Zero Emission Urban Bus System

Business cases for electric bus charging operation

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Jussi Ikäheimo (VTT) Marcus Jones (TRL) Denis Naberezhnykh (TRL) Ana Garcia (Endesa) Mario Canet Sabate (TMB)	VTT

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Zero Emission Urban Bus System

SUMMARY SHEET

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Abstract	The report studies the roles of different stakeholders, such as distribution system operators, charging operators and bus operators, involved in provision of flexible charging for electric buses and the related business models. Quantitative revenue analysis for selected business models is performed.
Key words	Electric vehicles, power grid, power markets
Thumbs Index	

INTERNAL DISTRIBUTION

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Entity	Short name	Country	Contact person
European Commission DG-MOVE	EC DG-MOVE	-	Mr Alain Van-Gaever
European Commission DG-MOVE	EC DG-MOVE	-	Mr. Jose Fernandez Garcia
European Commission DG-MOVE	EC DG-MOVE	-	Mr. Hugues Van Honacker

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#	Participant Partner Name	Short Name	Country
29	Teknologian tutkimuskeskus VTT Oy	VTT	FI
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SEVENTH FRAMEWORK PROGRAMME

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ACRONYMS

AMI	Advanced Metering Infrastructure
AS	Ancillary Services
BM	Balancing Mechanism
BRP	Balancing Responsible Party
CENELEC	European Committee for Electrotechnical Standardization
CHP	Combined Heat and Power
CSO	Charging Supply Organisation
CWE	Central Western Europe
DER	Distributed Energy Resources
DG	Distributed Generation
DR	Demand Response
DS	Distributed Storage
DSI	Demand-Side Integration
DSM	Demand-Side Management
DSO	Distribution System Operator
EE	Energy Efficiency
EMS	Energy Management System
EN	European Standard (developed by European Committee for Standardization)
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCR	Frequency Contrainment Reserve
FCR-D	Frequency Contrainment Reserve - Disturbance
FRR	Frequency Restoration Reserve
HV	High-voltage
LBR	Load Balance Responsible
LV	Low-voltage
PTA	Public Transport Authority
PTO	Public Transport Operator
PV	Photovoltaic (power generation)
RES	Renewable Energy Source
RTP	Real-time Pricing
ToU	Time of Use
TSO	Transmission System Operator
UCTE	Union for the Coordination of the Transmission of Electricity
V2G	Vehicle to Grid
VG	Variable Generation
VPP	Virtual Power Plant

Project funded by the European Commission
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CONTENTS

1. EXECUTIVE SUMMARY

Providing the driving energy for electric buses is the major barrier for their deployment. Electric bus chargers are relatively large power electronic loads, which can be quickly controlled. A number of business models for flexible charging of electric buses at the depot exist. Because buses can be thought of as electricity storages, the business models are largely the same as electricity storages in general. However, the normal business of the bus operator should be respected and greatly affect the business models.

The roles of different stakeholders are discussed in the report. The central role in charging control is that of the charging supply organization, which is in charge of planning charging schedules and offering the charging flexibility to upstream energy markets. This role can be assigned to an independent company or e.g. energy supplier of the depot. Other stakeholders include the distribution system operator, bus operator and public transport authority.

Simulations were performed to quantitatively study selected business models in the Nordic market environment. Both overnight charging and opportunity charging were considered. The resulting savings in energy and power-related costs (not inclusive energy taxes) ranged from less than one percent to eight percent. Both historical and simulated future market prices were used in the simulation.

2. INTRODUCTION

2.1 Background

Electric buses are quickly becoming mainstream in public transportation. Providing the driving energy for electric buses is the major hindrance for their deployment. The bus may rely on overnight charging, which requires a very large battery weighing up to two tonnes or more. On some routes a battery of practical size may not be enough for daily driving. Deep cycles (exploiting nearly all of the battery capacity) also decrease the lifetime of the battery. On the other hand, the bus may rely on charging along the route (so-called opportunity charging) (Gallo et al. 2014) or at end stops. This requires expensive high-power chargers and slows down the bus on its route. Indeed, not only is the energy storage a problem but charging electric buses can also represent a challenge for the grid.

Fortunately, charging buses can also represent an opportunity for electrical power systems (Wu 2013). This is because batteries are electrical energy storages and there is flexibility in the charging process. The flexibility – the ability to change the charging pattern rapidly in time and space – carries value in the power system. For example, if charging can be postponed during peak load and the use of expensive gas turbines can be avoided in power generation, system costs can be decreased. How this value can be collected in practise for the benefit of those parties who invest into and operate the electric bus infrastructure, is the subject of this report. The magnitude of the added value is also studied.

