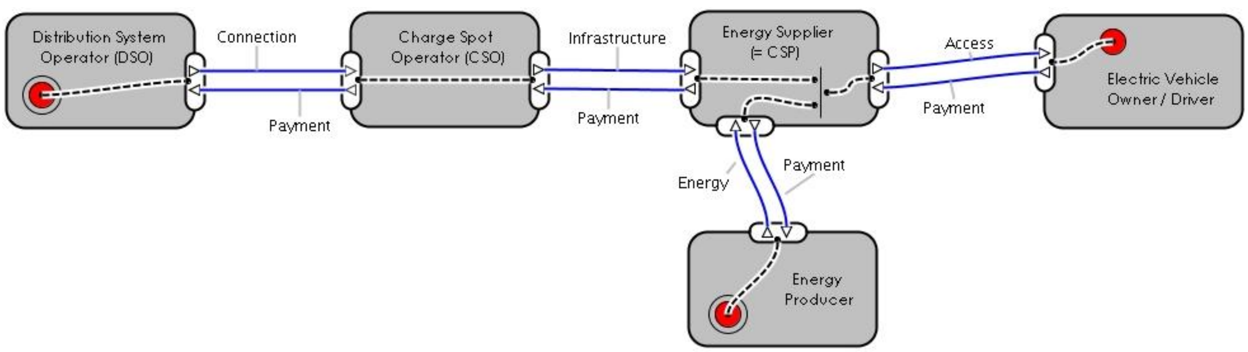


Figure 38: Revenue streams with energy supplier as charge service provider (CSP)

7.6 Consequences

The concept of smart charging and the shift of the energy contract affects several other design decisions, ranging from consequences on the structure of the energy market to changes in the metering functionality. In the current section, these consequences and changes are reviewed, including some of the design decisions as made for the reference architecture.

7.6.1 Consequences on the energy market

As identified in the previous sections, the "bottom-up" approach is based on price signals or other incentives that are used to influence the customer. In this market led scenario, the customer responds directly to market pricing signals, causing behavioral or systematic consumption change based on market mechanisms (International Energy Agency, 2003). However, in order to realize this approach and facilitate a demand-response scenario of smart charging, new kinds of energy markets need to emerge. In the European conceptual model of Smart Grids, depicted in Figure 39, three markets are identified that are expected to emerge in the smart grid of the future: the energy market, the grid capacity market and the flexibility market (CEN, CENELEC & ETSI, 2012). These markets show an overlap with the traffic light concept as identified in the previous section.

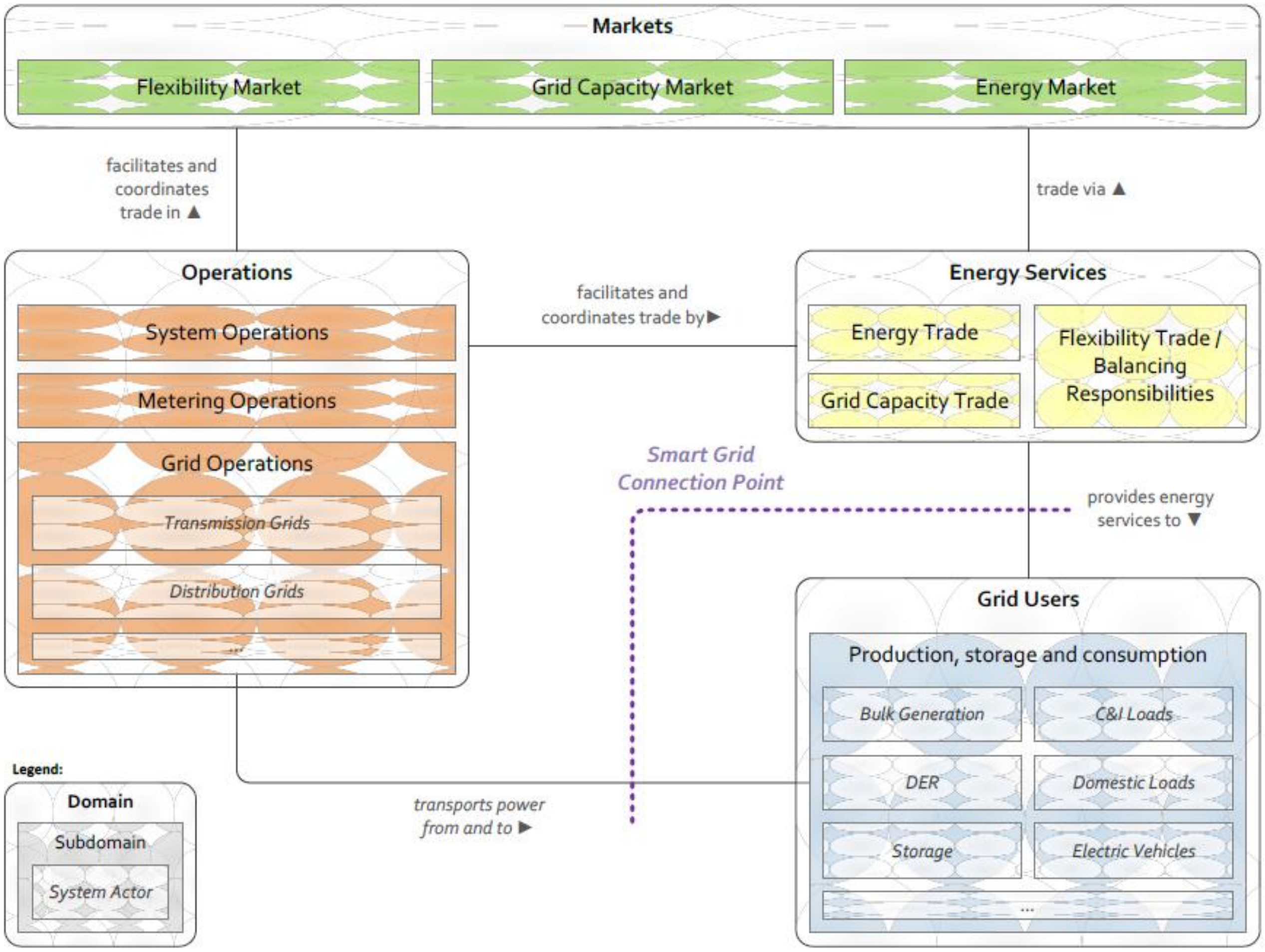


Figure 39: European conceptual model of Smart Grids (CEN, CENELEC & ETSI, 2012)

The energy market is concerned with the 'green' situation, which could either reflect a situation with fixed electricity prices, or variable prices based on a demand-response approach. This could for example consist of the day-ahead electricity prices, as we currently know, or more real-time based prices, such as the prices per 15 minutes as proposed by the Dutch government (Energeia, 2013). The grid capacity market gives distribution system operators the possibility to attach variable prices to grid capacity, in contrast to the fixed grip capacity prices as reflected in the current situation. In this way, the DSO can use a demand-response approach for congestion management, which reflects the yellow situation. The flexibility market can be compared to the imbalance market in the current electricity system. Currently, this market is controlled by the transmission system operator (TSO) and only includes large producers, large consumers and aggregated smaller units.

7.6.2 Consequences on location of control

Related to the discussion of smart charging is the decision of where to locate the control functionality that influences the charging process. The location of control is interrelated to the type of smart charging that is implemented. As mentioned in section 7.3.3, automated demand-response requires some kind of energy management system (EMS) that runs a software agent. A logical location for this EMS would be inside the electric vehicle. In the controlled charging scenario control is performed outside the charge point and/or electric vehicle. These options are reflected in ISO/IEC 15118, which mentions two options for scheduling: scheduling at the electric vehicle itself, and scheduling from a secondary actor (IEC, 2011).

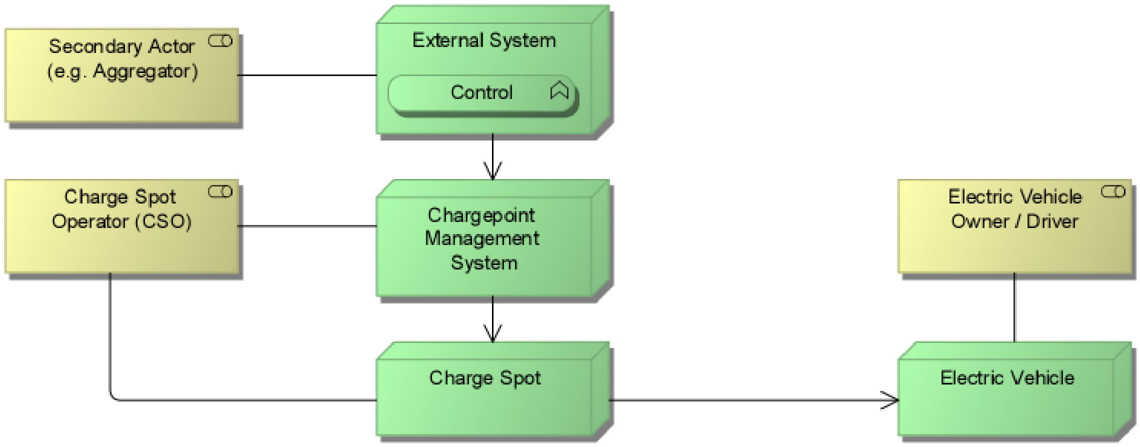


Figure 40: Control from a secondary actor

In the scenario with control from a secondary actor, the charge point receives control signals from a secondary actor and performs the charging process accordingly. In the current situation, where charge points are centrally managed by a charge point management system, this situation could be structured as depicted in Figure 40. In this situation, the secondary actor sends control signals to the charge point management system of the charge spot operator (CSO), which translates these control signals into commands towards the charge point. The charge point reacts to these control signals by adjusting its charging process.

Another possibility is to implement the control functionality within the electric vehicle. In this scenario, the charge point functions as a 'simple' electricity connection, and the electric vehicle contains an energy management system in order to control the charging process. To prevent overloading at the charge point, cable or electric vehicle, basic communication between electric vehicle and the charge point should be supported.

Roughly speaking, control can be executed at two locations: control from a secondary actor and control within the electric vehicle. In Table 9, the advantages and disadvantages for each of the two options are mentioned.

Scenario	Advantages	Disadvantages
Control from a secondary actor *(i.e., the 'Aggregator')*	1. Simple for the customer to understand 2. Feasible to realize in a relatively short period of time	1. Requires CSOs or OEM to provide ability to control to aggregator
Control within the electric vehicle	1. Distribution of control 2. Potential of lowering the costs of a charge point (no real-time communication needed)	1. Requires an internet connection within the electric vehicle 2. Implies a long transition period or the need for retrofitting

Table 9: Advantages and disadvantages concerning the location of control

As can be seen in the table, the option of control from a secondary actor is more feasible to realize in a short period of time and fits very well with the scenario of controlled charging. For demand-response charging, a local agent is eligible since this enables response at a low level, reflecting the bottom-up approach.

7.6.3 Consequences on metering

In the scenario where the energy contract is shifted towards the customer instead of the CSO, there is a need for another approach towards metering and financial settlement. In the current scenario, metering is done inside the charge point. Charge points contain a smart meter to meter the total usage per charge point, and two separate meters to meter the session usage for each of the charging outlets. This corresponds to the situation as described in chapter 2.3, and is drawn in Figure 41. In essence, metering is featured two times in the current situation.

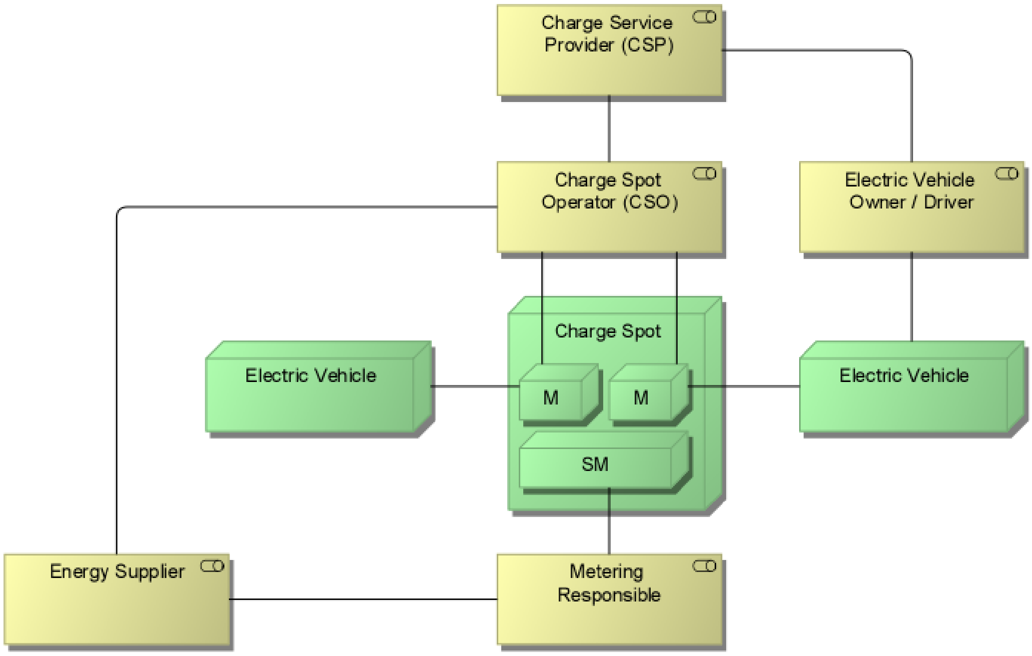


Figure 41: Metering at charge point (current scenario)

To distinguish between separate charging sessions, a single smart meter that aggregates the metering of charging sessions is not sufficient any longer as a basis for the financial settlement, and currently, the meter readings that are performed by the CSO are not trusted by energy suppliers.

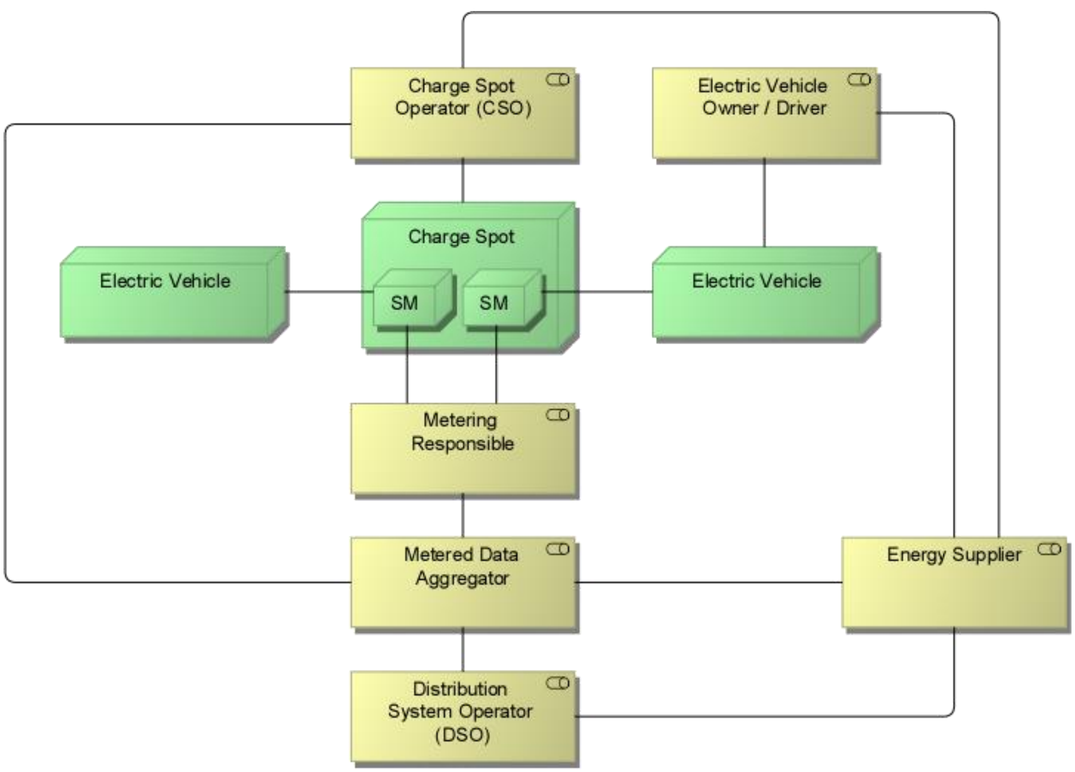


Figure 42: Scenario with a trusted party for sharing metering data.

One of the options to consider is to replace the separate meters that are installed and used by the CSO, with certified smart meters per outlet, managed and controlled by a trusted third party. These meters replace the current smart meter that provides aggregated meter readings. Based on a shared registry for the metering data of charge points, metering values can be exchanged between energy supplier, the DSO and CSO. This situation would be in line with the current "meter values registry" for regular connections, as mentioned in (EDSN, 2013). The option of a shared registry for metering data is depicted in Figure 42.

Another option to consider is to locate (part) of the metering functionality inside the electrical vehicle. In this scenario, the metering can be either split between charge point and electric vehicle, or could be fully located at the electric vehicle. In the last case, the electric vehicle contains a 'mobile' smart meter. Metering is executed in a similar way, as currently is the case for households. In the first case, both the electric vehicle and charge point contain separate meters; the electric vehicle contains a meter in order to settle for the consumed electricity, and the charge point contains a meter which is used by the CSO for the administration of the usage if its charge points, or for applying variable tariffs for the use of its charging infrastructure. In the second case, there is no metering (and communication) inside the charge point itself. This could significantly reduce the costs of the charging infrastructure. However, a business model needs to be thought of in which the CSO can still get compensated for the use of its charge points.

Roughly speaking, metering can be located at two locations: in the charge point with a shared meter or in the electric vehicle (which is usually referred to as a 'mobile' meter). In Table 10, the advantages and disadvantages for each of the two options are mentioned.

Scenario	Advantages	Disadvantages
Metering at charge point *(shared meter)*	1. Complies to the current situation 2. Ability to support 'switching' between energy providers and the use of your 'own' supplier 3. Ability to provide 'prepaid' cards for rental cars or travelers 4. Relatively easy capacity planning of local grid usage for a DSO	1. Need of a certified and trusted meter that can separate meter readings
Metering at electric vehicle *('mobile' meter)*	1. Alignment with the metering situation in households 2. Ability to support inductive charging	1. Requires certified metering architecture 2. Sensitive to security threats 3. Requires paradigm shift, radical change from current situation 4. How to handle 'guest' usage and/or rental cars?

Table 10: Advantages and disadvantages concerning metering location

7.7 Design choices

So far, the current chapter has described the main design alternatives and its consequences. Based on this analysis, we will now motivate the design choices that are made for the reference architecture. The main choice that needs to be made concerns the type of smart charging. As mentioned in section 7.3.4, the demand-response approach using two-way communication is the most favorable scenario for the implementation of smart charging. As identified in Table 8, this scenario involves radical changes when compared to the current situation. Flexible energy and grid prices are needed and energy management systems need to be implemented within electric vehicles. Because of this radical change, a migration architecture will be established, providing an interim solution as a first step towards the reference architecture. This migration architecture focuses on the realization of the objectives as identified for the current research that are feasible on a shorter timescale, and implements the scenario of controlled charging.

For both the reference and migration architectures, a new 'type' connection needs to be introduced for charging stations, on which various energy suppliers are allowed to deliver energy. This introduces the ability to ‘switch’ between energy suppliers, and allows the customer to have a direct contract for the provision of energy with its energy supplier, as described in 7.5.

In Table 11 the main choices that motivate the reference and migration architecture are listed. The motivation for the choice concerning location of control and metering location follow on the type of smart charging and the analysis as performed in the current chapter.

	Reference architecture	**Migration architecture**
Type of smart charging	Demand-response charging - price signals - energy contract	Controlled charging - control signals - flexibility contract
Location of control	Control from electric vehicle	External control of charge point
Metering location	Shared metering at charge point	Shared metering at charge point

Table 11: Main choices that motivate the reference and migration architecture

7.8 Conclusions

In the current chapter, the main choices that motivate the design of the reference architecture have been worked out. Based on a literature study, the main design alternatives have been described and its consequences have been analyzed. One of the relevant choices that are made is that the roles of energy supplier and charge service provider (CSP) have been merged into a single role. For both types of smart charging separate architectures will be worked out, based on the difference in short-term feasibility.

8 Reference architecture

The main objective of the current research involves the definition of a reference architecture for electric mobility with the purpose of facilitating interoperability between involved parties from the markets of electric mobility and the electricity system, and to realize a smart integration of electric vehicles within the electricity system. In the current chapter, we will define this reference architecture.

8.1 Introduction

As identified in chapter 5.1, a reference architecture captures the essence of existing architectures, and the vision of future needs and evolution to provide guidance to assist in developing new system architectures (Cloutier, Muller, Verma, Nilchiani, Hole, & Bone, 2010). The motivation for the creation and utilization of reference architectures can be to have a blueprint for the development of future systems and components, providing the possibility to identify gaps between the current and future situation. It can also be used to structure a certain domain and provide a foundation for communication about it to other domains that need to interoperate. Furthermore, it can be used to document decisions that have been taken during the development process of an infrastructure (CEN, CENELEC & ETSI, 2012). In the current chapter, a reference architecture will be defined for electric mobility.

8.2 Business layer

Based on the design choices made in the previous chapter, the business layer has been defined. The business layer includes all relevant market roles, relationships and processes. The business layer is depicted in Figure 43.