From the electrical energy system point of view bus charging comprises demand response (DR) and the various tools and methodologies developed for DR can be applied. Demand response (DR) refers to the ability of loads to quickly respond to power system needs. Other terms such as load flexibility and active demand mean roughly the same thing, whereas demand side management (DSM) is a wider term, where also the longer-term goals of strategic load growth and strategic load decrease are included. Within demand response resources, different degrees of freedom of control exist, as shown in Figure 1. Bus charging would reside in the “buffered” category.

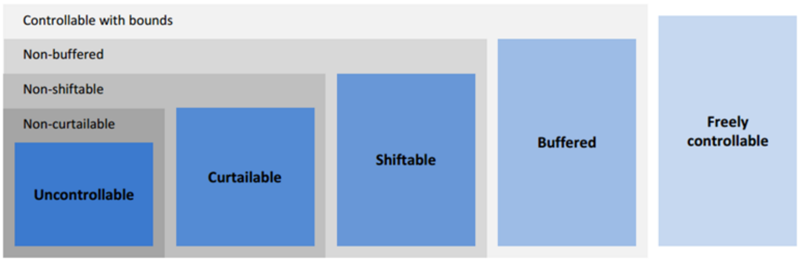

Figure 1. Categorization of flexibility resources according to the freedom of control by the CEN-CENELEC-ETSI Smart Grid Coordination Group (CEN-CENELEC-ETSI Smart Grid Coordination Group 2013).

Bus charging takes place in the environment, which has been set up by the involved companies and authorities, guided by the local legislation. The environment varies considerably from one city and country to another. The differences can concern e.g. ownership of assets, the degree of competition, grid tariffs, grid connection costs, energy markets, etc. Figure 2 shows an example of what actors (companies or other organizations) could be involved in different stages of the bus charging process. The roles of different actors may be different than shown in the figure and are discussed in the next chapter. The central actor from the point of view of this report is the charging service operator, which is also called charging supply organization (CSO) in this report.

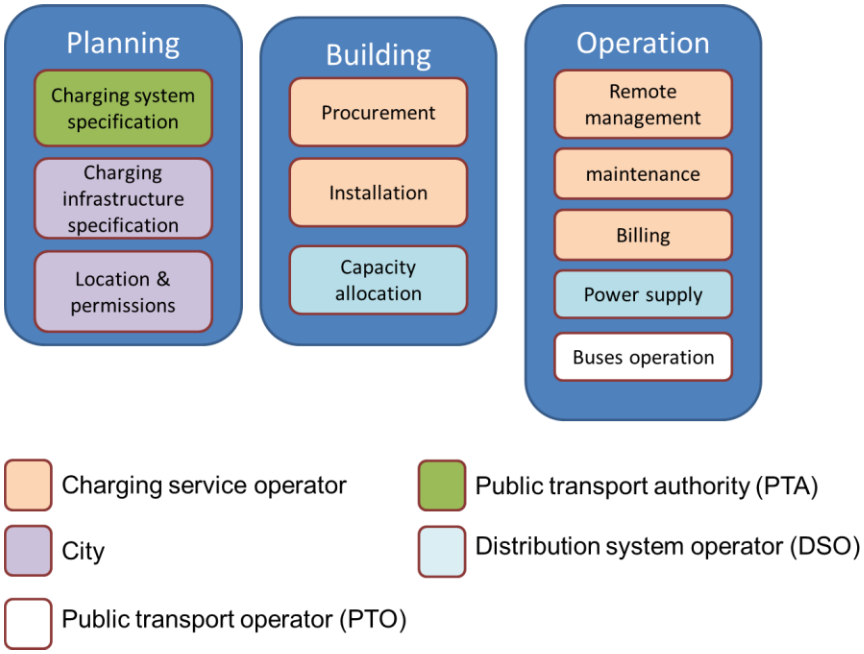

Figure 2: Different actors and their possible roles in different stages of the charging process (Laurikko et al. 2015).

In addition to variations in how the elecricity supply market operates in different countries the structure of the potential market for bus charging is made more complicated by the signficant differences that exist between cities in how bus services are regulated and delivered and how highway infrastructure is governed. There are wide variations in the extent to which public transport authorities have responsibility for providing bus services, whether operators are publicly or privately owned, and in the relationship between public transport authorities and highway authorities, which are not necessarily the same body. These differences all have implications for how a potential service might be set up, introducing a wide range of different types of contractual structures, and also affecting how the incentives, costs and benefits of any new business model are shared between different bodies, and between the public and private sector. It is not therefore possible to develop a single model that could be adopted everywhere; however consideration has been given in this report to how these different structures could influence the types of model that might be considered.

2.2 Drivers of the flexible charging business

2.2.1 Power price volatility

Due to the "compression effect" of variable generation, the profitability of base load and mid-merit generation will be decreased in a renewable power system (Helistö et al. 2017). If power is priced according to the marginal cost of the most expensive generator, the price will more often be either close to zero or very high, depending on if peak load generators are in operation or not. The presence of different types of energy storages can alleaviate this phenomenon.