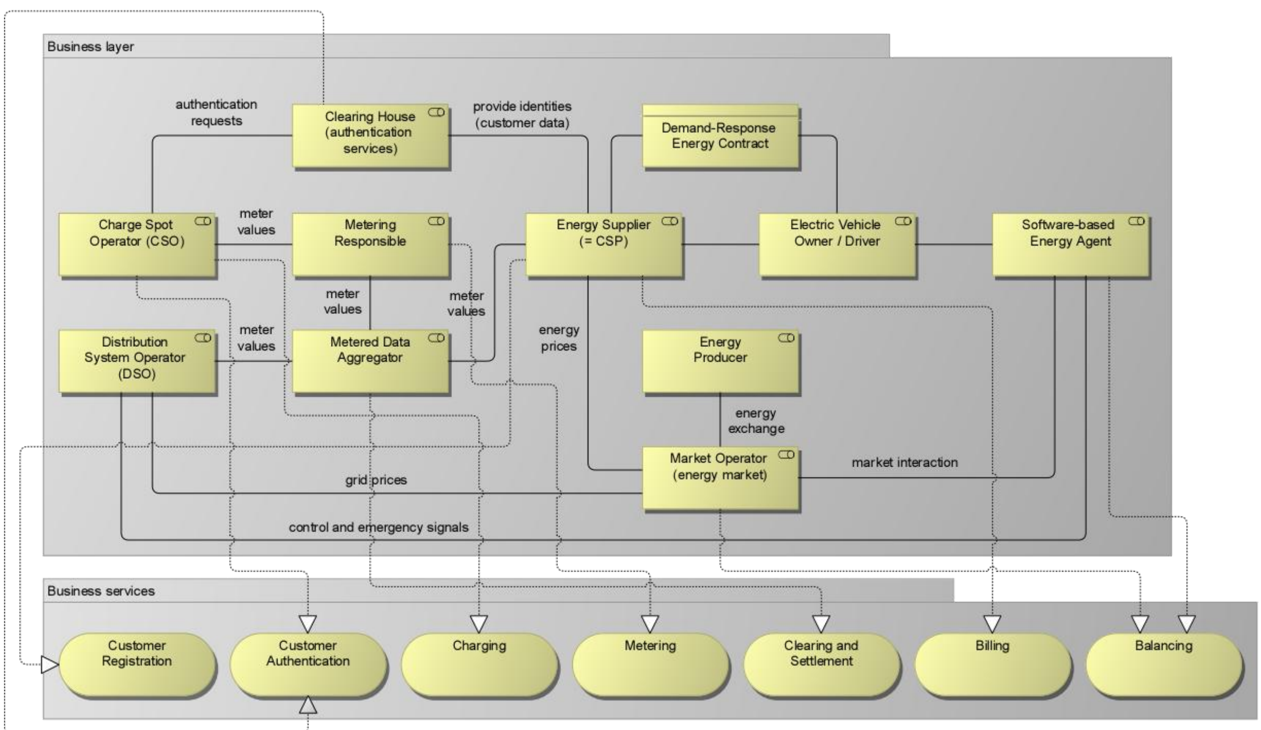


Figure 43: Business layer of the reference architecture

The business layer represents the to-be scenario, where smart charging is implemented in a demand-response manner, using the 'market integration' approach as defined by Kok (2013). In this approach, charge control is located inside the electric vehicle. A software-based energy agent is responsible for energy management and charge control, using a mechanism such as PowerMatcher (2013) or OpenADR (2013). System balance is realized by the organization of energy markets, as described in the European conceptual model of Smart Grids (please refer to Figure 39). The energy market reflects (near) real-time prices, reflecting grid capacity and energy supply. The distribution system operator (DSO) applies the traffic light concept (please refer to chapter 7.4), providing flexible grid prices in order to keep the system from becoming unstable. In case of 'emergency', the DSO will execute dedicated emergency actions by executing direct control over generation or demand in order to re-stabilize the system as far as a contract or regulation and legislation allows doing so. The roles of energy supplier and charge service provider (CSP) are merged into a single role, to reflect a situation where the customer has an energy contract for the provision of (mobile) electricity directly with the energy supplier itself. Metering occurs at the charge points itself; using separate smart meters for each of the power outlets. In order to bill the customer according to the prices, the smart meter has to measure with the same resolution as used for the price signals. If for example the price signal has a resolution of 15 minutes, metering data has to be collected in slots of 15 minutes as well (Kok, 2013). In order to support the financial settlement between CSO, DSO and energy suppliers, the role of 'metered data aggregator' is introduced as a trusted intermediary party. Based on a shared registry for the metering data of charge points, metering values are exchanged between energy supplier, the DSO and CSO (Figure 44).

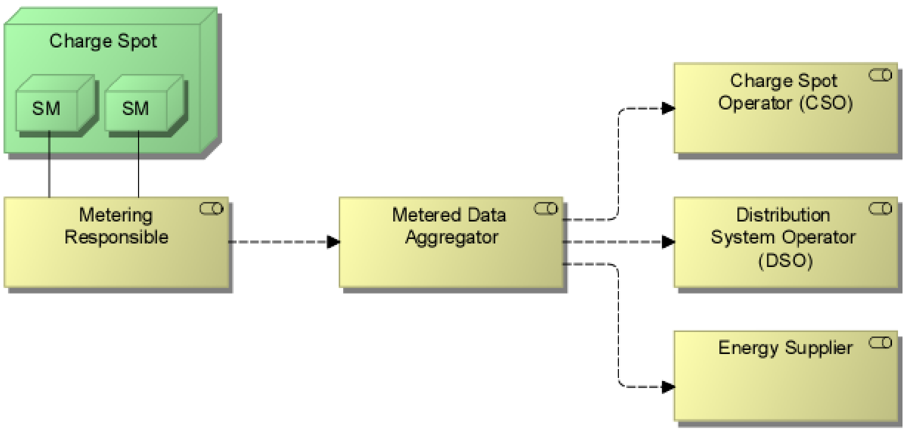


Figure 44: Data flows for metering data in reference architecture

8.3 Application layer

Based on business layer, the application layer has been designed in order to support each the business processes. The application layer is depicted in Figure 45. In the application layer, some systems that already exist in the current architecture are depicted (the charge point management systems, customer management systems, and clearing house application). In addition, a metering registry, market platform and on-board energy management system are introduced.

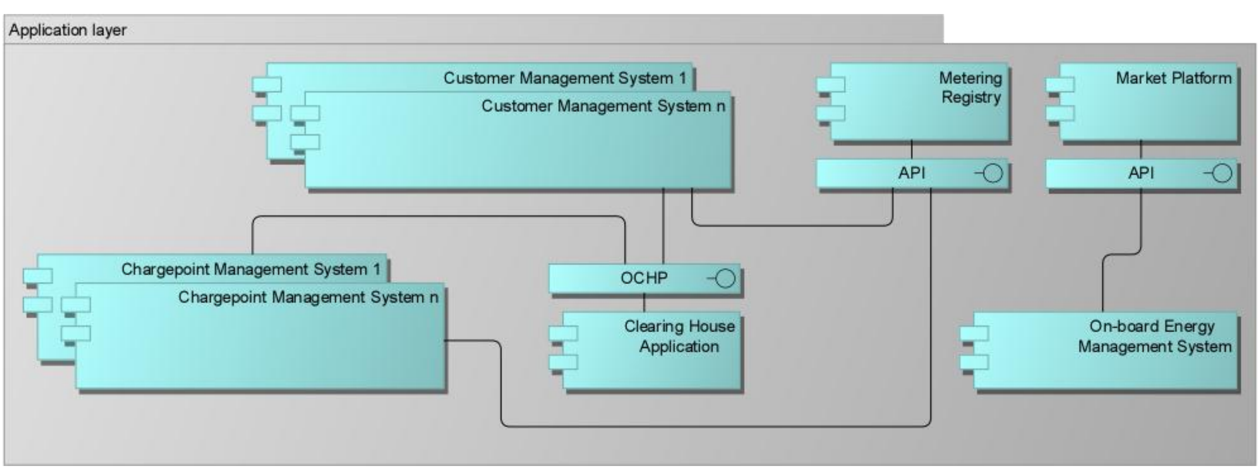


Figure 45: Application layer of the reference architecture

8.4 Infrastructure layer

The infrastructure layer is relatively simple, and consists of the charge point, the electric vehicle and several servers running each of the applications identified in the previous section. A local energy management server (EMS) is implemented within the electric vehicle, on which the on-board energy management system is implemented. The infrastructure layer is depicted in Figure 46.

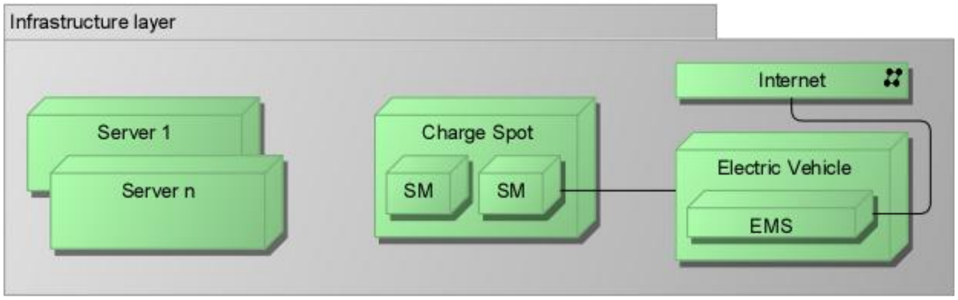


Figure 46: Infrastructure layer of the reference architecture

8.5 Overview

In order to draw a comprehensive overview of the reference architecture, the three layers (business, application and infrastructure) are synthesized in a single architectural overview. The reference architecture is shown in Figure 47, Please note that for comprehensibility, some relationships have not been drawn. The servers in the infrastructure layer realize the applications in the application layer, except for the on-board management system which runs on a local server inside the electric vehicle. These realization-relationships have however not been drawn. Also, both smart meters are related to the metering database; for simplicity, only one of the relationships has been drawn.

(the reference architecture is depicted on the next page)

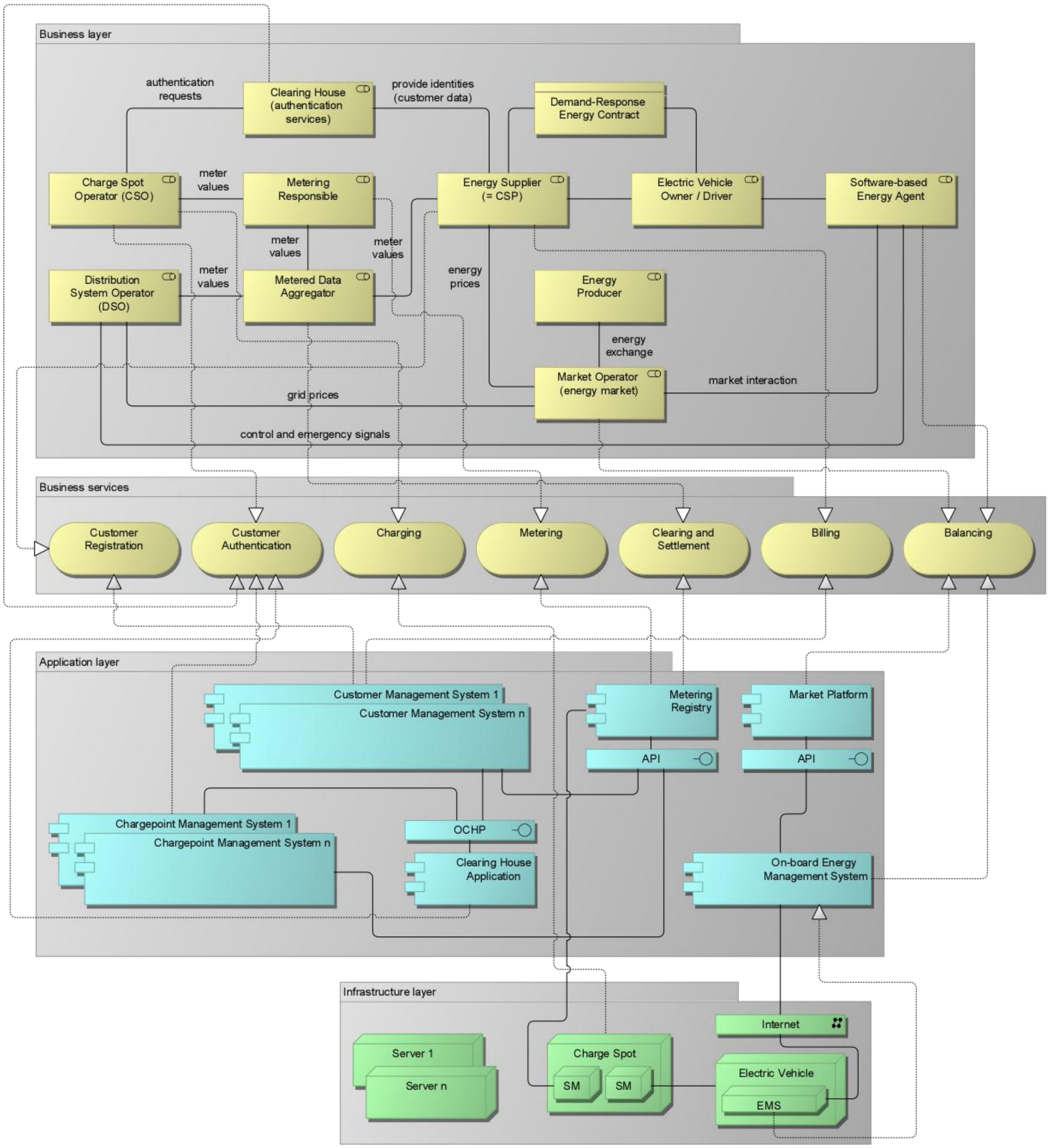


Figure 47: Overview of the reference architecture

9 Migration architecture

In order to provide a path for implementation and migration, a migration architecture is established, providing an interim solution as an intermediary step towards the reference architecture. In the current chapter, the migration architecture is described.

9.1 Introduction

In the reference architecture, smart charging is implemented in a demand-response manner, using the 'market integration' approach as defined by Kok (2013). However, as identified in one of the reports on the European mandate M/490, the barriers for participating in existing energy markets are high (CEN, CENELEC & ETSI, 2012). In the current situation and energy markets, small-scale flexibilities cannot be integrated easily. An intermediary solution where small-scale are aggregated into substantial flexibility offerings could be desirable. According to the report on M/490, this situation can be provided by additional concepts that close the gap between the small ratings of the individual flexibilities and the market places. As described in chapter seven, a widely discussed idea concerns the introduction of a new market role; the role of 'aggregator'. The aggregator is responsible for summing up flexibilities from several customers, and actively participates in energy markets or other commercial transactions to market these flexibilities. In the situation of an aggregator, the customer itself does not directly participate in flexibility markets, but provides the aggregator access to control its flexible resources (CEN, CENELEC & ETSI, 2012). The migration architecture is based on this situation, and implements smart charging in a controlled manner, using the 'centralized optimization' approach as defined by Kok (2013).

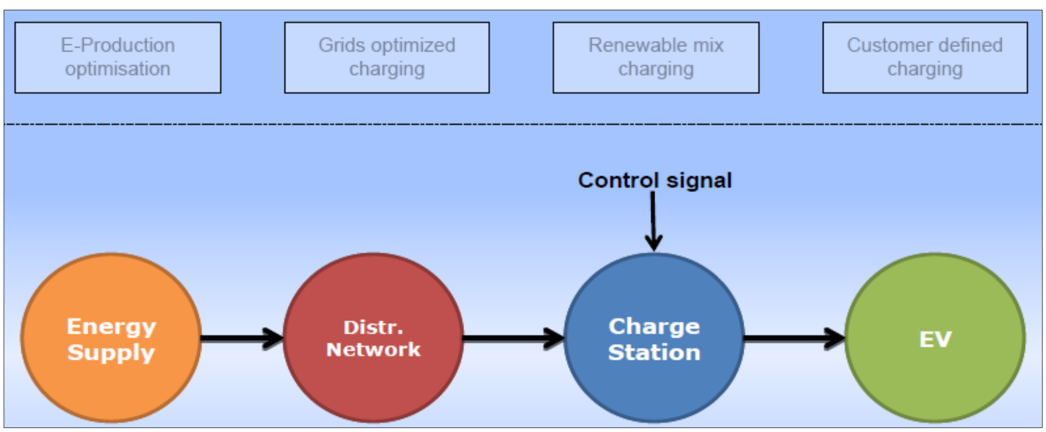


Figure 48: Supply chain for charging electric vehicles (CEN, CENELEC & ETSI, 2012)

For the migration architecture, the main design choice is that scheduling and control occurs from a secondary actor, described in ISO/IEC 15118 (IEC, 2011). A similar idea can be found in one of the reports based on the European mandate M/490, which identifies the supply chain for charging electric vehicles, depicting a control signal which is sent to the charging station (CEN, CENELEC & ETSI, 2012). In the migration architecture, the aggregator performs this central role of control. This idea is also reflected in the ADDRESS project, where the aggregator is the key mediator between the consumers on one side and the markets and the other power system participants on the other side (ADDRESS, 2009).

9.2 Business layer

The business layer of the migration architecture is depicted in Figure 49. As described in the previous section, the aggregator fulfills an important role in this architecture. It should be emphasized that the role of aggregator is about marketing modifications in demand, rather than energy profiles itself. In other words, aggregators sell a deviation from the forecasted level of demand, not a specific level of demand (ADDRESS, 2009) (Eurelectric, 2011). Just as for the reference architecture, the roles of energy supplier and charge service provider (CSP) are merged into a single role, reflecting a situation where the customer has an energy contract for the provision of (mobile) electricity, directly with the energy supplier itself. Also, metering occurs at the charge points itself; using separate smart meters for each of the power outlets. In order to support the financial settlement between CSO, DSO and energy suppliers, the role of 'metered data aggregator' is introduced as a trusted intermediary party. Based on a shared registry for the metering data of charge points, metering values are exchanged between energy supplier, the DSO and CSO.

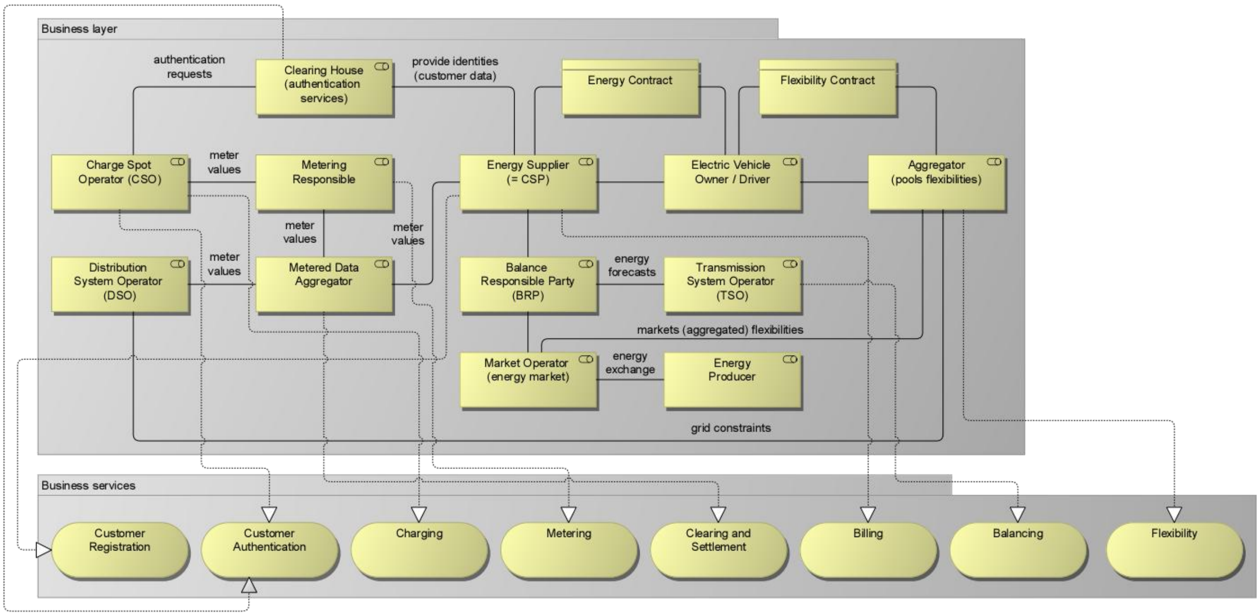


Figure 49: Business layer of the migration architecture

9.3 Application layer

In Figure 50 the application layer of the migration architecture is depicted. The main concept in this layer is the API on top of the charge point management systems, to reflect the ability for control from a secondary actor (please refer to Figure 40). The control signals are sent from a flexibility management system, that communicates with the systems of the distribution system operator (DSO), the energy market, and a mobile customer application through which the customers preferences can be given (such as time of departure).

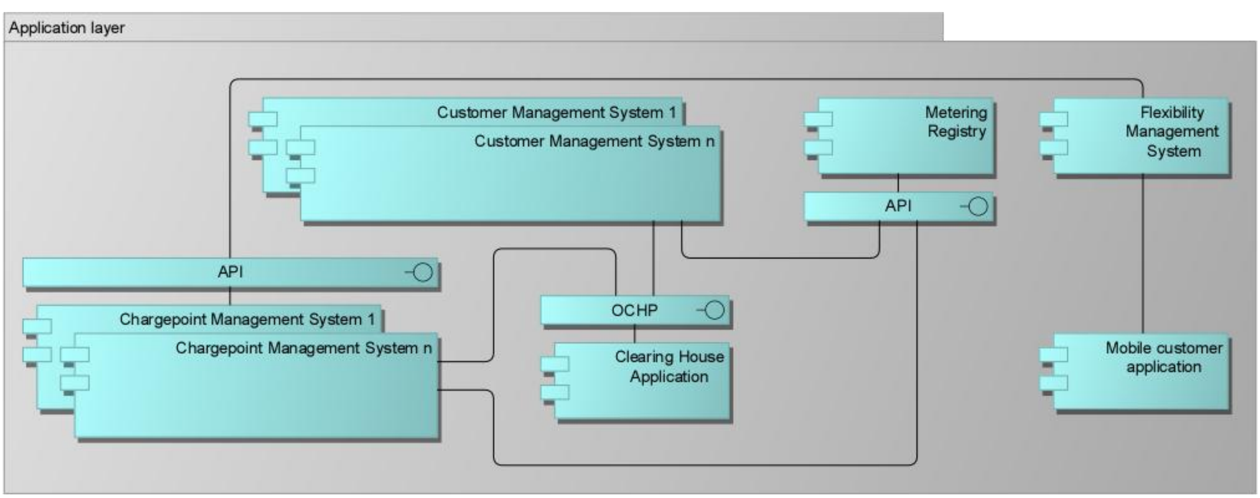


Figure 50: Application layer of the migration architecture

9.4 Infrastructure layer

In Figure 51, the infrastructure layer is depicted. This layer is relatively simple, and consists of the charge point, the electric vehicle and several servers running each of the applications as identified in the previous section.

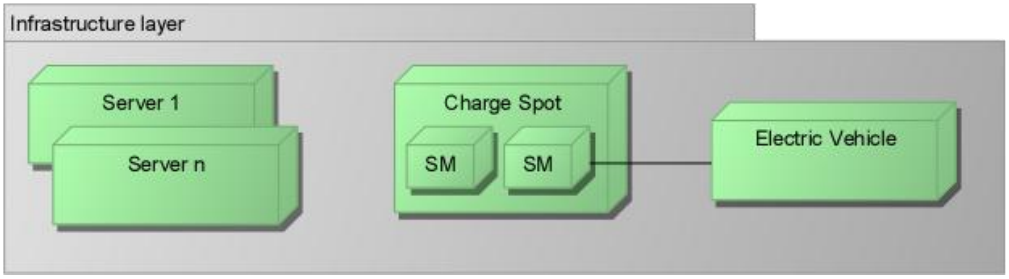


Figure 51: Infrastructure layer for the migration architecture

9.5 Overview

In order to draw a comprehensive overview of the migration architecture, the three layers (business, application and infrastructure) are synthesized in a single architectural overview. The migration architecture is shown in Figure 52Figure 47. Please note that for comprehensibility, some relationships have not been drawn. The servers in the infrastructure layer realize the applications in the application layer, these realization-relationships have however not been drawn. Also, both smart meters are related to the metering database; for simplicity, only one of the relationships has been drawn.

(the migration architecture is depicted on the next page)

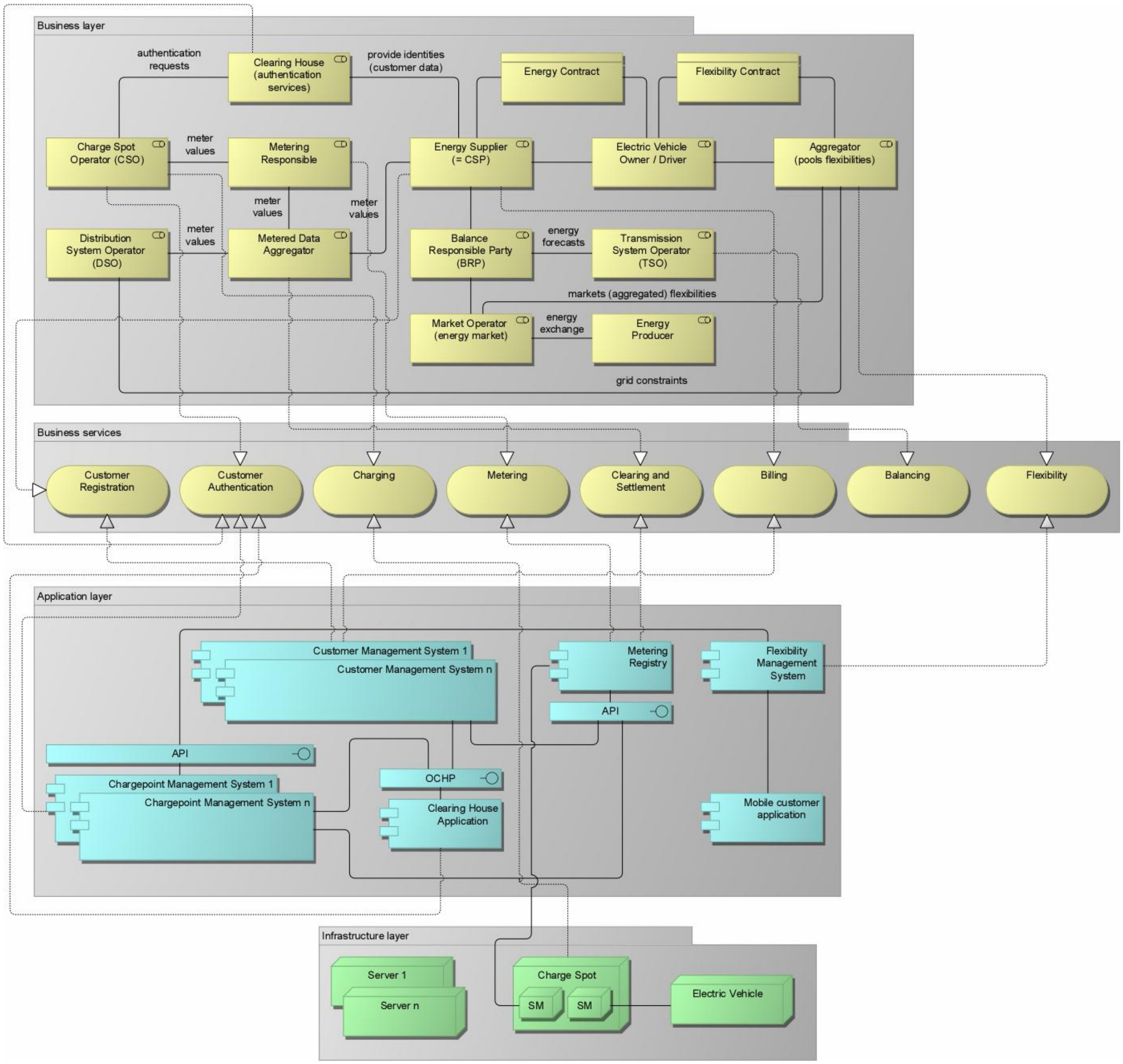


Figure 52: Overview of the migration architecture

10 Validation

In order to validate the reference architecture, expert interviews have been conducted. In the current chapter, the validation approach and results are presented. In addition, a rough estimation is made of the economic impact that can be realized when implementing the reference architecture.

10.1 Validation approach

For the validation of the reference architecture, we applied a qualitative approach. A series of structured interviews have been carried out with six experts in the field of three relevant sectors and/or disciplines involved in the current research: the energy sector, the sector of electric mobility, and the discipline of (enterprise) architecture. Each of the interviews has been performed as a structured face-to-face interview of about 1,5 hour. The interview consisted of an initial presentation on the background, motivation and design choices as made for the reference architecture. Following on this presentation, the reference architecture has been presented to each of the interviewees. These first two steps were carried out in about 15 minutes.

Interviewee	Company	Profession	Energy sector	Electric mobility	Architecture
Arjan Wargers	E-laad	Manager R&D and innovation	12	3	n/a
Andre Postma	Enexis	Manager smart grids	28	6-7	n/a
Gerrit Fokkema	EDSN	Manager architecture and products & services	25	n/a	15
Paul Broos	Eneco	Senior project manager 'elektrisch laden'	12,5	4	n/a
Pascal van Eck	University of Twente	Assistant professor in Information Systems	n/a	n/a	10
Theo Fens	Delft University, UCPartners	Senior researcher, CTO (partner)	15	1	15-20

Table 12: List of experts and their experience (in years)

The response rate for the external validations was 75% (6 out of 8). Two of the interviews could not be carried out due to scheduling problems with the interviewees.

10.2 Results

Overall, the interviewees showed confidence in the model and outlined that in principle, it can greatly improve the problems as identified in the current research. At the same time, several comments were mentioned that are covered in the current section. All interviewees agree that the current architecture is insufficient, since it does not support flexibility, and needs to be improved. The results are categorized into four sections, concerning respectively the current architecture, the role- and business model, the method for implementing smart charging, and the alignment with the objectives of the current research. Each of them is covered in a separate section.

One point of critique that came back in most of the interviews was the naming of 'Charge Service Provider' (CSP). According to the interviewees this name introduces confusion; people often entangle this name with the 'Charge Spot Operator' (CSO) and it is not clear which role is intended. Within several of the standardization committees, new naming conventions have been introduced. The relevant naming conventions are 'Infrastructure Service Provider' (ISP) for the realization of the charging infrastructure and 'e-Mobility Service Provider' (ESP) for the role of CSP as described in the current research.

10.2.1 Current architecture

Overall, the interviewees indicate that the current situation as modeled in the current research has been modeled correctly. In total, three remarks were made. The first remark concerns the naming decision as described above. The second remark is that the BRP purchases energy, not the energy supplier. This has to be adjusted in the current architecture. The last remark is that in the current situation, the clearing house is not a real role but just a system that is used for the bilateral settlement between ISP and CSP.

10.2.2 Shift of the energy contract

Overall, the interviewees agreed that the current business model is inadequate. Some of the descriptions for the current business model include 'complex', 'strange' and 'overdone'. The current model has been described as an 'add-on' for the electricity system, instead of being an integral part of it. Also, the current model is complex to combine with the idea of smart charging.

Even though the interviewees agreed upon the reasoning behind the improved business model, several interviewees mentioned a different approach towards improving the business model. Instead of a model where the electricity supplier acts as a service provider towards the customer, the e-mobility service provider (ESP) acts as an electricity provider towards it customers. In essence, this idea is the same, however, offers more flexibility and leaves the market open. The ESP is responsible to purchase electricity, and offers this as part of a service contract to the customer. In this scenario, energy is no longer a dedicated commodity, but part of a service offer.

Another interesting remark that has been mentioned by some of the interviewees is that in all cases where there is no dedicated energy supplier at a charge point, a 'residual' energy supplier is still needed for the situation where there is no EV connected to a charge point. A charge point still uses energy in this case and therefore needs a separate energy contract for residual energy. Most of the interviewees propose a model where the ISP still has an energy contract for residual energy, but whenever an EV is connected, the associated energy supplier is allocated.

10.2.3 Demand-response vs. controlled charging

In the discussion about the implementation of smart charging, various viewpoints have been mentioned. Overall, the interviewees agree that smart charging has to be based on incentives. However, the opinions concerning the implementation of these incentives vary. Real-time price signals are desirable for the future, but are not feasible in a short timescale since it is radical different from the current organization of the energy market. The current energy market is based on forecasts and reconciliation, and involves financial risks. One of the interviewees mentions that for the distribution system operator (DSO), price signals are not an adequate instrument at all; he mentions that the component of the energy prices that a DSO can influence is insignificant (since it concerns only a few cents); prices need to be increased at least a tenfold before having a little effect.

Even though most interviewees agreed that price signals offer the simplest mechanism and have their preference in long term, most of them mentioned that controlled charging is more feasible on a short term. This confirms the migration path as proposed in the current research. In the light of controlled charging, almost all of the interviewees mention the approach of using 'charging plans', just like having 'call plans' in the telecommunication industry.

One conclusion that can be made and that is acknowledged by most of the interviewees, is that it is important to implement both control and price signals in the communication between service provider (ESP) and the customer. Based on this notion, the traffic light concept has been mentioned in several of the interviews as well. Another conclusion that can be made on basis of the interviews is that the role of 'flexibility operator' (i.e. aggregator) is needed, translating the incentives from the DSO and energy market towards its customers. Most of the interviewees agree that for the case of EV, the ESP should be considered as the flexibility operator. Since the ESP is the final end-user of electricity, it can offer contractual agreements for flexibility and market this flexibility to the market.

10.2.4 Alignment with objectives

All of the interviewees with experience in the energy sector agreed that the situation as modeled in the reference architecture would enhance the integration between electric mobility and the electricity system, and reduce the potential impact of electric mobility. One of the main reasons given was that smart charging results in a better utilization of the electricity net. By applying control and scheduling in charging, less of the electricity cables need to be replaced. Price-based incentives are considered as an effective instrument for smart charging. One of the interviewees mentioned the importance of being able to react quickly enough as a boundary condition.

Overall, the interviewees agreed that the reference architecture depicts a situation that drives the adoption of renewable energy sources (RES) in the electricity system. One of the interviewees mentioned that the main problem with wind energy is overcapacity in moments of low demand. In the current situation, the ability to create demand is worth a lot of money. The main boundary condition is that enough electric vehicles are needed in order to offer the flexibility. However, when compared to household devices such as washing machines, electric vehicles have an enormous potential capacity. The idea of dynamic demand and supply can help significantly in solving the intermittency problem of renewable energy, which concerns its stochastic behavior. Being able to 'follow' the availability of supply offers a more effective solution than the globally examined opportunity of storage, since the latter involves a loss of energy. Some interviewees mentioned the importance of regulation for the success of RES integration.

Overall, the interviewees agreed that the current business model does not yield a profitable situation. Several of the interviewees pointed out that this is only the case for the realization of public charging infrastructure (the focus of the current research); for private and semi-public charging infrastructure positive business cases can be made. Several of the interviewees pointed out that the main reason for the negative business case of the current business model is its narrow scope. The realization and commercialization of public charging infrastructure is not profitable when regarding just the provisioning of uncontrolled charging. However, there is an enormous financial potential in the reduction of grid investments, the balancing of the electricity system and the storage of energy. Overall, the interviewees confirmed this potential. In order to do so, some boundary conditions have been mentioned, which include the importance of managing the various stakes, the importance of regulation and the required amount of electric vehicles.

None of the interviewees has been specifically asked about its judgment concerning the alignment of the reference architecture and the European standardization developments. The alignment with European standardization developments has therefore not been validated formally. However, in several of the interviews references were made to European standardization developments, and since at least two of the interviewees contribute to the standardization developments on a European level, we valued their opinion of great importance when analyzing the interviews.

10.2.5 Quality attributes

Because of time constraints during the interviews, we had only one opportunity to have an in-depth analysis about the quality attributes of the reference architecture. For the quality attributes, Pascal van Eck, assistant professor at the University of Twente has been interviewed. In this interview, the main remarks concerned the amount of arrows in the reference architecture, which has a negative effect on the clarity. The level of detail was judged as correct; it properly fits the intended purpose of the reference architecture. Pascal considered the reference architecture useful; it helps to create a common vocabulary that is needed in this situation where multiple organizations need to collaborate. The question whether the reference architecture is feasible was answered by the remark that this depends completely on the willingness of the involved stakeholders.

10.3 Interview reports

Each of the interviews has been recorded and analyzed afterwards. The relevant statements from each of the interviewees are worked out into short reports. The reports are included in appendix G.

10.4 Economic impact

In order to give a rough estimation of the economic impact of realizing the reference architecture, a simple calculation is performed in the current section. The reference architecture offers various potential financial opportunities for revenues that cannot be utilized in the current architecture. The main sources include revenues based on system balance, savings on grid investments and revenues based on energy storage.

10.4.1 Estimation of capacity

As can be seen in Table 5, one of the objectives of the Dutch government is to have one million electric cars in the Netherlands in 2025 (Rijksoverheid, Elektrisch rijden, 2012). The following table shows an overview of the charging characteristics as currently existing:

Charging time	Power supply	Voltage	Max current
6-8 hours	Single phase – 3,3 kW	230 V (AC)	16 A
2-3 hours	Three phase – 10 kW	400 V (AC)	16 A
3-4 hours	Single phase – 7 kW	230 V (AC)	32 A
1-2 hours	Three phase – 24 kW	400 V (AC)	32 A

Table 13: Charging characteristics (obtained from Wikipedia)

In the 'worst case' scenario, where every vehicle would charge at a rate of 3,3 kW, these million cars would have a total power capacity of 3,3 GW. When applying smart charging as defined in the report on M/490, the power demand can be adjusted between 0 and 3,3 GW in an ideal scenario (where all electric vehicles are connected to a charging station and are not yet fully charged).

10.4.2 Estimation of the imbalance market

In one of the statements of direction, the authors estimate the market size of the imbalance market (Hagemans, Fens, Bollen, Schoot Uiterkamp, & Venekamp, 2013). In order to do so, data concerning the imbalance has been downloaded from TenneT (fulfills the role of TSO in the Netherlands). According to their analysis, the electricity system has been adjusted downwards for a total of 423 GWh over 2011, and adjusted upwards for a total of 358 GWh. In the following table, these values are mentioned, including the average power that is involved in the adjustments.

Adjustment	Total adjustment	Average of involved power
Downwards	423 GWh	94 MW
Upwards	358 GWh	63 MW

Table 14: Imbalance adjustments over 2011 (Hagemans, Fens, Bollen, Schoot Uiterkamp, & Venekamp, 2013)

In the energy sector, PTEs (Dutch abbreviation for 'Programma Tijd Eenheden') are used to model timeslots of 15 minutes. A single day consists of 96 PTEs; a year has 35040 PTEs. According to their study, in 2011, adjustments were needed in 52% of all PTEs for downward adjustments, and in 48% of PTEs for upward adjustments.

10.4.3 Imbalance costs

In the interview with Andre Postma, Andre mentioned that the imbalance costs involve hundreds of millions every year. According to an internal study at Alliander, the imbalance costs over 2011 are estimated at a value of 171 million in 2011. Another illustration of the high costs involved with imbalance can be seen in the wind energy sector. According to the Telegraph, over £1 million was handed out to the operators of thirteen Scottish wind farms to shut down their wind farms a single day. In total about £3.6 million of constraint payments were made to wind farm companies in April, the highest monthly total since September 2011 (The Telegraph, 2013).

The article about the constraint payments in Scotland mentions that £348,349 was paid to shut off the Crystal Rig II wind farm (The Telegraph, 2013). This wind farm contains 60 wind turbines of 2,3 MW each; resulting in a total capacity of 138 MW (Fred.Olsen Renewables, 2013). When charging at a rate of 3,3 kW, about 42.000 EVs are needed to absorb this capacity.

10.4.4 Estimated impact

The figures as identified in the previous sections give an indication of the costs involved with imbalance. Even though a detailed calculation of the estimated economic impact goes far beyond what is possible in the current master project, we argue that several millions of savings on an annual basis is a realistic estimation. In addition, the costs that distribution system operators can save on grid investments and the potential revenues that can be gained when applying vehicle-to-grid concepts could add up and increase the economic impact even further.

10.5 Conclusions

In the current chapter, the reference architecture has been validated by the conduction of expert interviews. Overall, the interviewees acknowledged that the reference architecture would result in the objectives as stated in the current research. At the same time, some critical notes and improvements have been proposed. In the next chapter we will therefore propose improved versions of the reference and migration architectures.

11 Improved architectures

Based on the feedback from the validation research, improved versions of the reference and migration architectures are modeled in the current chapter. These architectures encompass the final artifacts of the current research.

11.1 Introduction

The main conclusion that can be made on basis of the validation research is that instead of a situation in which the role of charge service provider (CSP) is merged with the role of energy supplier, the role of e-mobility service provider (ESP) will emerge. This role replaces the 'old' role of charge service provider (CSP). The ESP acts as the final end-user of electricity, and either buys electricity through the energy supplier, or acts directly on the energy market itself. Most of the interviewees agree that in the scenario of controlled charging, the e-mobility service provider (ESP) can adopt the role of 'aggregator', translating the incentives from DSO and the energy market towards its customers on basis of a flexibility contract. However, to increase understandability, we chose to keep their roles separated. The role of ESP is added to both the reference and migration architecture, and as a result, the similarity of the business layers from both architectures increases. The business layer of the reference architecture is depicted in Figure 53.

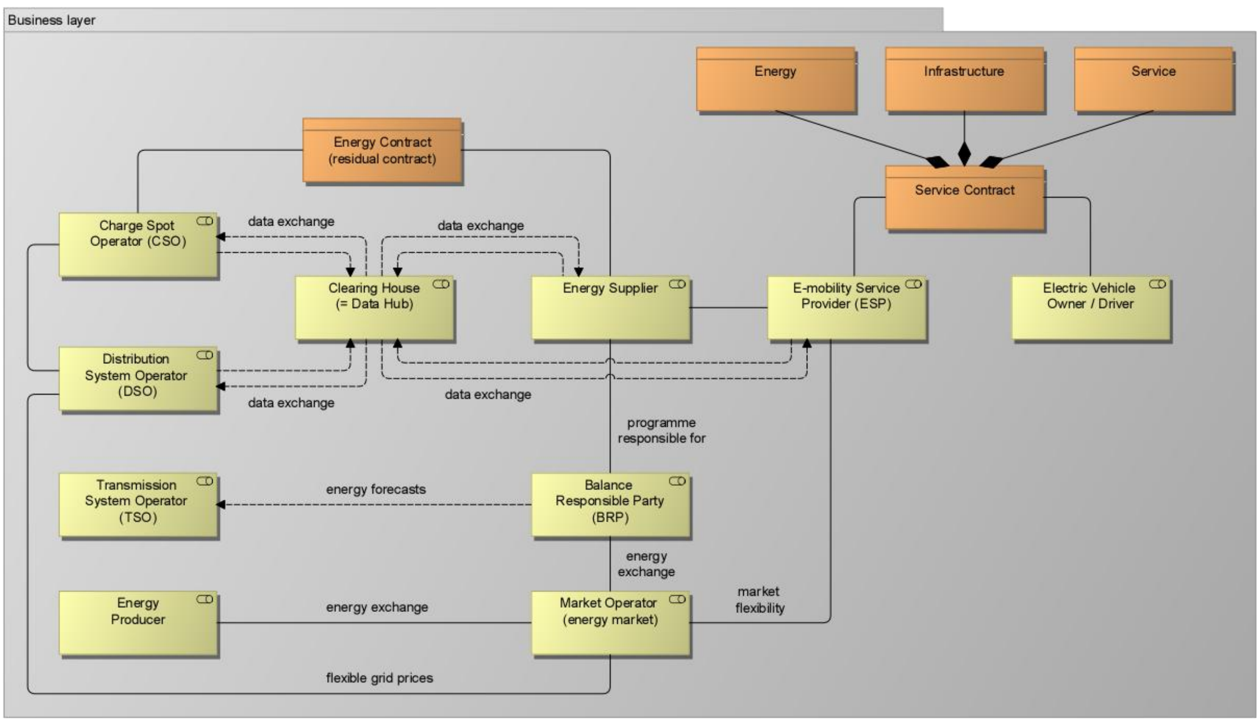


Figure 53: Business layer of the improved reference architecture

11.2 Overview

An improved version of the reference architecture is depicted in Figure 54. In addition, an improved version of the migration architecture is depicted in Figure 55.

11.2.1 Main changes

When compared to the previous version of the reference and migration architecture, the improved architectures have been adjusted in the following ways: both the architectures have separated roles for the e-mobility service provider (ESP) and energy supplier. In addition, two separate contracts for the provision of energy are included; one contract concerning 'residual' energy (the energy that is consumed by a charge point during the time that no electric vehicle is charging) and the 'energy contract' as part of the service contract towards the electric vehicle owner / driver. Also, in both architectures the role of clearing house has been adjusted into a data hub, reflecting the increased amount of data concerned with this role. In both architectures a mobile customer application has been added, to reflect the ability for the customer to influence the charging behavior from his/her mobile phone. Lastly, some minor adjustments have been made in the overall structure and design of both architectures.

11.2.2 Improved reference architecture

Figure 54 depicts an improved version of the reference architecture:

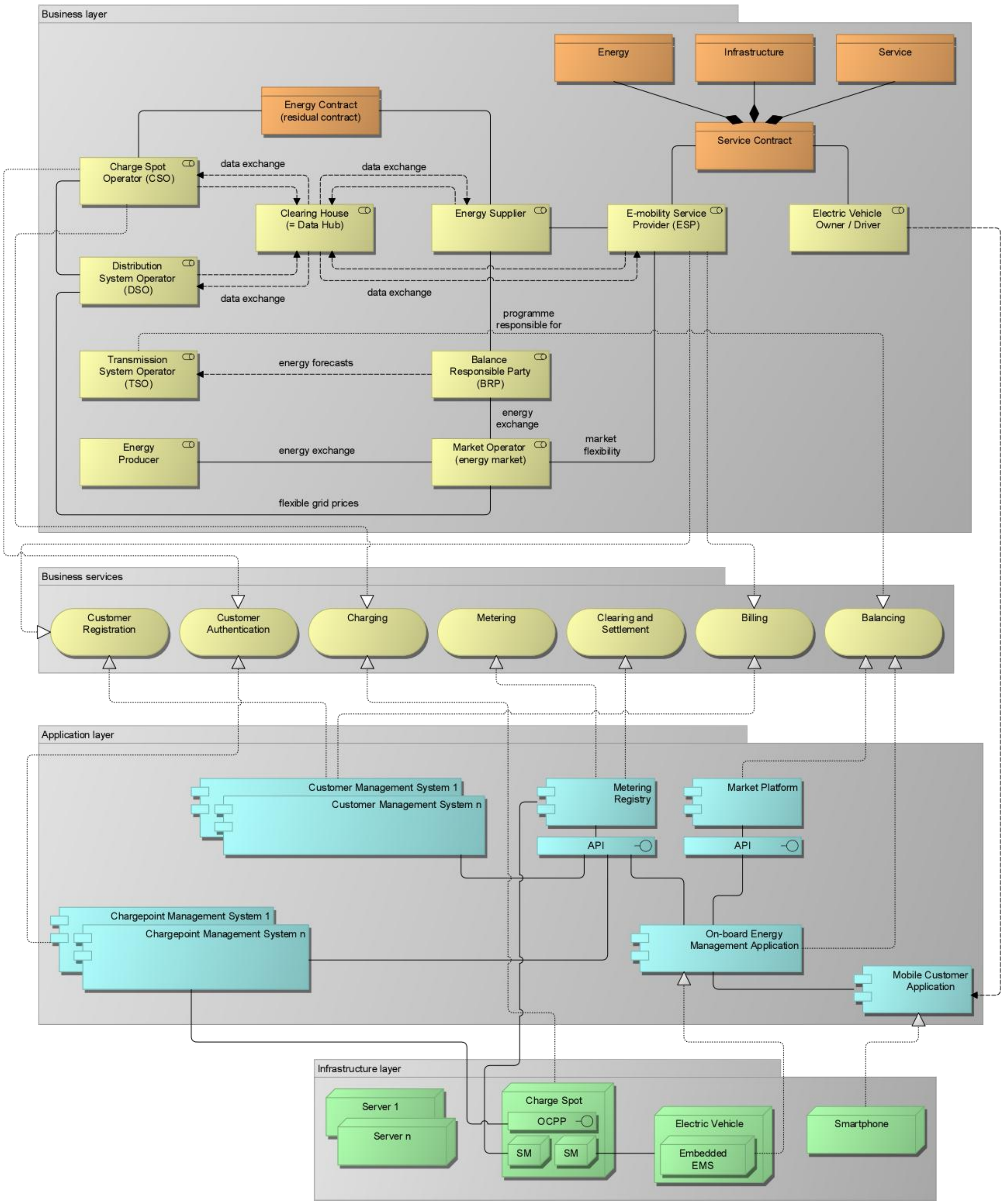


Figure 54: Improved reference architecture

11.2.3 Improved migration architecture

Figure 55 depicts an improved version of the migration architecture:

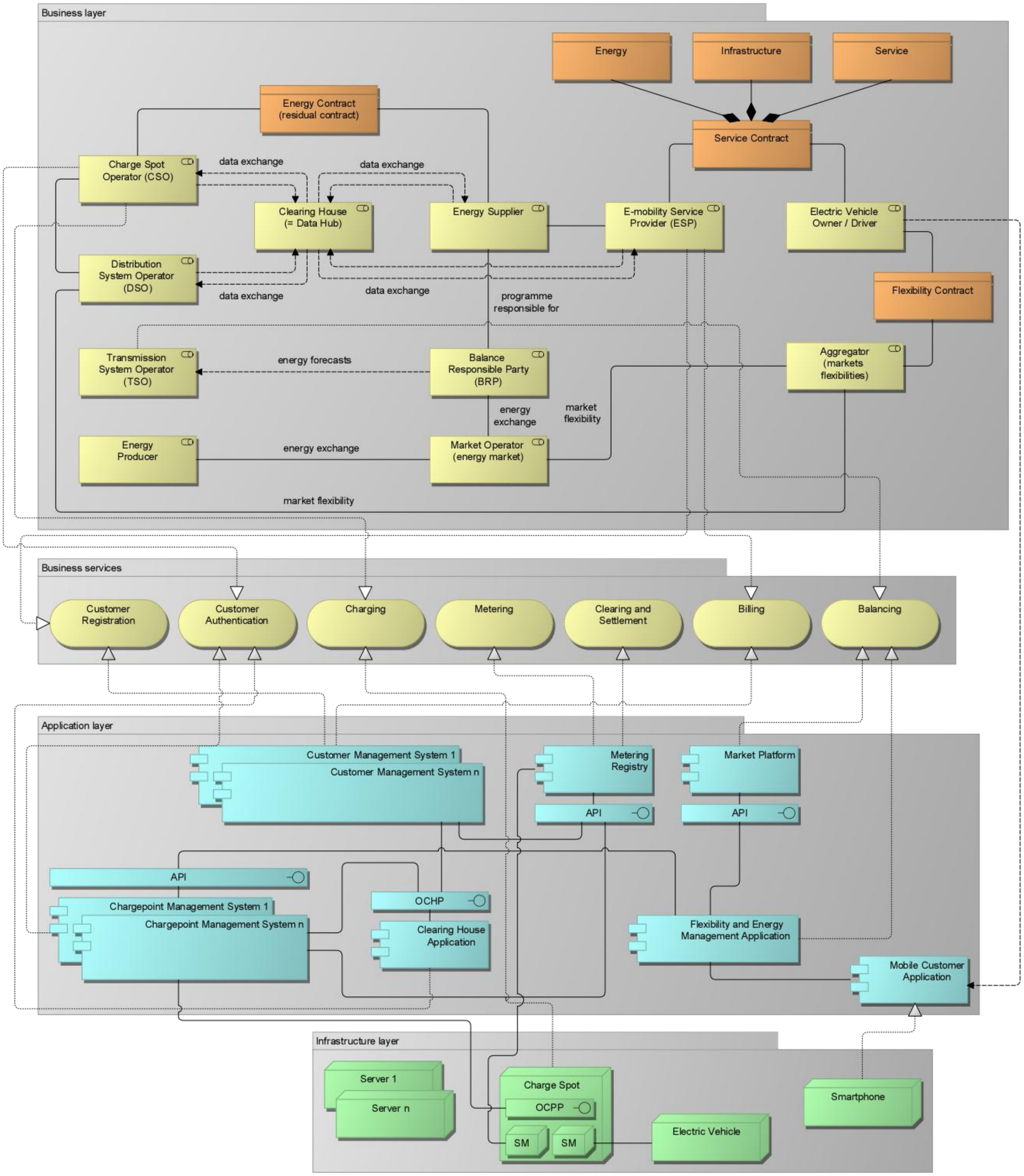


Figure 55: Improved migration architecture

11.3 Gap analysis

To support the implementation, migration and/or further research concerning the proposed architectures, we will summarize the main differences between the current architecture and the migration and reference architectures as proposed. Figure 56 and Figure 57, as displayed on the following pages, show a graphical gap analysis for the reference and migration architectures. Please note the following coloring legend when viewing the figures.

(green)	New elements
(orange)	Existing, but changed elements

11.3.1 Business layer

In the current architecture, the charge spot operator (CSO) has an energy contract with the energy supplier, and essentially resells this energy to the electric vehicle owner / driver. In both the reference and migration architectures, this energy contract is replaced with a residual energy contract; which means that the CSO only purchases energy for the 'stand-by' time of its charge points, when no electric vehicle is charging. In the reference architecture, the ESP is the final-end customer of energy, and purchases energy for its customers. The ESP replaces the role of charge service provider (CSP) as used in the current architecture. Instead of 'directly' reselling the energy, the energy is packed into a service contract which consists of three parts: energy, infrastructure and service.

In the reference architecture the role of market operator is changed. The markets are adjusted to reflect (near) real-time markets for both energy and grid capacity. The prices are bound to location and time. In contrast to the current architecture, the distribution system operator (DSO) applies flexible grid tariffs that are exchanged with the market operator. The ESP acts on the markets that are organized by the market operator in order to translate the needs from both the DSO and the energy market into price and/or control signals to its customers. The customers can respond to these price signals in a manner of automated demand-response (please refer to section 7.3.2 for background information on demand-response charging).

In the migration architecture, the market operator does not apply (near) real-time prices. In this architecture, the aggregator markets the flexibility of its customers directly to the DSO (on basis of contractual agreements) and on the wholesale and imbalance markets. Please refer to section 7.3.1 for background information on controlled charging and the role of the aggregator.

11.3.2 Application layer

In the reference architecture the clearing house application (as is present in the current architecture) is replaced by a data hub. This data hub functions as the central platform to exchange various kinds of EV-related data, including the authentication data that is currently stored in the clearing house application. Another function of the data hub is to function as a central metering registry and switch for the exchange of metering data. In the migration architecture, the clearing house is still present, and functions to exchange authentication data. For the exchange of metering data, a separate metering registry is used.

In both the reference and migration architectures, the market platform represents the main platform that is realized by the market operator. In the migration architecture, this platform can be the same platform as used in the current architecture. For the reference architecture, the platform needs to be adjusted to reflect real-time prices and include a market for flexible grid capacity.

In the reference architecture an on-board energy management application is used, which represents the local software agent that reacts on the price signals which are sent by the e-mobility service provider (ESP). In the migration architecture, the aggregator uses control signals, which are sent to an API on top of the chargepoint management system that is used by the charge spot operator (CSO). Since this (open) API does not yet exist in the current architecture, this is considered as an important change in the migration architecture.

In both the reference and migration architectures, a mobile application is introduced that the electric vehicle owner can use in order to provide and/or change his charging needs. Please note that in the reference architecture, the electric vehicle owner can also provide its needs through the on-board energy management system.

(please note: the gap analysis continues on page 74)

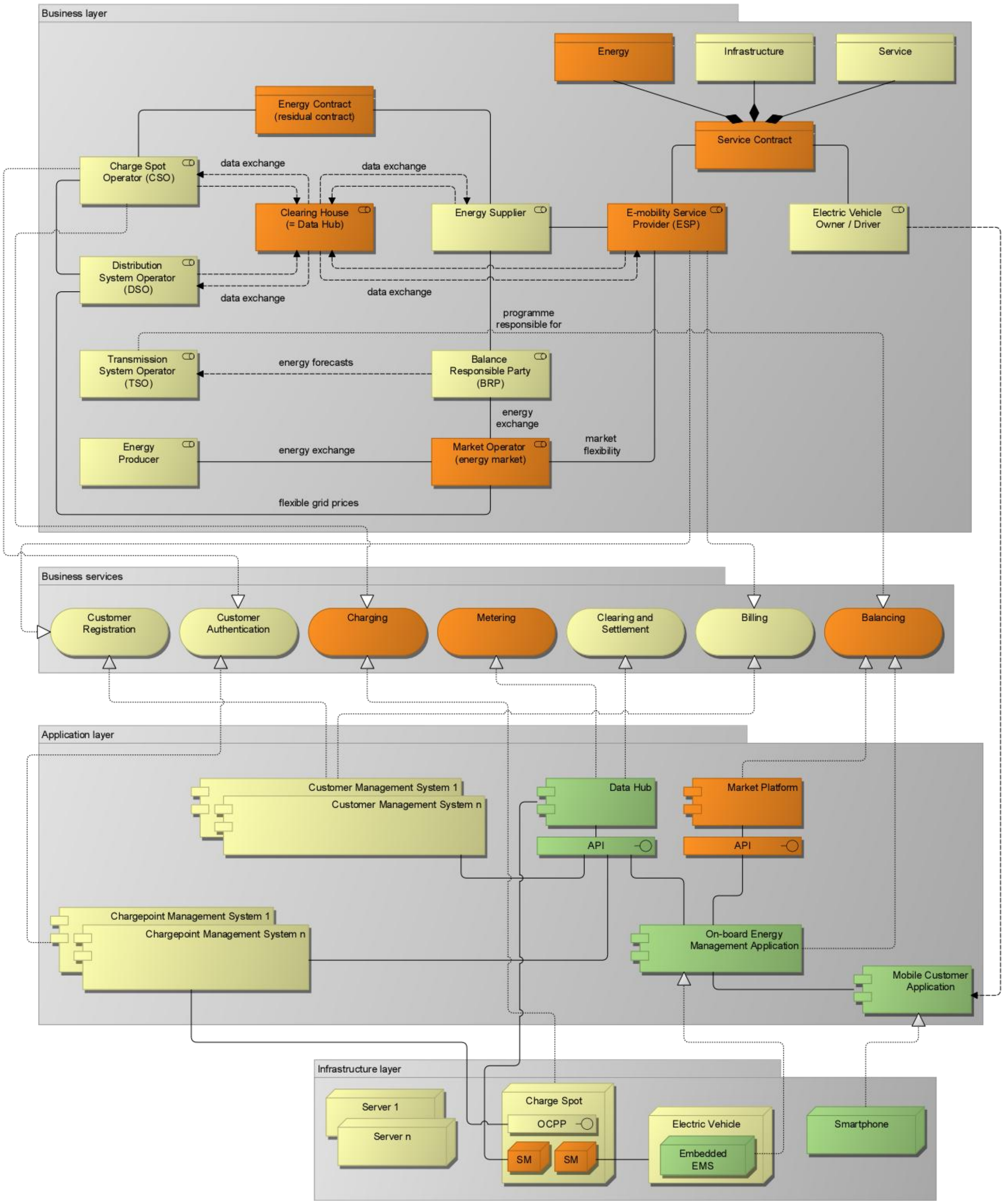


Figure 56: Gap analysis for the reference architecture

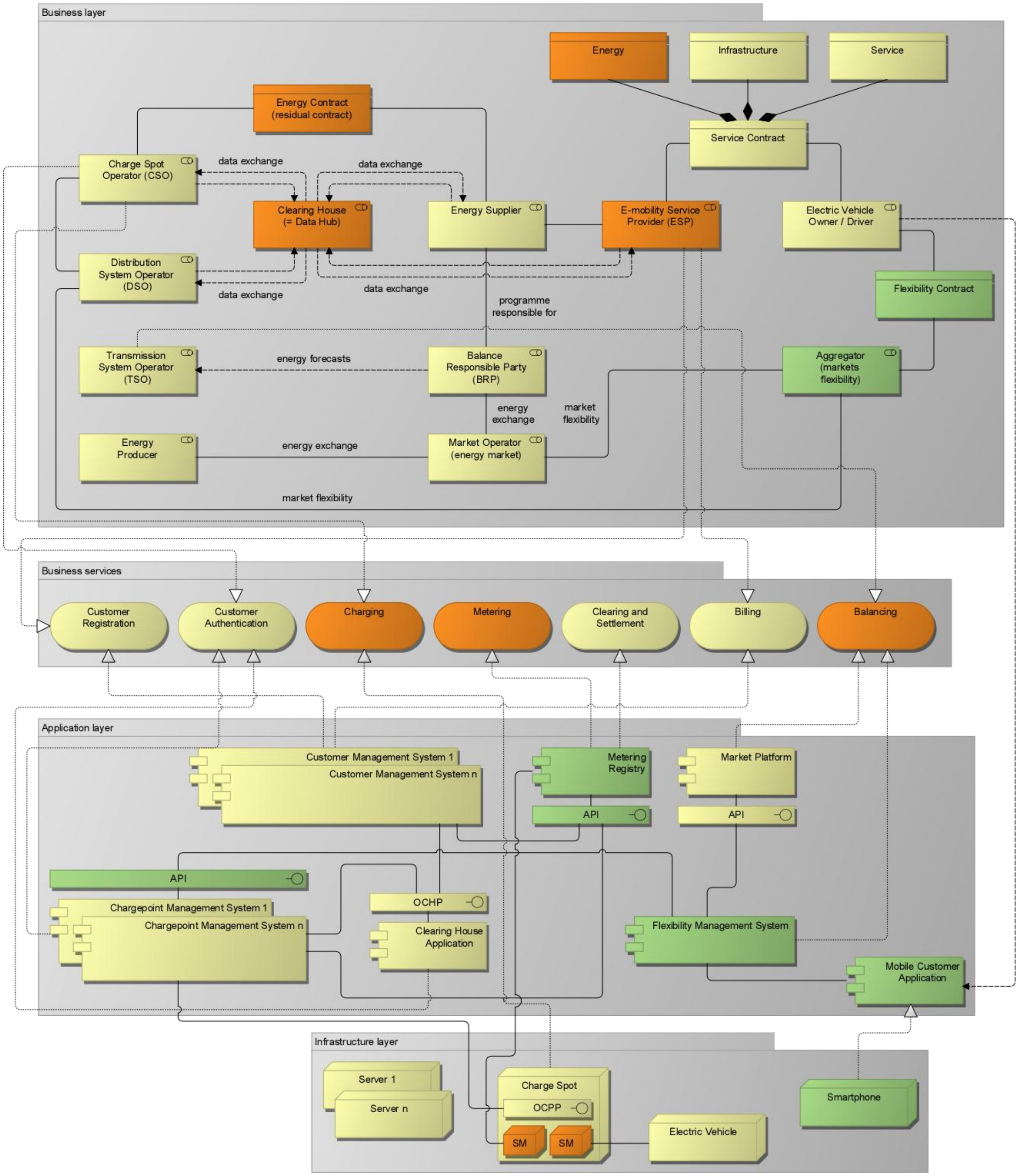


Figure 57: Gap analysis for the migration architecture

11.3.3 Infrastructure layer

In both the reference and migration architectures, the main change is the removal of redundant (smart) meters. For each of the outlets, a single meter is used, of which the metering data is shared between the relevant stakeholders. Also, in both architectures a smartphone is added to reflect the ability to use a mobile customer application. In the reference architecture an embedded software client is to run the energy management system.

12 Conclusions

The current research proposes a reference and migration architecture for electric mobility. As a final step the research questions as defined in the first chapter are examined in the current chapter, and recommendations for practice are given. As any other research, the current research involves certain limitations. Based on these limitations, topics for further research are identified.

12.1 Research questions

As defined in the first chapter, the central research question of the current research is:

"What must be stated in a reference architecture for electric mobility, in order to facilitate interoperability between involved parties from the markets of electric mobility and the electricity system, and realize a smart integration of electric vehicles within the electricity system?"

In order to answer the central research question and structure the research, a decomposition of the main problem has been applied, resulting in several research questions. In the current section, a reflection is given on each of the research questions.

1. **What is electric mobility?**
   In order to answer the first research question, our approach consisted of a literature study towards the definitions and classification concerned with electric mobility. In order to understand the market for electric mobility, a literature study on the history and important developments in electric mobility has been conducted. In addition, various sources have been studies in order to define the market roles in electric mobility that are relevant for the current research. Lastly, the charging infrastructure is examined.

   Based on the definition from Gartner (2012), electric mobility has been defined as the concept of using electric technologies, in-vehicle information, and communication technologies and connected infrastructures to enable the electric propulsion of vehicles. Four types of electric vehicles can be classified, which are depicted in Figure 5. The history of the realization of a public charging infrastructure in the Netherlands started in 2008. The most important developments in electric mobility in the Netherlands include the start of the foundation 'E-laad' and the studies by TNO, Innopay, EnergieNed, Netbeheer Nederland and Accenture towards a market model for electric mobility. On a European level, the most important developments concern the standardization mandates by the European Commission.

2. **What is the current architecture for electric mobility?**
   In order to answer the second research question, our approach consisted of various steps and results in a model of the current architecture. Since the current architecture for charging electric vehicles depends largely on the electricity market, the first step involves an in-depth analysis of the electricity market. This analysis can be found in chapter 3 of the current research, and includes a literature study towards relevant market roles. One of the main conclusions in the analysis of the electricity market is that its nature is changing, involving an increase in renewable energy sources (RES) and the decentralization of electricity generation.

   The second step concerns a description of the approach we applied towards enterprise architecture; this can be found in chapter 5. The approach as applied in the current is based on open standards; using the 'Architecture Development Method' (ADM) from TOGAF, and ArchiMate as the modeling language and framework, as proposed by Iacob, Jonkers, Quartel, Franken, & Van den Berg (2012).

   The third step involves the actual synthesis of the electricity model and the market roles, concepts and processes from electric mobility. This can be found in chapter 6 of the current research.

To answer the research question itself, we conclude that the current architecture for electric mobility essentially exists of the addition of an electric mobility layer on top of the existing electricity market. In the current architecture, the charge spot operator (CSO) is the formal end-user of electricity, and introduces the 'connection point' between the electricity model and the model for electric mobility.

3. **What is the motivation behind a reference architecture for electric mobility?**

In order to answer the third research question, our approach consisted of a problem analysis that results in the definition of objectives for the reference architecture. The problem analysis focuses on the problems that currently exist in the market of electric mobility, but more importantly, it identifies a weak alignment between the electricity system and electric mobility. Based on the problem analysis, objectives are stated to serve as a basis for the reference architecture. The last step in our approach consists of a literature study towards possible solution directions to be applied in the reference architecture.

As an answer to the research question, the main objectives origin from the problem analysis. This problem can be summarized as follows: the emergence of electric mobility introduces new threats and opportunities in relation to the electricity system; however, to mitigate the threats and utilize the opportunities a better alignment is needed. The main threat of electric mobility is the potential impact on the electricity system, the main opportunity of electric mobility is that it can absorb shortages and surpluses in electricity supply by charging intelligently, which can reduce imbalances in the electricity system. In addition, the current business model for electric mobility is inadequate and does not yield a profitable situation. Therefore, the following objectives have been defined:

a. Optimal integration with the electricity system
b. Accommodating the adoption of renewable energy sources (RES)
c. Optimization of the current business model

In addition to these objectives, a fourth objective is stated, concerning standardization developments. According to TNO & Innopay (2010), fragmentation is expected to occur if all parties seek to achieve their own goals in isolation within a starting market. Fragmentation can delay the adoption of electric vehicles, which is obviously not in the public interest. For the development of a reference architecture for electric mobility, it is therefore important to include alignment with standardization developments as a main objective. Therefore, the following objective has been defined in addition:

d. Alignment with European standardization developments

As a last remark, some quality attributes for the reference architecture have been determined. These attributes served as a modeling guideline during the design of the various architectural models in the current research.

4. **What must be stated in a reference architecture for electric mobility?**

In order to answer the fourth research question, our approach consisted of various steps. These steps include a literature study towards enterprise architecture, a literature study towards alternative design choices and their implications, and the modeling of the reference architecture. In addition, a migration architecture has been modeled as a migration path towards the reference architecture.

As identified in chapter 5.1, a reference architecture captures the essence of existing architectures and the vision of future needs and evolution to provide guidance to assist in developing new system architectures (Cloutier, Muller, Verma, Nilchiani, Hole, & Bone, 2010). The motivation for the creation and utilization of reference architectures can be to have a blueprint for the development of future systems and components, providing the possibility to identify gaps between the current and future situation. It can also be used to structure a certain domain and provide a foundation for communication about it to other domains that need to interoperate. Furthermore, it can be used to document decisions that have been taken during the development process of an infrastructure (CEN, CENELEC & ETSI, 2012)

In the current research, we use the enterprise architecture approach as proposed by Iacob, Jonkers, Quartel, Franken, & Van den Berg (2012). The approach described by the authors is based on open standards; using the 'Architecture Development Method' (ADM) from TOGAF, and ArchiMate as the modeling language and framework. To structure the reference architecture, we use three layers that correspond to the phases B, C and D of the TOGAF ADM. These phases concern the creation of the business, information systems and technology architectures.

The main architectural choices that have been made involve the implementation of 'smart charging'; how to integrate flexibility and intelligence in the charging process, the location of control and the metering of the usage of electricity for individual charging sessions.

The reference and migration architectures can be found in chapter 8 and 9 of the current research, and formulate the answer to the fourth research question. In chapter 11 improved versions of the reference and migration architectures can be found.

5. **What is the evaluation of the reference architecture?**
In order to answer the last research question and validate the reference architecture, our approach consisted of a series of structured interviews that have been carried out with six experts in the field of the three relevant sectors and/or disciplines involved in the current research: the energy sector, the sector of electric mobility, and the discipline of (enterprise) architecture. Each of the interviews has been performed as a structured face-to-face interview of about 1,5 hour. The interview consisted of an initial presentation on the background, motivation and design choices as made for the reference architecture. Following on this presentation, the reference architecture has been presented to each of the interviewees.

All interviewees acknowledged the problems in the current architecture. Overall, the interviewees acknowledged the problems that the reference architecture would result in the objectives as stated in the current research. At the same time, some critical notes and improvements have been proposed. Based on these remarks, improved versions of the reference and migration architectures have been modeled that encompass the final artifacts of the current research.

Reflecting on the main research question, we conclude that the improved architectures form a useful blueprint for the realization of an integrated solution for electric mobility and the electricity system. The integration of electric mobility and the electricity system is expected to drive the integration of renewable energy sources (RES), to have a positive impact on the business case for the charging infrastructure and to prevent potential threats towards the electricity system. In addition, the architectures provide a common vocabulary for further discussions, aggregating various concepts from literature. The current research can be used as a reference work towards these concepts, helping market players in making the right steps forward.

12.2 Limitations

As any other research, the current research involves certain limitations. Even though the reference and migration architecture seem to provide a promising solution template, the level of abstraction is relatively high. The field of electric mobility is still immature, and therefore the main focus of the current research has been on analyzing market roles, processes and high-level design choices. The current research provides insight into an integrated solution for electric mobility and the electricity system, but does not provide (a complete description of) the solution itself. As a result, especially the application layer is still very abstract and needs further attention in order to provide concrete directions for the involved stakeholders.

Another limitation regards the validation of the reference architecture. Although the reference architecture has been discussed extensively with leading experts, the number of interviews that could be performed is relatively low. Also, due to timing constraints, little attention has gone towards the quality attributes of the reference architecture. We believe that further validation research might result in improved feedback and uncover further issues in the reference architecture.

Also, although the current research presents a very simplistic financial analysis to estimate the economic impact of the reference architecture, little attention has been given towards concrete financial models and/or business cases.

12.3 Further research

Further research can improve the results of the current research, and help in taking the right steps forward towards an integrated solution for electric mobility and the electricity system. As mentioned in the previous section, a limitation of the current research is the relatively high level of abstraction. Further research is needed in order to give more detailed specifications for each of the architectural layers.

Secondly, as already pointed out in the previous section on limitations, it will be very interesting to further validate the reference architecture with relevant stakeholders. Also, the development of one or more concrete business cases can help to open the discussion with the stakeholders.

In the current research, we did not take into account the potential possibility of inductive charging. Further research is needed in this area, and the potential implications for the reference architecture.

12.4 Recommendations

During the course of this research, knowledge is gained in electric mobility and its integration within the electricity model. Based on this experience, several recommendations can be made towards Alliander, as well as the general research subject of electric mobility.

12.4.1 Recommendations for Alliander

As has become evident in the current research, a smart integration of electric mobility and the electricity system offers the opportunity to utilize the grid more effectively and save costs in grid investments as a result. One of the restraining factors is the high investment that is needed to realize the public charging infrastructure. A promising step forward would be to cut down these costs. Two options to do so have emerged during the current research. The first option is to introduce service level agreements (SLAs) that offer a CSO the use of a cheaper connection when complying with specific norms such as the use of certified meters and the provision of access to these meters. This way, the infrastructure is 'shared' between the CSO and Alliander, and offers the opportunity to save costs for both parties. Another option is to continue on collecting evidence for the usefulness of the 'DSO model', where the DSO is responsible for the charging infrastructure. This approach can result in a cost-efficient, accelerated deployment of charging spots, and support standardization by the avoidance of heterogeneous technologies (EDSO, 2012).

During the interviews, the requisite of the role of e-mobility service provider (ESP) became clear, translating the incentives from the DSO and energy market towards its customers. An interesting option for Alliander would be to have a proof of concept for the communication and processes between Alliander and a (simulated) ESP.

12.4.2 General recommendations

One conclusion that became clear during the current research and that is acknowledged by most of the interviewees is that it is important to implement both control and price signals in the communication between service provider (ESP) and customer. It would therefore be interesting to implement a proof of concept that uses these signals and/or to extend the current standards (such as OCPP) to include these signals. In order to realize interoperability between market players, a significant step forward would be to develop an open API on top of the current back-office systems, so that other stakeholders can get access to (specific) charge point functionality.

Appendix

A. Market roles for electric mobility

In this section the results of a literature study on market roles for electric mobility are presented; relevant market roles are identified and definitions for each of the roles are given.

A1. Electric Vehicle Driver

Person or legal entity using the vehicle and providing information about driving needs and consequently influences charging patterns (IEC, 2012, p. 12)

Source	Actor	Description
Green eMotion	Vehicle Driver	Human, currently driving the vehicle (Green eMotion, 2013, p. 4)
IEC	E-mobility User	Person or legal entity using the vehicle and providing information about driving needs and consequently influences charging patterns (IEC, 2012, p. 12)
IEC	E-mobility Customer	Legal entity being associated to an E-mobility Service Provider (IEC, 2012, p. 10)
TNO & Innopay	Customer	A type of party that is commercially responsible for the purchase of electricity from a charge point (TNO & Innopay, 2010, p. 6)
E-clearing.net	EV Customer	An EV customer uses an electric vehicle for local transport and needs electricity for direct mobility needs. The EV customer is able to charge his/her car at home or uses public infrastructure (E-clearing.net, 2012, p. 5)

A2. Charge Service Provider (CSP)

The EV Service Provider operates as a contract party for the EV customer. The EV Service Provider takes care of the end user authentication and billing processes (E-clearing.net, 2012, p. 6)

Source	Actor	Description
Green eMotion	Electric Vehicle Service Provider	Offers e-mobility services to the end customers (Green eMotion, 2013, p. 3)
IEC	E-mobility Service Provider	Legal entity that provides services to the Electric Vehicle User (EVU) related to the operation of an EV (IEC, 2012, p. 11)
TNO & Innopay	Service Provider	*No clear definition provided*
E-clearing.net	EV Service Provider	The EV Service Provider operates as a contract party for the EV customer. The EV Service Provider takes care of the end user authentication and billing processes (E-clearing.net, 2012, p. 6)
CEN, CENELEC & ETSI	E-mobility Service Operator	A party offering specific services for the charge management of electric vehicles. Services included in the EV Charging Energy (e-Mobility) Service. This role is at the interface of the mobility world, which includes the vehicle (including all associated domains with the electric world), and the energy supply (including all the associated domains). Such type of operator will ease the interface with customers, allowing a good optimization of the charge management to the user needs (CEN, CENELEC & ETSI, 2012, p. 86)

A3. Charge Spot Operator (CSO)

Operates charging stations, receives charge plans and is responsible for the execution of a charge plan. Other responsibilities: Authenticate or relay to CSP for authentication, negotiation of charging capabilities and finally executing charging service request within boundaries (grid capacity, RE/E-availability) (CEN, CENELEC & ETSI, 2012, p. 84)

Source	Actor	Description
Green eMotion	EVSE Operator	In charge of managing EVSEs (Green eMotion, 2013, p. 4)
IEC	E-mobility Infrastructure Operator	Legal entity that operates and maintains the EVSE (IEC, 2012, p. 11)
TNO & Innopay	Charge supplier	A type of party that offers charging via one or more charge points to customers (TNO & Innopay, 2010, p. 6)
E-clearing.net	Local Charge Provider	The (local) Charge provider operates as contract party for the Energy Supplier. The Charge Provider purchases the Electricity from the Energy Supplier and will send the EV-service provider an invoice for the delivered Electricity (E-clearing.net, 2012, p. 6)
CEN, CENELEC & ETSI	Charge Spot Operator	Operates charging stations. Receives charge plans and is responsible for the execution of a charge plan. Other responsibilities: Authenticate or relay to CSP for authentication, negotiation of charging capabilities and finally executing charging service request within boundaries (grid capacity, RE/E-availability) (CEN, CENELEC & ETSI, 2012, p. 84)

A4. Original Equipment Manufacturer (OEM)

An entity that produces electric vehicles and provides EV services related to their own build electric vehicles (Green eMotion, 2013, p. 32)

Source	Actor	Description
Green eMotion	Original Equipment Manufacturer	An entity that produces electric vehicles and provides EV services related to their own build electric vehicles (Green eMotion, 2013, p. 32)
IEC	Electric Vehicle Manufacturer	Legal entity responsible for all the technologies inside the EV also in relation to the data communication (IEC, 2012, p. 9)

A5. Clearing House

The Clearing House acts as a roaming enabler. It can collect contractual data either from the marketplace, where the business partners can store their bilateral contracts, or can ask the involved parties by itself. Another option is, that the clearing house stores a subset of contract information in its own database. It forwards the CDR to the corresponding EVSP of a customer who has charged at a foreign location. The clearing house does the authentication of charging requests when it is asked by the EVSE operator (Green eMotion, 2013, p. 7)

Source	Actor	Description
Green eMotion	Clearing House	Authenticates and processes contractual and financial transactions (Green eMotion, 2013, p. 7)
IEC	Data Hub	Data Hub is the neutral entity mediating between two partners to provide services for validation and exchange of technical information. A Data Hub operated by a trusted party will be able to manage contract relations, technical aspects and security certificates (IEC, 2012, p. 10)

E-clearing.net	EV Clearing House	Gives "Roaming Support" for every EV Service Provider. The ultimately goal is that the EV-customer can easily charge his Electrical Vehicle on every charging station of every EV Service Provider (E-clearing.net, 2012, p. 7)

B. Market roles in the electricity system

In this section the results of a literature study on market roles within the electricity system are presented; relevant market roles are identified and definitions for each of the roles are given.

B1. Energy Consumer

Entity or person that consumes electricity (EG3, 2013) (ENTSO-E, 2011).

Source	Actor	Description
CEN, CENELEC & ETSI	Consumer	A party that consumes electricity. As the consumer can also generate energy using a Distributed Energy Resource, he is sometimes called the "Prosumer" (CEN, CENELEC & ETSI, 2012, p. 84)
ENTSO-E	Consumer	A party that consumes electricity (ENTSO-E, 2011, p. 14)
EG3	Customer / Consumer	Entity or person being delivered electricity (EG3, 2013, p. 45)

B2. Energy Producer

A party that produces electricity; this is a type of party connected to the grid (ENTSO-E, 2011, p. 17)

Source	Actor	Description
ENTSO-E	Producer	A party that produces electricity. This is a type of party connected to the grid (ENTSO-E, 2011, p. 17)
EG3	Generator	Generating electricity, contributing actively to voltage and reactive power control (EG3, 2013, p. 44)
CEN, CENELEC & ETSI	Producer	Uses the definition as defined by ENTSO-E
European Parliament and Council	Producer	A natural or legal person generating electricity (European Parliament and Council, 2003, p. 4)

B3. Energy Supplier

Interestingly, the EG3 gives two definitions of a 'Supplier', based on two different perspectives. When viewing from the (current) energy market perspective, their definition mainly concerns the contractual agreement with end customer relating to the supply of electricity.

Note: Both the IEC and CEN, CENELEC & ETSI refer to ENTSO-E for their definitions on the role of 'Energy Supplier'. However, the role of 'Energy Supplier' is not present in the (current version of the) ENTSO-E role model.

Source	Actor	Description
ENTSO-E	Energy Supplier	No description available
Green eMotion	Energy Retailer	Delivers electricity to the charging spot (Green eMotion, 2013, p. 3)
IEC	Energy Supplier	Entity that offers contracts for supply of energy to a consumer (the supply contract). Within this role he will initiate demand-supply management activities. Note: in some countries referred to as

		Retailer (International Electronical Commission, 2012, p. 12) *Note: This definition refers to ENTSO-E as its source. However, the role of 'Energy Supplier' is not present in the ENTSO-E role model.*
CEN, CENELEC & ETSI	Supplier	Entity that offers contracts for supply of energy to a consumer (the supply contract). Within this role he will initiate demand-supply management activities. Note: in some countries referred to as Retailer (CEN, CENELEC & ETSI, 2012, p. 92) *Note: This definition refers to ENTSO-E as its source. However, the role of 'Energy Supplier' is not present in the ENTSO-E role model.*
EG3	Supplier	Has a contractual agreement with end customer relating to the supply of electricity (EG3, 2013, p. 45)
EG3	Supplier	A grid user who has a grid connection and access contract with the TSO or DSO. They will provide new services, real-time information, energy efficiency services and dynamic energy pricing concepts with Time-of-Use (ToU) and local aggregation of demand and supply (EG3, 2013, p. 44)
EG3	Retailer	Entity selling electrical energy to consumers - could also be a grid user who has a grid connection and access contract with the TSO or DSO (EG3, 2013, p. 44)
CEN, CENELEC & ETSI	Retailer	*Uses the definition as defined by EG3*
E-clearing.net	Energy Supplier	The Energy Supplier is contracted by the (local) Charge provider to deliver the Electricity against the contracted tariffs (E-clearing.net, 2012, p. 6)
De Vries	Retailer	Provide electricity to consumers, buying electricity wholesale, paying to use the transmission and distribution grids, and doing the billing (De Vries, 2004, p. 40)
Energy Research Centre of the Netherlands	Supplier	Responsible for the sale of electricity to customers (retail). Producer and supplier can be the same entity but this is not always the case. A supplier can also be a wholesale customer or independent trader who purchases electricity with the purpose to resell it in the system (Van Werven & Scheepers, 2005, p. 17)

B4. Transmission System Operator

A party that is responsible for a stable power system operation (including the organization of physical balance) through a transmission grid in a geographical area (ENTSO-E, 2011, p. 19)

Source	Actor	Description
CEN, CENELEC & ETSI	Transmission System Operator	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity. Moreover, the TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area (CEN, CENELEC & ETSI, 2012, p. 93)

ENTSO-E	System Operator	A party that is responsible for a stable power system operation (including the organization of physical balance) through a transmission grid in a geographical area. The System Operator will also determine and be responsible for cross border capacity and exchanges. If necessary he may reduce allocated capacity to ensure operational stability (ENTSO-E, 2011, p. 19)
EG3	Transmission System Operator	Responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area.
De Vries	System Operator	Maintains system stability and manages the energy balance within a 'control zone'. Where actual demand and supply deviate from the amounts that were contracted by market parties, the system operator maintains the power balance continuously. A second task is to provide (or contract) sufficient black-start power (De Vries, 2004, p. 36)
De Vries	Transmission Operator	Manages a transmission system. He guards against congestion, maintains reliability of transmission service and provides ancillary services for transport. There can be multiple transmission operators per control zone (De Vries, 2004, p. 36)
European Parliament and Council	Transmission System Operator	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long term ability of the system to meet reasonable demands for the transmission of electricity (European Parliament and Council, 2003, p. 4)

B5. Distribution System Operator

Responsible for regional grid access and grid stability, integration of renewables at the distribution level and regional load balancing (EG3, 2013, p. 44)

Source	Actor	Description
Green eMotion	Distribution System Operator	Provides the power connection point to the charging spot. Is responsible for the voltage stability in the distribution grid (MV/LV grid). Is in charge of providing the energy metering to other market actors (i.e. EVSP, TSO, EVSE Op.) unless there is another actor doing this (i.e. Metering Point Operator). (Green eMotion, 2013, p. 3)
IEC	Distribution System Operator	According to the Article 2.6 of the Directive: "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity". Moreover, the DSO is responsible for regional grid access and grid stability, integration of renewables at the distribution level and regional load balancing (International Electronical Commission, 2012, p. 10)
EG3	Distribution System Operator	Responsible for regional grid access and grid stability, integration of renewables at the distribution level and regional load balancing (EG3, 2013, p. 44)

European Parliament and Council	Distribution System Operator	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long term ability of the system to meet reasonable demands for the distribution of electricity (European Parliament and Council, 2003, p. 4)

B6. Metering Responsible

The ENTSO-E identifies four separate roles concerning electricity metering: Meter Operator, Metered Data Collector, Metered Data Responsible and Metered Data Aggregator (ENTSO-E, 2011). In our role model, this separation is not relevant; therefore these roles are aggregated into the role of 'Metering Responsible'.

Source	**Actor**	**Description**
EG3	Metering Operator	The entity that offers services to provide, install and maintain metering equipment related to energy supply. In most EU member states the DSO is also metering operator (EG3, 2013, p. 45)
ENTSO-E	Meter Operator	A party responsible for installing, maintaining, testing, certifying and decommissioning physical meters (ENTSO-E, 2011, p. 16)
ENTSO-E	Metered Data Collector	A party responsible for meter reading and quality control of the reading (ENTSO-E, 2011, p. 16)
ENTSO-E	Metered Data Responsible	A party responsible for the establishment and validation of metered data based on the collected data received from the Metered Data Collector. The party is responsible for the history of metered data for a Metering Point (ENTSO-E, 2011, p. 16)
ENTSO-E	Metered Data Aggregator	A party responsible for the establishment and qualification of metered data from the Metered Data Responsible. This data is aggregated according to a defined set of market rules (ENTSO-E, 2011, p. 16)
CEN, CENELEC & ETSI	Meter Operator, Metered Data Collector, Metered Data Aggregator	*Uses the definitions as defined by ENTSO-E*
IEC	Meter Operator	*Uses the definition as defined by ENTSO-E*

B7. Balance Responsible Party

A party that has a contract proving financial security and identifying balance responsibility with the imbalance settlement responsible of the market balance area entitling the party to operate in the market. This is the only role allowing a party to buy or sell energy on a wholesale level (ENTSO-E, 2011, p. 13)

Source	**Actor**	**Description**
ENTSO-E	Balance Responsible Party	A party that has a contract proving financial security and identifying balance responsibility with the imbalance settlement responsible of the market balance area entitling the party to operate in the market. This is the only role allowing a party to buy or sell energy on a wholesale level (ENTSO-E, 2011, p. 13)
EG3	Balance Responsible Party	Ensures that the supply of electricity corresponds to the anticipated consumption of electricity during a given time period and financially regulates for any imbalance that arises (EG3, 2013, p. 44)

CEN, CENELEC & ETSI	Balance Responsible Party	*Uses the definition as defined by ENTSO-E*

B8. Market Operator

Provides a market place for trading physical and financial contracts for capacity allocation (EG3, 2013, p. 44)

Source	Actor	Description
EG3	Power Exchange	Provides a market place for trading physical and financial contracts for capacity allocation (EG3, 2013, p. 44)
ENTSO-E	Market Operator	The unique power exchange of trades for the actual delivery of energy that receives the bids from the Balance Responsible Parties (BRP) that have a contract to bid. The Market Operator determines the market energy price for the Market Balance Area after applying technical constraints from the System Operator. It may also establish the price for the reconciliation within a Metering Grid Area (ENTSO-E, 2011, p. 16)
CEN, CENELEC & ETSI	Market Operator	*Uses the definition as defined by ENTSO-E*
IEC	Energy Market	Commodity markets that deal specifically with the trade and supply of energy (purchase and sale of energy products). Energy market may refer to an electricity market, but can also refer to other sources of energy. Note: It typically describes a wholesale market for energy producers and energy retailers (International Electronical Commission, 2012, p. 12)
Green eMotion	Marketplace Operator	Operates the platform and communications, and manages access to and working of the marketplace (Green eMotion, 2013, p. 6)
De Vries	Market Operator	Matches supply and demand by organizing markets, such as a spot market and term markets, and/or by coordinating energy programs by generators and loads (De Vries, 2004, p. 40)

C. Full list of roles in the energy market (ENTSO-E)

Role	Description
Balance Responsible Party	A party that has a contract proving financial security and identifying balance responsibility with the Imbalance Settlement Responsible of the Market Balance Area entitling the party to operate in the market. This is the only role allowing a party to nominate energy on a wholesale level
Balance Supplier	A party that markets the difference between actual metered energy consumption and the energy bought with firm energy contracts by the Party Connected to the Grid
Billing Agent	The party responsible for invoicing a concerned party
Block Energy Trader	A party that is selling or buying energy on a firm basis (a fixed volume per market time period)
Capacity Coordinator	A party, acting on behalf of the System Operators involved, responsible for establishing a coordinated Offered Capacity and/or NTC and/or ATC between several Market Balance Areas
Capacity Trader	A party that has a contract to participate in the Capacity Market to acquire capacity through a Transmission Capacity Allocator
Consumer	A party that consumes electricity
Consumption Responsible Party	A party who can be brought to rights, legally and financially, for any imbalance between energy nominated and consumed for all associated Accounting Points
Control Area Operator	Responsible for: (1) The coordination of exchange programs between its related Market Balance Areas and for the exchanges between its associated Control Areas. (2) The load frequency control for its own area. (3) The coordination of the correction of time deviations.
Control Block Operator	Responsible for: (1) The coordination of exchanges between its associated Control Blocks and the organization of the coordination of exchange programs between its related Control Areas. (2) The load frequency control within its own block and ensuring that it's Control Areas respect their obligations in respect to load frequency control and time deviation. (3) The organization of the settlement and/or compensation between its Control Areas.
Coordination Center Operator	Responsible for: (1) The coordination of exchange programs between its related Control Blocks and for the exchanges between its associated Coordination Center Zones. (2) Ensuring that its Control Blocks respect their obligations in respect to load frequency control. (3) Calculating the time deviation in cooperation with the associated coordination centers. (4) Carrying out the settlement and/or compensation between its Control Blocks and against the other Coordination Center Zones.
Grid Access Provider	A party responsible for providing access to the grid through an Accounting Point and its use for energy consumption or production to the Party Connected to the Grid.
Grid Operator	A party that operates one or more grids.
Imbalance Settlement Responsible	A party that is responsible for settlement of the difference between the contracted quantities and the realized quantities of energy products for the Balance Responsible Parties in a Market Balance Area.
Interconnection Trade Responsible	Is a Balance Responsible Party or depends on one. He is recognized by the Nomination Validator for the nomination of already allocated capacity

Market Information Aggregator	A party that provides market related information that has been compiled from the figures supplied by different actors in the market. This information may also be published or distributed for general use
Market Operator	The unique power exchange of trades for the actual delivery of energy that receives the bids from the Balance Responsible Parties that have a contract to bid. The Market Operator determines the market energy price for the Market Balance Area after applying technical constraints from the System Operator. It may also establish the price for the reconciliation within a Metering Grid Area
Meter Administrator	A party responsible for keeping a database of meters.
Meter Operator	A party responsible for installing, maintaining, testing, certifying and decommissioning physical meters
Metered Data Collector	A party responsible for meter reading and quality control of the reading.
Metered Data Responsible	A party responsible for the establishment and validation of metered data based on the collected data received from the Metered Data Collector. The party is responsible for the history of metered data for a Metering Point.
Metered Data Aggregator	A party responsible for the establishment and qualification of metered data from the Metered Data Responsible. This data is aggregated according to a defined set of market rules.
Metering Point Administrator	A party responsible for registering the parties linked to the metering points in a Metering Grid Area. He is also responsible for maintaining the Metering Point technical specifications. He is responsible for creating and terminating metering points.
MOL Responsible	Responsible for the management of the available tenders for all Acquiring System Operators to establish the order of the reserve capacity that can be activated
Nomination Validator	Has the responsibility of ensuring that all capacity nominated is within the allowed limits and confirming all valid nominations to all involved parties. He informs the Interconnection Trade Responsible of the maximum nominated capacity allowed. Depending on market rules for a given interconnection the corresponding System Operators may appoint one Nomination Validator
Party Connected to the Grid	A party that contracts for the right to consume or produce electricity at an Accounting Point.
Producer	A party that produces electricity.
Production Responsible Party	A party who can be brought to rights, legally and financially, for any imbalance between energy nominated and produced for all associated Accounting Points
Reconciliation Accountable	A party that is financially accountable for the reconciled volume of energy products for a profiled Accounting Point.
Reconciliation Responsible	A party that is responsible for reconciling, within a Metering Grid Area, the volumes used in the imbalance settlement process for profiled Accounting Points and the actual metered quantities
Reserve Allocator	Informs the market of reserve requirements, receives tenders against the requirements and in compliance with the prequalification criteria, determines what tenders meet requirements and assigns tenders.
Resource Provider	A role that manages a resource object and provides the schedules for it.
Scheduling Coordinator	A party that is responsible for the schedule information and its exchange on behalf of a Balance Responsible Party. For example in the Polish market a Scheduling Coordinator is responsible for information interchange for scheduling

	and settlement.
System Operator	A party that is responsible for a stable power system operation (including the organization of physical balance) through a transmission grid in a geographical area. The System Operator will also determine and be responsible for cross border capacity and exchanges. If necessary he may reduce allocated capacity to ensure operational stability.
Trade Responsible Party	A party who can be brought to rights, legally and financially, for any imbalance between energy nominated and consumed for all associated Accounting Points
Transmission Capacity Allocator	Manages the allocation of transmission capacity for an Allocated Capacity Area. For explicit auctions: The Transmission Capacity Allocator manages, on behalf of the System Operators, the allocation of available transmission capacity for an Allocated capacity Area. He offers the available transmission capacity to the market, allocates the available transmission capacity to individual Capacity Traders and calculates the billing amount of already allocated capacities to the Capacity Traders

Source: (ENTSO-E, 2011)

D. Charge Detail Record (CDR)

Field	Required	Description	Example
CDR_ID	Yes	Record number; unique per Infra_Provider_ID	471
Start_datetime	Yes	Start date & time of charging session	2013-03-01T11:45:30+02:00
End_datetime	Yes	End date & time of charging session	2013-03-01T14:45:30+02:00
Duration	No	Duration of the charging session	3:00:00
Volume	No	Energy volume delivered in kWh	0,0024
Charge_Point_Address	No	Location of the charge point	Overijssellaan 5
Charge_Point_ZIP	No	Location of the charge point	7543 WC
Charge_Point_City	No	Location of the charge point	Enschede
Charge_Point_Country	No	Location of the charge point	NLD
Charge_Point_Type	No	Charge point type	3
Product_Type	No	Type of product delivered	0
Tariff_Type	No	Identified type of tariff used by EVSO	1
Authentication_ID	Yes	Customer identification, decoded RFID as stored in the central register	ABCDEF12
Contract_ID	No	Customer contract (external ID) identification as stored in the central register	NL-ESS-123456-7
Meter_ID	No	Meter identification	4539
OBIS_Code	No	OBIS object identification of the meter	1-1:1.8.0
Charge_Point_ID	Yes	Identifies the physical socket that was used during the charging session	641678
Service_Provider_ID	Yes	ID of the recipient of the CDR, as stored in the central register	e-laad
Infra_Provider_ID	Yes	ID of the sender of the CDR, as stored in the central register	e-laad

Source: (P2, 2012)

E. History of the market for electric mobility

In order to provide some background on the developments in the market for electric mobility, this section will review the main history of electric mobility in the Netherlands and on a European level in order of time. The developments of the electric vehicle itself are considered out of scope for this section.

The history of the EV charging infrastructure in the Netherlands starts in 2008 when Eneco introduced the first public charging point, the NRGSPOT. This charge point was part of a demonstration project in Rotterdam, and allowed customers to charge their electric vehicle for a small charge (Eneco, 2008).

As the number of electric vehicles in the Netherlands increased, the Dutch network operators realized that a large-scale introduction of electric vehicles would significantly influence their electricity grids. To be able to predict and cope with these effects, cooperating network operators started the foundation 'E-laad'. One of its main goals was to realize 10.000 public charging points in the Netherlands. In October 2009, E-laad commissioned its first public charging point, located at the parking lot of the University of Tilburg (Technisch Weekblad, 2009).

In July 2009, the Dutch government published a plan of action for the development of electric mobility in the Netherlands. In this document, electric vehicles are considered as a highly promising option in order to increase sustainability, strengthen the energy position and structurally boost the economy. One of the contributions from the government was the establishment of the so-called "Formule E-team", with members from sectors regarded as essential for a successful introduction and deployment of EV. The primary task of the team was to promote the market development and removal of barriers in EV developments (Tweede Kamer der Staten-Generaal, 2009).

In the same period the municipality of Amsterdam started a EV project, of which the main objective was to improve the city's air quality. In November 2009, the first public charging station in Amsterdam was realized in collaboration with the Dutch energy supplier Nuon and property developer Heijmans (Michel, 2012).

In the same year E-laad initiated the development of the Open Charge Point Protocol (OCPP), together with the initial partners Logica (providing the IT components) and Alfen (providing the charge points). The goal for OCPP was to offer a uniform solution for the method of communication between charge point and a central system. OCPP provides a protocol that makes interoperability possible between a charge point and a central system, allow charging stations and central systems from different vendors to easily communicate with each other. The first version of OCPP was ready for use in March 2010. OCPP started small but has currently been adopted by over 400 in 35 different countries including USA, China, Singapore, Germany, France and Russia (OCPP, 2012).

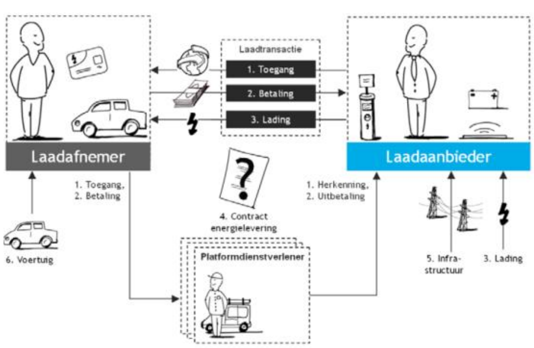


Figure 59: Provider model (TNO & Innopay, 2010)

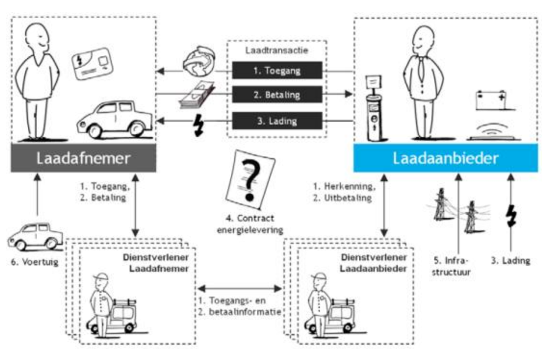


Figure 58: Network model (TNO & Innopay, 2010)

In the year that followed, EnergieNed and Netbeheer Nederland commissioned Accenture to conduct an initial study to work towards a market model for Electric Vehicles. In this study, market models from the telecom & banking sector are analyzed to serve as an example. The intention of the study was to open up the dialogue between relevant market parties. The results, made public in April 2010, presents three market models and agrees on the "provider model" as the preferred model. In this model, a service provider acts as an intermediary between customer and charge point operator (EnergieNed & Netbeheer Nederland, 2010).

Against the background of this study, the Ministry of Transport (also on behalf of the Ministry of Economic Affairs) asked TNO and Innopay to provide insight into the needed developments to establish the proposed market model. This has led to a plan of action for the development of a market model for EV charging services, although it does not provide the exact details of the roles, functions, processes and techniques for the implementation of charging services (TNO & Innopay, 2010). In the study, the provider model is further analyzed, and another model, the "network model", is introduced. In this model, the service provider is split into two service providers: one for the customer and one for the charge point operator. In the longer term, this network model is desirable to realize the most freedom of choice, innovation and a dynamic market. Based on their analysis, the advice is given to:

1. Start on working out agreements for the network model, because this model ultimately meets the best of the premises as stated by the Ministries of Economic Affairs and Transport
2. In the short term, facilitate the platform model and work out the necessary agreements for access and settlement. At the same time, prepare for the division of roles.
3. Evolve the introduction of the market model based on the developments within the market

Following the advice as mentioned in the previous paragraph, the Ministry of Economic Affairs, Agriculture and Innovation (together with Energie Nederland and Netbeheer Nederland) asked Innopay to submit a proposal for the necessary processes needed for the further development of a market model for EV charging services. Based on a consultation process in which 25 parties participated, this has led to a roadmap action for the implementation of a market model for EV charging services (Innopay, 2011). The roadmap contains three phases:

1. Preparation: Principles and preconditions get established, a set of requirements is drawn
2. Development: agreements are made that are necessary to implement the market model
3. Network realization: Based on the agreements market implement their products and services and create the initial network and charging infrastructure. Also, a management organization has to be established in order to govern the agreements between market parties.

As a next step, the Ministry of Economic Affairs, Agriculture and Innovation (again, together with Energie Nederland and Netbeheer Nederland) asked P2 to start the development of a market model for electric transportation. Various market players and clients were closely involved in the design and development of the market model. In spring 2012, several documents were delivered, including the blueprint for the creation of a so-called EV management organization and an initial set of basic agreements for the technical and commercial interoperability of public charging points (Geerts & Groosman, 2013). As a result and in order to implement the EV management organization, various Dutch charge point operators and service providers establish the eViolin association in November 2012 (E-laad, 2012).

In the middle of the development of the market model as described above, another milestone is reached when it gets possible to charge electric cars at public charging points across Dutch borders. E-laad, Ladenetz.de from Germany and Blue Corner from Belgium collaborate to provide this service (Energeia, 2011).

On a European level, the European Commission signed a standardization mandate concerning the charging of electric vehicles (European Commission, 2010). The mandate was signed in Brussels in June 2010, and its main targets were to promote the development of an internal market for electrical vehicles, avoid market fragmentation and discourage the imposition of market barriers. In order to reach these targets, the mandate endorsed the importance of a joint solution on interoperability and the need of adopting a harmonized approach for interoperability between charge point and EV. The mandate, M/468, identified the following subjects to be treated:

a) Interoperability and connectivity between EVSE, charge connector and EV

b) Smart-charging issues with respect to the charging of electric vehicles
c) Safety risks and electromagnetic compatibility

As a response to the European mandate, a focus group on European Electro-Mobility Standardization was established, comprising representatives of standards organizations at national level and European-level associations with an interest in electro-mobility. In October 2011, the focus group delivered a report as an initial answer to M/468, in which proposals to the standardization organizations are made in respect of standardization activities. The report covers the following areas:

a) Connectors and charging systems
b) Smart charging
c) Communication between EV and EVSE
d) Batteries
e) Electromagnetic compatibility
f) Regulation

In the report, lists of regulations and standards are provided. The list of standards gives an overview of all standards developed within the main technical committees of CEN, CENELEC, ISO, IEC, SAE and UL related to EV components, EV performance and safety specifications (Focus Group on European Electro-Mobility, 2011).

On March 30, 2012, in the town of Vaals in the Netherlands, the 'Treaty of Vaals' is signed by seven organizations managing the public charging infrastructure for electric vehicles in their respective countries in Europe: Netherlands, Germany, Belgium, Luxembourg, Ireland, Portugal and Austria. Partners are collaborating on the first open European Clearing House for electric vehicles, making it possible to provide cross-country charging services and international information exchange on charging electric cars. The IT is based on an open standard, the Open Clearing House Protocol (OCHP), which facilitates automatic data exchange (International Energy Agency, 2012).

F. Validation interview

This is the validation interview to be used for the master thesis of Allard Brand: "Smart integration of electric vehicles within the electricity system: Towards a reference architecture for charging electrical vehicles"

12.4.1 Name

12.4.2 Profession

12.4.3 Company

12.4.4 Date

12.4.5 Years of experience

Years of experience in the energy sector	
Years of experience in the electric mobility sector	
Years of experience in (enterprise) architecture	

12.4.6 Agreement to be listed

I agree to be listed in the master thesis with my name, profession and company, in the chapter concerning the validation of the reference architecture

- ○ Yes
- ○ No

12.4.7 Design choices

In the reference architecture, smart charging is implemented according to the use-case of 'demand-response charging', where the integration between electric mobility and the electricity system is solely based on price signals. The concept of demand-response implies a "bottom-up" approach, where customers become active in adapting their consumption patterns. How do you evaluate this design decision in light of the architectural drivers? How do you evaluate the degree in which the reference architecture supports the use-cases identified in Figure 70? Would you agree that the reference architecture reflects the demand-response approach for charging?

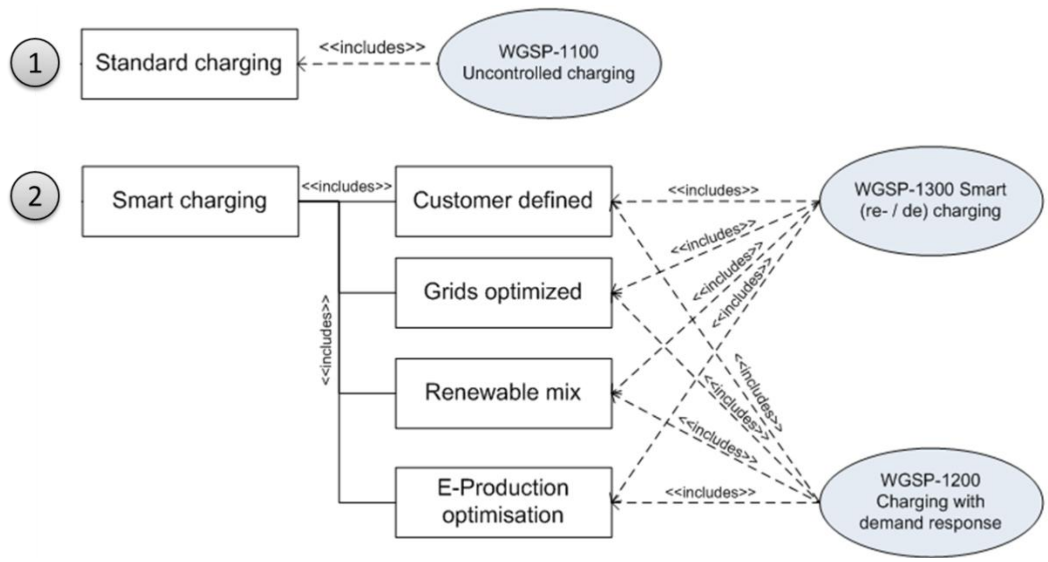


Figure 60: Use cases for charging electric vehicles (CEN, CENELEC & ETSI, 2012)

In the current situation and energy markets, the small-scale flexibilities cannot be integrated easily. An intermediary solution where small-scale are aggregated into substantial flexibility offerings could be desirable. For the migration architecture, smart charging is implemented according to the use-case of 'controlled charging'. The main idea is that in this approach, a new market role is introduced, which is the role of 'aggregator'. The aggregator is responsible for summing up flexibilities from several customers, and actively participates in energy markets or other commercial transactions to market these flexibilities. The customer itself does not directly participate in flexibility markets, but provides the aggregator access to control its flexible resources.

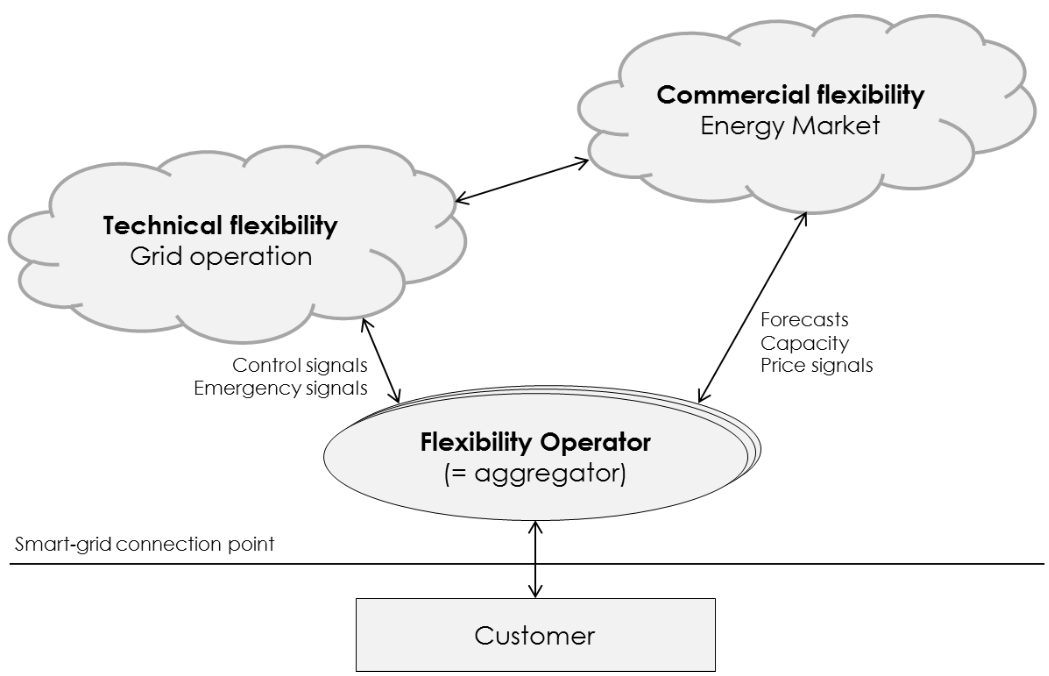


Figure 61: Flexibility operator gathering flexibilities; adapted from (CEN, CENELEC & ETSI, 2012)

This scenario implies that the charge point receives control signals from a secondary actor and performs the charging process accordingly. In the current situation, where charge points are centrally managed by a charge point management system, this would result in the following (high-level) architecture:

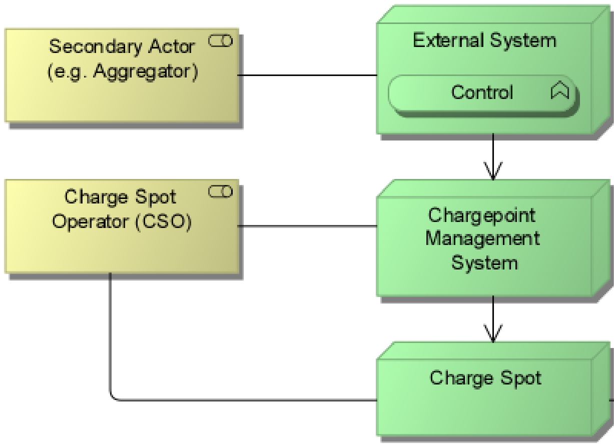


Figure 62: Control from a secondary actor

How do you evaluate this design decision?

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In the current scenario, the charge spot operator (CSO) has an energy contract with the energy supplier; therefore a revenue flow exists from CSO to energy supplier. However, in reality, the energy is offered to the customer during the charging process. In order for the customer to compensate the CSO for the energy, the charge service provider (CSP) mediates between customer and CSO. The customer has a service contract with the CSP, which charges the customer based on the charging session duration and power. Since it is legally not allowed to resell energy, the CSP applies hourly rates.

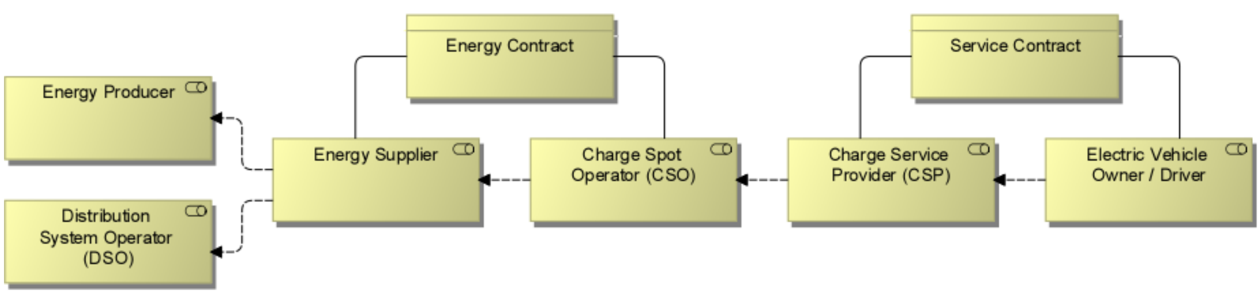

Figure 63: Revenue streams in the current situation

We argue that the current model is inadequate in several ways. One could argue that the structure as depicted in Figure 63 is rather oblique, since even though electricity is legally not being resold, this is essentially still the reality. In addition, customers have no ability to choose their own energy supplier when charging. Also, a relative long chain of cash flows or revenue streams has been identified, resulting in several cost locations for the end customer. Would you agree that the current model is inadequate?

In the reference architecture, the charge service provider (CSP) is removed as a separate role; its responsibilities are assigned to the energy supplier. This results in a simplified model, as depicted in Figure 64.

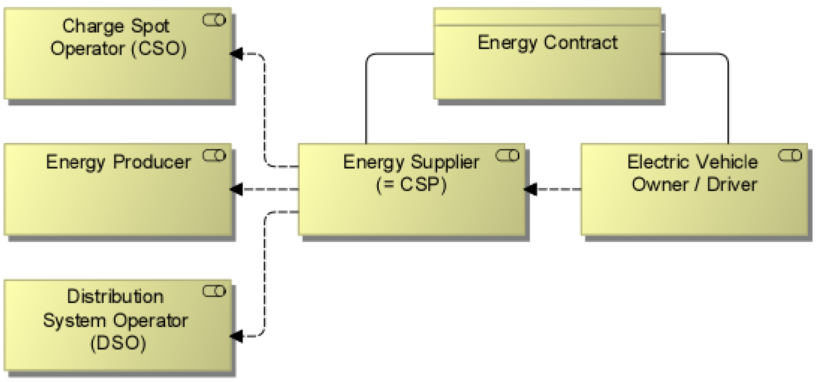

Figure 64: Revenue streams with energy supplier as CSP

The main reasoning behind this design decision is to reduce the complexity, increasing the similarity between electric mobility and the current household scenario. How do you evaluate this design decision? What advantages and disadvantages can you identify?

In addition, another step in simplifying the business model could be applied. In the current situation, the role of 'Charge Spot Operator' (CSO) is a separate role; however, when looking to reference markets, it could be argued that this responsibility could be assigned to one of the already existing roles. Two models can be thought of:

1. The 'DSO model', where the DSO acts as CSO
2. The 'ATM model', where the energy supplier acts as CSO

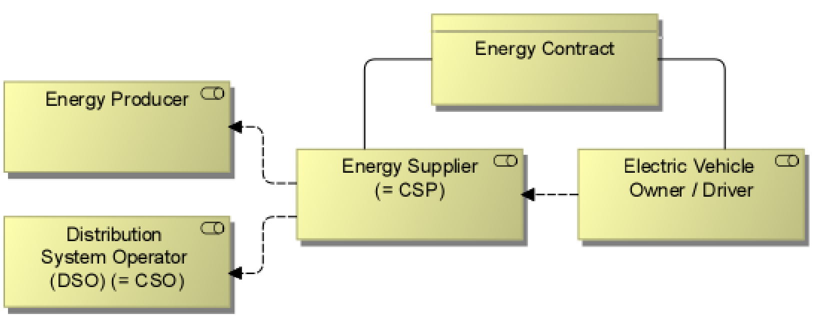

Figure 65: Revenue streams in the 'DSO model' (complies with the current household situation)

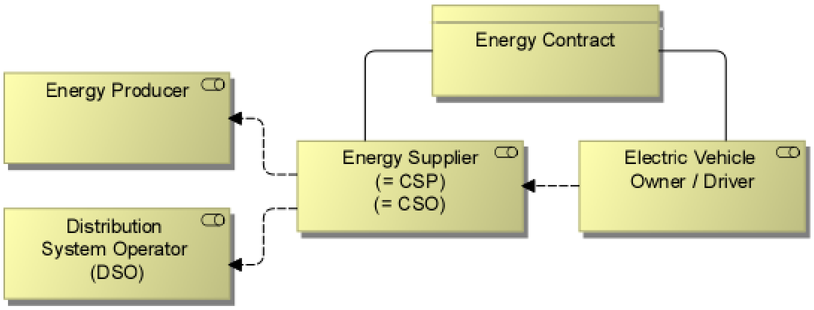

Figure 66: Revenue streams in the 'ATM model'

In the current scenario, metering is done inside the charge point, and an energy contract exists between energy supplier and CSO. Charge points contain a smart meter in order to meter the total usage per charge point, but also two separate meters for each of the electricity outlets for the metering of charging sessions. This situation is drawn in Figure 67. For the sake of comprehensibility, the figure represents a simplified overview where the role of the clearing house is abstracted into a relationship between CSO and CSP.

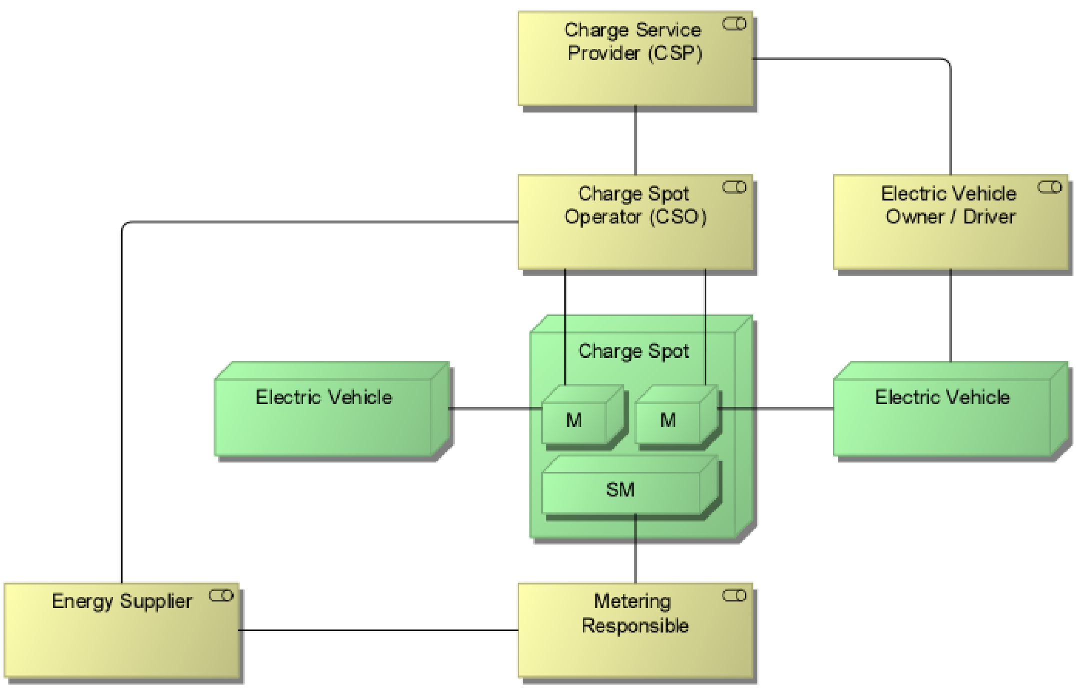

Figure 67: Metering at charge point (current scenario)

In the reference architecture, the 'metered data aggregator' plays an important role (as depicted in Figure 68), which could be fulfilled by an independent party such as EDSN in the Netherlands. In this scenario, the separate meters are replaced with certified smart meters per outlet, managed and controlled by a trusted third party. These meters should replace the current smart meter that provides aggregated meter readings. Based on a shared registry for the metering data of charge points, metering values are exchanged between energy supplier, the DSO and CSO. This situation would be in line with the current "meter values registry" for regular connections. How do you evaluate this design decision?

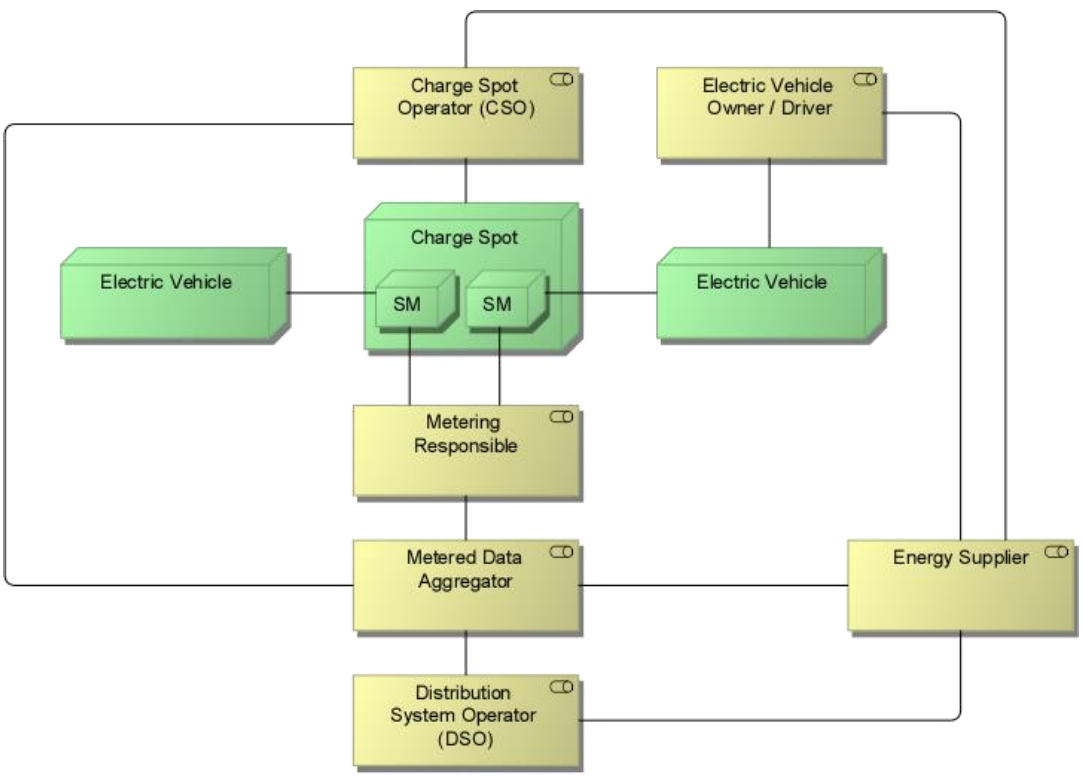

Figure 68: Scenario with a trusted party for sharing metering data

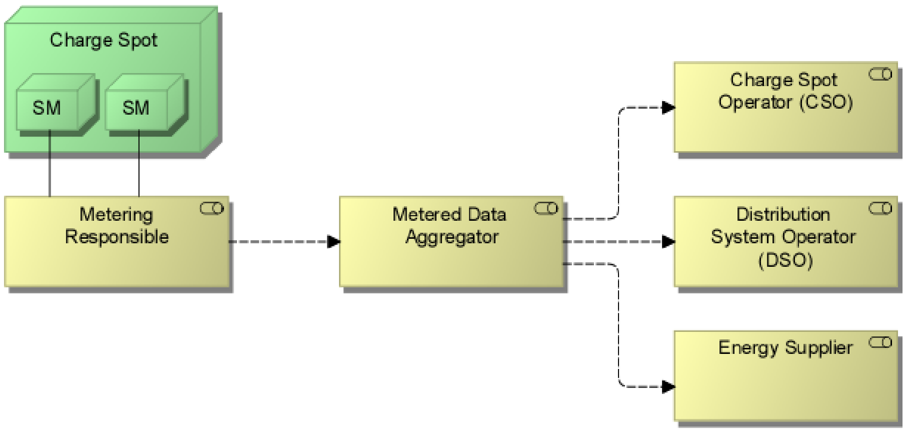

Figure 69: Data flows for metering data in reference architecture

12.4.8 Alignment with objectives

The first objective for the reference architecture is to enhance integration between electric mobility and the electricity system, and reduce the potential impact of electric mobility. When comparing the reference architecture to the current situation, does the reference architecture achieve this objective sufficiently? If so, why; if not, why not?

The second objective for the reference architecture is to enhance integration of renewable energy sources. The reference architecture should depict a situation that drives the integration of renewable energy sources in the energy system. Would you argue that this is the case?

According to Onoph Caron, the director at E-laad, the business case for the realization of charge points has been a negative business case up to now. Would you agree with this statement? If so, what do you think are the main reasons for this, and how could this be solved?

One of goals of the reference architecture is to realize an improved business case for electric mobility. In order to do so, the reference architecture makes use of the flexibility offered by electric vehicles; offering storage capacity for the electricity grid and flexibility in demand. Would you argue that this could indeed improve the business case for electric mobility? What would be the boundary conditions to do so?

12.4.9 Quality attributes

One of the buzzwords in enterprise architecture is interoperability. Would you say the reference architecture helps to increase interoperability between the relevant market roles?

The reference architecture aims to provide a clear and holistic view of both the areas of electric mobility and the electricity system. The aim is to describe the various components and, basically at one glance, tells what it is all about. The architecture compresses a fairly large amount of information into a set of models, whilst at the same time maintaining clarity. How do you evaluate the clarity of the reference architecture?

A reference architecture should have the right level of granularity; providing both a holistic view and sufficient level of detail at the same time. Would you argue that the reference architecture provides this right level of granularity? If not, what could be improved?

Can you identify any mistakes or wrong assumptions in the reference architecture? Are there any modifications that you would like to see reflected in an improved version?

Would you argue that the reference architecture is complete and covers all relevant items? Can you identify any missing aspects that you would like to see reflected in an improved version?

The main goal of the reference architecture is to provide a relevant and potentially beneficial framework to the involved stakeholders. Would you argue that the reference architecture fulfills this goal? Would you consider the reference architecture of use for yourself?

Although the reference architecture is theoretical and based on current research, the reference architecture aims to reflect a feasible situation. Do you think the reference architecture outlines a situation that is feasible? If so, in what timeframe do you expect that the reference architecture could be realized?

G. Interview reports

G1. Andre Postma (Enexis)

According to Andre, electric mobility does not form a threat to the electricity system at all; the market just needs to ensure that it can handle all of the events that come towards it, whatever they may be. The growth of electric mobility is no different from the problem of aging assets; it is possible to provide a solution. We need to properly examine the developments in the market and choose the right solution; solving the 'problem' in the most efficient way. The orthodox solution is to invest a lot of money in expanding assets; the question is whether this is a smart solution or not, which is one of the main ideas behind the developments within the area of smart grids.

The smart grid ideology is not part of the current architecture for electric mobility at all. The first projects in order to realize public charging infrastructure purely focused on charge facilities without load management. However, the premise has always been that this architecture needs to evaluate into an integrated solution. Andre has been able to convince the top management of Enexis of the importance of electric mobility, precisely because of the future potential of load management. However, the roadmap towards this situation contains several stages. Electric vehicles should be considered as one of the enablers to really get smart grids off the ground.

Currently, the debate about market roles for electric mobility is huge. At the moment I'm participating at the highest European level of standardization. At this level, we are busy with naming conventions for market roles on two levels: the technical committee eight from the IEC, and the e-mobility group coordination group on basis of the European mandate M/468. In both cases we are trying to achieve unity in naming. Andre is part of both groups.

Andre mentions that the role of 'charge service provider' (CSP) is unclear, since it might also mean that it provides infrastructure. Currently, most parties agreed on the naming convention of 'e-mobility service provider' (ESP). This role does not only provide customer cards, but does much more. These services include the procurement of energy, the provision of parking services, reservation services, and sending signals in order to realize smart charging. Andre mentions that in the model for sustainable processes (based on M/490), it is assumed that two markets will exist, namely a grid and an energy market. A flexibility operator is positioned in between and acts on these two markets, combining the wishes from these two markets and translating it into a flexibility contract towards it clients. The ESP can be considered as this flexibility operator. Whenever the ESP is large enough, (e.g. over 10,000 customers), it can bypass the energy supplier (retailer) and directly access the wholesale and balancing markets. This could make a much better business case for an ESP. In addition, the role of 'clearing house' will evolve in the future, and include much more types of information exchange. Data such as the time of the day, duration, place, power and available flexibility all need to be exchanged, and should all be cleared. In essence, all data that is required for a smart grid needs to be included.

Andre mentions that in the latest reports from both Eurelectric and EDSO, the ESP is regarded as the final end user of electricity. This means that the driver of the electric vehicle is not the end user of electricy, nor the CSO. According to Andre, this needs to be corrected in the reference architecture. The ESP can acquire its energy through an energy supplier (retailer) but may also directly engage on the energy market. The ESP provides a service package to its customers, of which one of the parts is the provision of energy. Since this is the model as approved by Eurelectric, it means that stakeholders from over the entire energy sector agree, which is an important step.

Andre does not believe in the effectiveness of price-based incentives from the DSO. According to him, the incentives that a DSO can issue are so small, that no customer will react to it. Even when the price of transport would be increased in tenfold, the customer is unlikely to respond according to Andre. In order to justify his statement, Andre mentions the following estimation of the current cost structure for charging:

Item	Cost price	Expressed in terms of
Transport	€ 0,02 – 0,03	kWh
Energy	€ 0,05 – 0,07	kWh
Taxes	€ 0,15	kWh
Infrastructure	€ 0,15	hours
Parking	Significantly higher	hours

Table 15: Cost structure for charging service

If we need to steer on basis of transport incentives, no customer will react. My vision, and the vision of Enexis, is that this will not work. Giving the transport away for free has no effect on the total cost for the charging service, so the only possibility is to adjust upwards. We do not assume this is a realistic situation. The only way this can work is by translating it into a flexibility contract with an ESP. Price incentives do work in academic studies, but in practice you need a tenfold increase to have little effect. Studies in adjusting schedules for washing machines result in the same conclusion, if you do this on the basis of price signals, people do nothing. However, if you offer people a contractual agreement of unburdening, people are willing to participate.

For the reference architecture, both types of signals need to be implemented. According to Andre, four types of signals can be exchanged: status signals, price signals (incentives), control signals, and emergency signals. The difference between emergency and control signals is that control signals are sent towards a flexibility operator, and emergency signals directly into the grid. You need to implement both control and price signals because solely working with incentives will not work for the DSO. According to Andre, price signals are exchanged between the energy market and the flexibility operator, and control signals between the DSO and the flexibility operator. A flexibility operator may choose to send either control signals or price-based incentives to its customers. This is subject to the type of flexibility contract it has with its customers. Andre refers to call plans for mobile phones, which exists in all shapes and sizes, having specific bundles and/or a credit limit.

Andre agrees that the current architecture is insufficient. Using the current architecture for smart charging introduces a lot of complexity, since the charging spot is allocated to a single energy supplier. In the future, a flexible allocation of energy supplier should be possible. Based on the customer that is connected to the charge point, another ESP and energy supplier might be allocated to the charge point. If there is no vehicle connected, there should also be an energy supplier allocated.

Andre mentions that the reference architecture still refers to a model based on dedicated energy supply. However, the business case for the ESP can be made much more interesting if you can purchase energy in a larger scale, since this implies a different tax rate (saves about 15 cents per kWh in taxes).

In the discussion on market models, Andre mentions that it is important to keep roles separated, since otherwise you would entangle roles and actors. The first step is the definition of a role model; the next question is who will fulfill each of the roles, which results in a market model. Both the DSO and ATM models are different interpretations of the same role model; the same roles are assigned to other parties. It is important to use roles for the reference architecture. When comparing the ATM and DSO market model, Andre recommends the DSO model, since this could drastically reduce the costs of the charging infrastructure. In the current situation, metering and fuses are redundant, which is necessary since the DSO is not the owner of the infrastructure. Another solution would be to introduce service level agreements (SLAs) with CSOs; such a SLA would include a specification of the metering and fuses to be used, and the provision of access to these components for the DSO. On basis of such an SLA, the DSO can offer a reduced tariff for the grid connection, resulting in lower costs as well.

According to Andre, the reference architecture (when adjusting the proposed changes) can indeed realize the objectives of a better integration with the electricity system, the integration of renewable energy sources and an optimization of the current business model. In the current architecture, system balance is provided by the BRP; this involves hundreds of millions of transactions every year. By using flexible load management, a significant part of the imbalance can be settled, which is worth a lot of money. According to Andre, storage should be avoided if possible, since storage means a loss in efficiency. Load management is the preferred solution, since this involves significant lower costs.

Andre mentions that the greatest risk of integrating wind energy is surplus capacity at times of low demand. This problem can be seen in different countries. The current solution is curtailment, which means that the windmill is physically turned off. However, if you are capable to create demand in times of surplus capacity, you could make a business case for wind energy operators. The reference architecture can therefore definitely result in a better integration of renewable energy, but also improve the business case for the realization of charging infrastructure. However, in order to do so, it is important to have sufficient cars. In the case of implementing 10 GW of wind power in the North Sea, a surplus capacity of 3 GW would be a realistic scenario. In order to cope with this capacity, you need at least one million cars that are capable of charging with 3 kW of power. However, cars with more power are emerging (up to 22 kW nowadays). Since a wind farm of 10 GW will not be realized today or tomorrow, you do not need one million cars either; this can increase synchronously. However, people need to realize the potential of electric vehicles. Consider for example the case of changing the demand of refrigerators, washing machines and dryers; you need a serious amount before this would offer enough flexibility. The flexibility of an electric vehicle is enormous when compared to the flexibility within households. The integration of solar energy is a different story, since this is bound to local net constraints, which is more difficult to realize.

G2. Arjan Wargers (E-laad)

Arjan confirms that the current situation has been modeled correct. When explaining that one of the decisions behind the reference architecture involves that customers get a customer card from their energy supplier to charge their electric vehicle, Arjan mentions that you should actually implement it the other way around. Arjan agrees with Andre Postma that the charge service provider (CSP) should be the final end user of energy, which purchases electricity on the market. The CSP sells the energy to its customers in the form of a service that partly consists of electricity, but also involves access to the charging infrastructure, the ability to make reservations, etc. This situation is depicted in Figure 70. It makes a significant difference whether one is talking about a formal supplier or not, since in the case of a formal supplier, the supplier requires a supply license. This implies that every CSP has to act in accordance with the rules of an energy supplier, which would restrict the parties that can act in the market for electric mobility. Arjan argues that this is not a good idea.

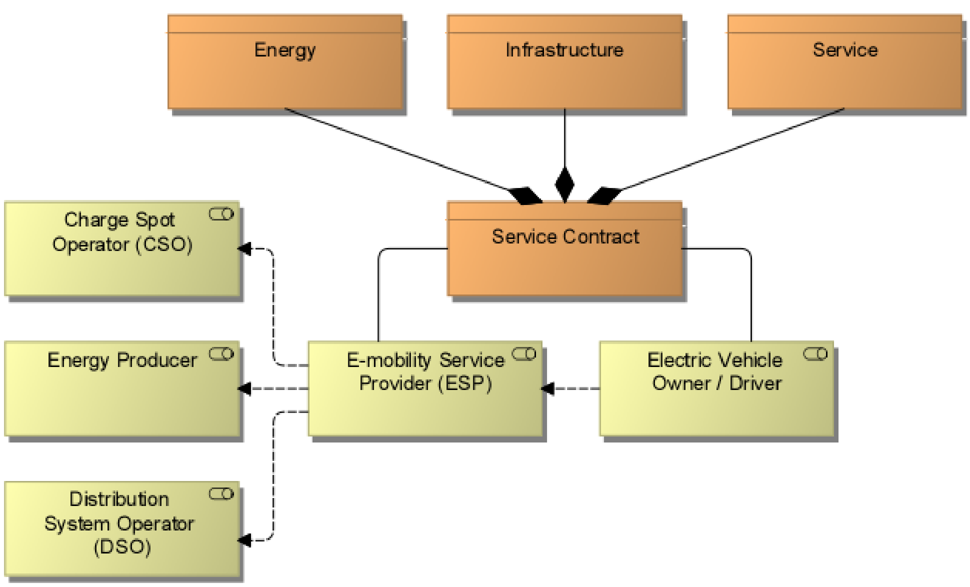

Figure 70: Contract structure and revenue streams according to Arjan Wargers

Arjan mentions that the role of 'charge service provider' (CSP) does not fit very well and that most parties agree on the naming convention of 'e-mobility service provider' (ESP). As mentioned previously, an ESP may not simply sell energy to its customers. There are two possibilities; it either purchases its electricity from a formal energy supplier or it purchases it directly from producers through the market. Arjan is not 100% sure whether the last option is allowed and mentions that in any case, it is wise to separate the roles of ESP and energy supplier. In this situation, an ESP could take the role of energy supplier as well, or an energy supplier the role of ESP.

In the discussion on price versus control signals, Arjan mentions that it would not be a wise plan to start with control signals, except for private and/or semi-public environments. When considering parking lots at major retail chain, control signals could help to charge electric vehicles within the available capacity, and customers will understand this limitation. However, if you introduce grid control without price incentives for public charging, you have to explain a lot more when compared to working on basis of variable prices. The story that flexibility is worth economic value is much easier to accept than the story in which we tell that we 'check' or 'control' the whole situation. Arjan mentions that we actually need both control and price signals. Arjan refers to the traffic light model, in which the green situation refers to a 'carte blanche' situation for the ESP. In the orange situation, we run into grid limits, and a negotiation will occur with all cars that threaten the electricity system: 'who wants to be flexible?'. Arjan thinks that this should always begin with price incentives, also for the technical capacity. Technical signals (from the DSO) must, according to Arjan, start on the basis of price incentives. From a customer perspective, this will increase understanding when electric vehicles need to charge at decreased power.

When mentioning that there are still two possibilities of how to communicate with the customer (based on price and/or control signals), Arjan mentions that he believes that for the time being, the flexibility operator (in this case, the ESP) will send control signals towards its customers so that it can offer flexibility on an aggregated level. According to Arjan, ESPs should be able to compete with each other partly based on how they handle flexibility. However, at the same time Arjan mentions that he prefers a situation in which the customer decides (whether or not by means of an automated agent) whether to charge or not, based on a price incentive. A separate entity such as a flexibility operator is more to (temporarily) solve the situation technically. In an ideal situation, we should allow the customer to respond until an emergency situation occurs and intervention is needed. In order to do so, a regulatory framework is very important. The system or distribution operator needs to have control, but this should be regulated in such a way that this can only occur in emergency situations; the basis should be price-based incentives.

When discussing the design decision of a shared metering registry, Arjan mentions the example of EDSN. In the current energy market, EDSN acts as a central data hub, forwarding messages and performing switches, etc. For the case of electric mobility we also have various stakeholders that want to exchange information; the charge spot owner (CSO), the DSO, CSP and/or other third parties. If you compare this with the energy system, one would expect a party similar to EDSN that mediates between CSO on one hand and all other relevant stakeholders on the other hand. This party should offer a platform that executes the forwarding, tracking and logging of all data that relates to the charging of electric vehicles; in other words, a kind of 'data hub'. To conclude the discussion, Arjan mentions that a central metering registry is indeed desirable in order to support a choice between various energy suppliers. According to him the current situation is odd, since the final customer has a choice between various CSPs but not between energy suppliers, this implies that the market is currently not that 'open' anyway.

Regarding the realization of charging infrastructure, Arjan mentions that given his experience and cost of capital at E-laad, the only way to finance the public charging infrastructure is on basis of the DSO model. This model implies that the realization of charging infrastructure has to be done by an independent facilitator party (in this case, the DSO), and that on top of this layer, a free market should be realized. The current situation implies redundant fuses and metering. In the case that the DSO owns the public charging infrastructure, this redundancy can be solved. At the same time, Arjan argues that the separation between CSO and CSP is artificial and theoretical. According to Arjan, it is very strange that even though the CSP 'has' all the customers, it has little power in the infrastructure chain. In most markets (such as the banking and telecom sector), the one that owns the contracts with the end customer has the most power in the chain. Arjan concludes that he prefers the DSO model, but in the case that we (as the Netherlands) want to stick to leave everything open to be a free market, the model in which the roles of CSP and CSO are merged (the ATM model) is a very good option.

According to Arjan, the reference architecture does indeed enhance the integration between electric mobility and the electricity system. Instead of renewing cables to support peak loads, loads can be shifted when electric vehicles are integrated in an intelligent manner. According to Arjan, there is more than enough capacity at other, non-peak moments, which offers a significant incentive to shift demand. The integration of solar and other renewable energy sources (RES) increases the complexity of balancing supply and demand, and thus increases the incentive for a situation in which one can influence demand even more. According to Arjan, the reference architecture therefore certainly contributes to an improved integration of RES.

When discussing the objective of improving the business case for public charging infrastructure, Arjan mentions that this completely depends on how wide one draws the scope. Currently, the realization of charging infrastructure in itself does indeed involve a negative business case. One of the reasons he mentions is that public charging may not result in substantially higher costs when compared to charging at home. The small margins that are currently made on top of the electricity price result in a difficulty to earn money. However, according to Arjan, there is a huge potential when imbalance can be reduced and electric vehicles can be used as storage capacity. The situation as depicted in the reference architecture, where the interests of relevant stakeholders are merged, can result in a significantly improved business case.

G3. Paul Broos (Eneco)

Paul confirms that the current situation as depicted in the presentation is right. Paul has one comment, which is that the ‘clearing house’ of the current situation is not a clearing house in the formal sense, since there are solely bilateral settlements between the involved parties. The current ‘clearing house’ (CIR) is mainly used for authentication and should be considered as a system instead of a role.

Paul mentions that the starting point for the current model was to realize a model for electric mobility on top of the current electricity system, without having to radically adjust the current situation. Electric mobility is therefore realized as a chain on top of the already existing energy chain; this makes it a complex story.

When discussing the design choices behind the reference architecture, Paul mentions that the aggregation of the roles of charge service provider (CSP) and energy supplier coincides with the discussion that currently runs about being able to switch between energy suppliers at public charge points. Paul refers to the positioning paper from Eurelectric that outlines a model where the energy supplier is altered (‘switched’), based on the preferences of the customer. In this model, the CSP is renamed to ‘e-mobility service provider’ (ESP), and is the central pivot of the whole story. The role of energy supplier is legally speaking a classic party. Paul therefore proposes to say that the ESP will take a number of tasks from the traditional supplier; it aggregates and clusters the flexibility of its customers. Any balance thereof will come in the traditional energy system; the ESP purchases energy, runs the financial risk and can ‘play’ with the flexibility of its customers on the day itself.

Paul agrees that eventually, ‘smart charging’ has to happen by means of price incentives (as is the case in the reference architecture), since otherwise you get a 'big brother is watching you' situation. However, in the current electricity market, the main principle is that electricity demand has to be predicted and purchased in advance; there are financial risks involved in order to keep the electricity system in balance. Paul does not dare to say whether real-time pricing will be path that we need to take, since real-time pricing is so fundamentally different when compared to the current situation.

Paul mentions that he is part of a working group that looks at the potential for a grid market, an actual discussion that is also mentioned in the current research. According to Paul, it is generally assumed that the ESP will translate (price) signals from the distribution system operator (DSO) and the energy market to the customer. In the present situation, a fixed rate for grid capacity is used in the Netherlands; the DSO can therefore not directly work with price incentives towards customers. An ESP could however step into a contract with the DSO and translate the interest from the DSO into (price) signals. In this case, the role of 'flexibility operator' is integrated in the role of e-mobility service provider (ESP). This implies that the current role of the charge service provider (CSP) will change significantly. In the current situation, small businesses can become CSP and give out customer cards. However, this will change soon, since in order to be competitive, knowledge of the energy sector will be needed.

Paul expects a mixture between the two models for smart charging; he expects price signals to be given from a flexibility operator (as mentioned previously). Paul mentions that in 2050 everything is indeed likely to be real-time. On a short timescale the role of 'flexibility operator' is however a more practical form. If you look at 'stroomopwaarts' and its impact on the current electricity systems, changes like this involve millions of investments. In addition, the market needs a long period in order to be able to convert. This confirms the reasoning behind the reference and migration architectures as proposed in the current research. Paul mentions that until we can apply real-time pricing, a flexibility operator can offer flexibility contracts that can be compared with subscription plans for mobile phones. Subscription plans such as 'bronze', 'silver' and 'gold' include a certain amount of flexibility, and include the ability to override this flexibility for a single (or more) instance(s).

When discussing possible market models, Paul mentions that there are strong arguments for the socialization of the public charging infrastructure (as in the 'DSO model'). However, when the consequence of this model involves that the costs for the infrastructure end up for the whole population (even them without an electric vehicle), people will start to complain. From a practical perspective there is very much to say for the DSO model, but it is a very sensitive discussion at the same time. In order to realize an infrastructure where the customer can use its debit card at a charge point, an investment of about € 500 is needed for every charge point; this is not an option. Paul mentions that the roles of ESP and CSO could be merged (as in the ATM model); however, the roles should still be kept separate in the reference architecture. As an ESP you can choose to realize charge point; this should however not be required.

In the discussion about the design choice of a shared metering registry, Paul confirms that such a registry should be realized indeed and refers (again) to the discussion about 'switching at the pole' that currently runs. The registry should keep track of the consumption of different energy suppliers (or ESPs); based on this registry the usage of the energy suppliers can be set off against each other and be settled subsequently. Paul mentions that in addition, a CSO also needs its 'own' energy contract since the charge point also uses energy in 'stand-by' mode (when no electric vehicle is connected).

In the evaluation of the reference architecture on basis of the objectives, Paul mentions that the question whether the reference architecture will result in an increased adoption of renewable energy sources (RES) is very interesting. Paul is not sure whether this will happen, since real-time price incentives are still miles away. A flexibility operator can only react on the flexibility that is linked to RES when acting on the balancing market, but this is very risky. Prices can in- and decrease very strongly on this market; so on one hand this is very interesting and can result in significant financial benefits, on the to other hand you need to know exactly what you are doing. You need to react quickly enough and take the financial risks that are involved. However, this might yield a pretty competitive situation for the role of ESP, since some ESPs might dare to go beyond the other.

According to Paul, the reference architecture will indeed result in an improved integration with the energy model, since the current model is very rigid. The situation as sketched in reference architecture is much better because it offers the ability of improved control.

In the discussion about improving the business case, Paul confirms that the current business case for public charging infrastructure is negative indeed. According to Paul, the total costs of ownership for a public charge point for several years are about six to eight thousand dollars. The situation as depicted in the reference architecture can surely contribute to a more positive business case; but Paul does not dare to say whether it can turn it into a completely positive one. In addition, Paul mentions that regulation is extremely important, municipalities determines what one can and cannot do. Regarding the application of vehicle-to-grid scenarios, the number of charge cycles that the batteries inside electric vehicles support need to be improved first. In the current situation, about 2,000 charging cycles can be performed for a Nissan Leaf, and about 10,000 for a PHEV such as the Opel Ampera. When you would allow an electric vehicle to discharge at a charge point; you will currently reach this amount very soon.

G4. Pascal van Eck (University of Twente)

When explaining the background and structure of the reference architecture, Pascal wonders how the customer is defined in the current research: who exactly is the 'electric vehicle owner / driver'. According to Pascal, one can find a 'Greenwheels' car in almost every single street in Amsterdam. In addition, Pascal mentions the example of car2go, a start-up that provides electric vehicles at a fixed rate per minute throughout the city of Amsterdam. In general, one can find a 'Greenwheels' car parked closer than its private car. Pascal mentions that it is undeniable that a group of people in the cities exists that will less attach to a car that is privately owned, and asks whether this group of people is included in the current research as well.

In the discussion about options for 'smart charging', Pascal mentions that he believes the most in price incentives for controlling demand, but since he has no experience in the energy sector this is preference is unfounded. Because of the low level of experience in the energy sector, we decide to focus the interview on the construction and structural validity of the reference architecture.

In the remainder of the interview, several aspects of the reference architecture are analyzed at which Pascal gives his judgment. These aspects include clarity, level of detail, correctness, completeness, usefulness and the practical feasibility of the model. Pascal mentions that it is a positive thing that the application layer is relatively abstract and does not contain a high amount of 'blocks'. It gives a clear overview, although the relatively low amount of blocks is almost suspicious. Pascal mentions that I should not pretend that this is a comprehensive, all-embracing overview of the required applications, but that only the relevant and interfacing systems are modeled on a high-level. In order to support the process of metering, many more applications are needed than just a single 'metering registry'; however, these have been abstracted into a single entity. Pascal argues that although the level of abstractness fits the phase and purpose of the reference architecture very well, this should be made more explicit.

A downside of the reference architecture is the amount of arrows in the reference architecture; there are far too many arrows according to Pascal. He advises to make a second variant of the reference architecture (a second 'viewpoint') with much less arrows, since for some stakeholders a simple graphic may work a lot better than the reference architecture as currently modeled. Pascal mentions that it can be useful to use different models for different purposes. To judge the correctness of the reference architecture, Pascal mentions that it would be interesting to investigate to what extent the reference architecture reflects reference architectures of reference disciplines such as the banking sector.

Pascal confirms the usefulness of the reference architecture, since sooner or later, organizations want to have this type of models as they need to work together or exchange information. The reference architecture helps to create a common language, and can help organizations in order to open the discussion. Questions like 'what application do you use to realize the customer management system?' can be asked on basis of the reference architecture, and help organizations to implement the model.

According to Pascal, the practical feasibility of the reference architecture largely depends on the willingness of the stakeholders; the period until 2025 is a very long time.

G5. Gerrit Fokkema (EDSN)

Gerrit agrees that electric vehicles offer a lot of (potential) flexibility, but mentions that the challenge is to actually use this flexibility. Gerrit wonders why we cannot use an ordinary debit card to pay at charge points, and refers to the model we currently use for unattended petrol stations.

According to Gerrit, controlling the charging process (i.e. 'smart charging') is mainly about technique, it is something one can do separately from the financial flows. At the same time Gerrit mentions that incentives should naturally be linked with the financial flows. Gerrit explains that as a customer, you want to be able to charge your vehicle when you need it and know when it is fully charged. The need of the distribution system operator (DSO) is to steer in this process. If there is a high amount of energy supply via solar panels, you can transfer the energy directly into the car and do not need to send it any further upwards the electricity grid. Based on this discussion, I explain that there are three main interests, the wishes of the customer, the DSO and the actual supply / demand of (renewable) energy.

In the current situation, the DSO cannot issue any pricing incentives. Gerrit raises the question why one would put a 'rod' in the hands of the DSO, with which it can influence the charging process. According to Gerrit it is all about finding the balance between the requisites for an efficient utilization of the electricity grid and the legal task the DSO has to provide a 'sufficient' level of infrastructure. Gerrit agrees that in the end, citizens of the Netherlands pay for the infrastructure, and that it would be beneficial for all to use this infrastructure efficiently. Gerrit mentions that it is still important to consider whether one would put the ability to control and restrain the flow of electricity in the hands of the DSO. Gerrit mentions that there is already another incentive from the energy supplier, which is the prevention of imbalance; and prefers to realize the balance of the electricity system in the market. At the same time, Gerrit realizes that the interests of the DSO may be contrary to the balance of the energy system, which is part of the motivation behind the current research.

Gerrit mentions that in the situation as depicted in the reference architecture, the DSO needs the ability to give 'local' price signals that are bound to a certain region; this introduces additional difficulties. We need a network tariff that is bound to both the time and place of use. In the current situation, we have a fixed network tariff that is based on the principle of solidarity: 'we do it together and therefore it is payable'. If you remove this principle, the role of DSO will radically change, and might have to split up in more regional-based operators.

In the Netherlands, we used to pay for the volume of electricity that was transported over the network. However, in 2009, this model has been changed into a capacity based model, where you pay for the connection that has been realized for you. In the future, problems will emerge in the current electricity system, and a flat fee is therefore no longer sufficient. However, how can you link the grid tariff in a fair way? You want to link the tariff to customer behavior, based on usage per unit of time. However, at the same time one should not pay for the behavior of its neighbors. This raises a difficult issue; in a situation where everyone can respond to price incentives it is fair to apply (near) real-time pricing and flexible grid tariffs. However, we currently have a capacity based rate, and the story as depicted in the reference architecture does not fit very well in the current situation. However, as soon as everyone is able react, it will be a neutral component on basis of which everyone can steer. Based on this discussion, Gerrit argues that the model should be neutral to all customers.

In the discussion about the options for 'smart charging', Gerrit raises the question why one cannot simply provide its charging needs at the charge point itself. The charge point could display a menu with various options such as 'fast charging', 'charge as cheap as possible' or with a predetermined time of departure. In addition, Gerrit mentions that the aggregator can take the role of energy supplier and/or charge spot operator (CSO) as well. Suppose you have over a thousand of charge points; based on this infrastructure you have some flexibility to offer to the electricity market. In other words, why would one not merge the roles of CSO and flexibility operator (i.e. aggregator)? Gerrit agrees that he prefers the use of price signals, since market functioning offers a simple mechanism to reach the objectives of 'smart charging'.

Gerrit mentions that even though he understands the origins of the current model, he agrees that the current situation is not a smart way to address electric mobility. According to Gerrit, the current model is a little overdone. In addition, Gerrit confirms that the metering is currently performed redundantly; the DSO 'owns' a smart meter and in addition, two non-qualified meters of the CSO are present. Gerrit agrees that it would be an improvement to be able to use the customer card from your energy supplier; however, he would like to take it another step further and offer the ability to use your debit card at charge points.

In the discussion and validation of the reference architecture on basis of the objectives, Gerrit mentions that a free market with price-based incentives (e.g. prices based on electricity volume per unit time) fits the best. Technically, the situation as depicted in the reference architecture is feasible. However, Gerrit mentions that although price incentives offer a viable instrument, a change in mindset is a significant and necessary step. It is important to migrate to regional price incentives in such a way that everyone will think and act in a regional and (near) real-time basis. According to Gerrit, the adoption of renewable energy sources (RES) can be increased, as long as legislation supports in doing so.

G6. Theo Fens (Delft University and UCPartners)

According to Theo, the model of the current situation has been outlined correctly. In the current situation, a party such as Essent puts down charge points. However, one could imagine that there a separate company with the role of aggregator and/or facilitator will emerge, that provides charging infrastructure that is not associated with a single energy supplier, but dynamically allocates the energy supplier that is associated with the customer card. This would improve the process of 'sourcing', since this could make it less complex to predict usage (the energy supplier can predict usage on basis of the daily driving distances of its customers instead of the occupation of charge points).

In terms of market structure, it would be very useful if you align electric mobility with the current structure of the electricity system. In the current electricity system, system balance is mainly performed on basis of usage predictions (the so-called 'E- and T-programs'). However, you have to keep the market open and free; any party requesting authorization should be able to become energy supplier and/or realize charge points. This may result in the fact that the companies that realize charge points purchase and sell their own energy. In this case, they will probably buy their energy on the wholesale market and not through the established energy suppliers (retailers), since this would mean that they have to pay the retail price.

Theo explains that we have three stages in the balancing process in the Netherlands: primary, secondary and tertiary control. Primary control (also referred to as regulating capacity) concerns the national frequency power control, an automatic system that constantly monitors the frequency of the electricity network. Power stations are automatically adjusted on basis of this system. Secondary control (also referred to as reserve capacity) concerns the interventions that are performed when the primary control mechanism cannot handle it anymore. This stage is partially performed automatically and partially by hand, and involves the up- and downward adjustment of demand and/or supply. This works on basis of contracts. Tertiary control (also referred to as emergency capacity) is executed when we exit the range of power reserve (one should think of over 100 MW). This control also works on basis of contracts; very heavy loads or close plants are started and/or stopped. This can include power plants that are already running at a low level, but also include the start-up of additional gas plants (which can quickly start). The main story is that with each of the control stages, balancing the system is becoming increasingly expensive. In the Netherlands we have codes 0, 1, 2 (regulating capacity = 0, reserve capacity = 1 and emergency capacity = 2). On top of this structure, we have an emergency system. In this situation we cut off loads, where hospitals are cut off last. This involves real blackouts; whole grid sections are cut off. This is why we have to balance the system, and is the background for importance of the E- and T-programs.

In the current situation, E- and T-programs are made for every 15 minutes. In the intraday markets, prices may vary per 15 minutes. In theory, the systems (like the APX) are prepared to organize the market around these 15-minute timeslots ('Programma Tijdseenheid', PTE); however, this is currently not done.

Theo mentions that the current research is very useful, since the transition towards electric mobility must be done in a managed way. For someone who drives about 20,000 miles a year, the standard annual consumption of electricity might double and will have a significant impact on the electricity system.

In the discussion about the two ways for 'smart charging', Theo asks who will close the energy contract with the end customer? Theo mentions two models; one model in which the aggregator offers its services to energy suppliers, and a model in which the aggregator has a direct contract with the end customer. In the first case, the aggregator could offer energy suppliers the service for the operational control of a specified number of connections. The DSO may be willing to pay for this service, since it is important for the DSO to ensure grid stability. Theo mentions that we are actually talking about program responsibility at a DSO level instead of TSO level. In the second case, the aggregator has a contract with the end customer itself; and purchases electricity itself. According to Theo, the most sensible option is not clear yet. The question is whether we stick to the current model, or apply a new model. Theo agrees that an aggregator could physically control charge points with agent technology.

According to Theo, both control and price signals need to be implemented. Grid management activities involve control signals, since these are 'hard' technical constraints; 'local T-programs' to prevent the electricity grid from overloading. If one stays without these technical boundaries, price signals can be used. Theo refers to the traffic light concept. The DSO does not provide price incentives but hard (operational) stimuli, since the DSO may not exhibit commercial activities. Theo mentions the difference between technical restrictions and commercial needs. The DSO pays the aggregator for the service, not for the volume of electricity. In other words, technical flexibility is a service (service) that should be offered for a fixed rate. On the other hand, we have commercial commodities, which involve the amount of kWh delivered at specific time. According to Theo, the aggregator can send both price and control signals to its customers; Theo refers to traffic light model again. Within the grid capacity the aggregator gives either price or control signals; beyond grid capacity control signals should also be possible.

When discussing the current situation, Theo confirms that the model as currently applied is not very smart from a management and economic point of view. The responsibility of the DSO currently stops at the connection of the charge point to the electricity grid; which results in redundant metering. This implies that for every charge point, an unnecessary smart meter is installed (about €70 each). Theo mentions that in the past another model has been proposed in which the charge point is technically equated to a meter, not in home but down the road. This model has been rejected. The model essentially involved a similar situation as applied for households. We have thought about this model for about ten years, so why don't we apply this for electric mobility as well? Theo mentions that for installation of metering devices for households is also performed by installer X, Y or Z, and not the DSO itself. One could even imagine a model in which external companies manage the charge points; however, the technical responsibility still lies at the DSO. Theo prefers a model in which the DSO is responsible for the realization of public charging infrastructure; however, when this is not accepted, regulation and standards should be made for metering in such a way that various parties, including the DSO, could read the meter.

When validating the reference architecture on basis of the objectives, Theo argues that the reference architecture depicts a beautiful combination of dynamic demand and supply management, which is not based on profiles but on the actual balance between demand and supply. When the wind starts blowing, I can dynamically adjust the cars that are currently charging. Theo mentions that shifting demand is preferred above storage, since everything you do not need to store is profit; at the moment you store energy this implies a loss of efficiency. One critical note that Theo makes is that in order to realize the reference architecture, one should pay attention to the administrative processes that are involved, for these processes might be the most difficult to realize.

Theo agrees that the reference architecture can result in an increased adoption of renewable energy sources (RES), since it might solve intermittency problems; stochastic behavior is suddenly something you can utilize. Theo mentions that the reference architecture does not necessarily help in preventing the electricity network from overloading (since this is something that one wants to prevent at all times anyway), but that the electricity network can be utilized more efficiently. When discussing the business case, Theo mentions that an important reason for the negative business case is the small amount of electric vehicles driving around. According to Theo, achieving an economy of scale is a very important aspect in the success of electric mobility and the public charging infrastructure. As soon as we have a million electric vehicles, the business case is suddenly very different.

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