2.2.2 Distribution network voltage variations

As the electric buses appear to be on the edge of mass market adoption, DSO's are facing new challenges and opportunities due to the fact of recharging them through the local electricity grid. Some of the effects of integrating ebuses can represent opportunities to use these as distributed storage devices that support power systems operation. Electric buses can potentially be an attractive form of responsive demand that can be used to provide operation flexibility. This flexibility takes a more prominent role due to forecast uncertainties and variability related to intermittent generation and demand, which are expected to increase the need for flexibility in future power systems (Coppola et al. 2012).

2.2.3 Frequency deterioration

Frequency deterioration caused by shifts in generation and reduction of load self-regulation is likely to continue. The following challenges will amplify this trend (Statnett et al. 2016) :

- Faster, larger and more frequent changes in generation and power flow will further exacerbate real-time imbalances.
- A significantly higher proportion of the generation portfolio will be directly weather-dependent, as well as less predictable, less flexible and less controllable.
- Periods with few hydro power plants with reservoirs in operation, which makes it difficult to source a sufficient volume of frequency containment reserves and down-regulating resources.

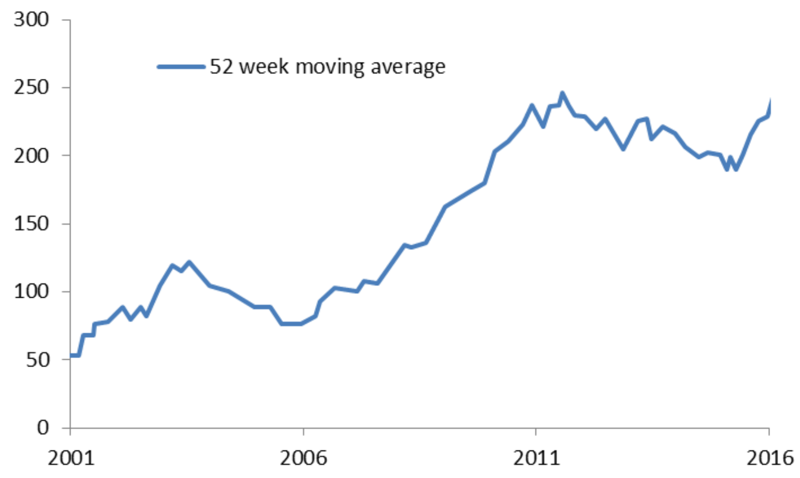

Figure 3: The number of minutes per week the Nordic grid frequency has spent outside the normal frequency band (49.9–50.1 Hz) as function of time (Statnett et al. 2016).

3. STAKEHOLDERS IN THE BUSINESS MODELS

According to Freeman (2010) a firm's stakeholder could be any group or individual who can affect or is affected by the achievement of the firm's objectives. In case of the flexible bus charging, the important stakeholders are:

- charging supply organization (CSO) (charging operator)
- public transport operator (bus operator)
- public transport authority (PTA)
- distribution system operator (DSO)
- transmission system operator
- electricity retailer
- balancing responsible party

Other stakeholders include market operators, possible technical integrators (e.g. the flexibility gateway mentioned below).

3.1 Role of the Charging Supply Organization

The charging supply organization (CSO) or charging operator is a role which can be taken by a separate company or by an existing company such as the electricity supplier. The charging supply organization must

1) forecast the needs for flexibility in different types applications on different markets,
2) makes sure (together with DSO) that that the provision of services complies with the operation of distribution grids
3) makes contracts with grid operators and other participants for provision of flexibility; participates markets in case organized markets are present
4) follows the grid tariffs and retail tariffs
5) follows electricity consumption in each bus route
6) optimizes the charging schedules of buses according to the offered services, possibly in real time

The task of installing and maintaining the charging equipment could also be given to the CSO company. In this case, the CSO should pass the costs to the bus operators in a transparent manner. A conflict of interest may arise in the case if the CSO decides the charges paid for charging infrastructure and optimizes charging schedules.

3.1.1 Ownership structures

Several different arrangements for the infrastructure ownership and operation are possible. For example, the number of bus operators and the ownership of the charging equipment can be different in different European cities. For example, in Barcelona there is only one bus operator, who also owns the depots. In London there are several operators, who each have their own depot. In Helsinki region there are several operators and a number of depots, some of which are rented by the city to a single operator, and some are used by several bus operators.

The alternative with least risk to the bus operator is if the PTA or city makes the investment to the charging equipment. This is the normal alternative with roadside chargers but is also possible with depot charging. However, the alternative suffers from the poor standardization situation of electric bus charging systems. Bus operators would possibly be restricted to certain few bus models which are compatible with the chosen charger or forced to request expensive modifications to the charging interface. The alternative is also most natural if the PTA or the city owns the depot.

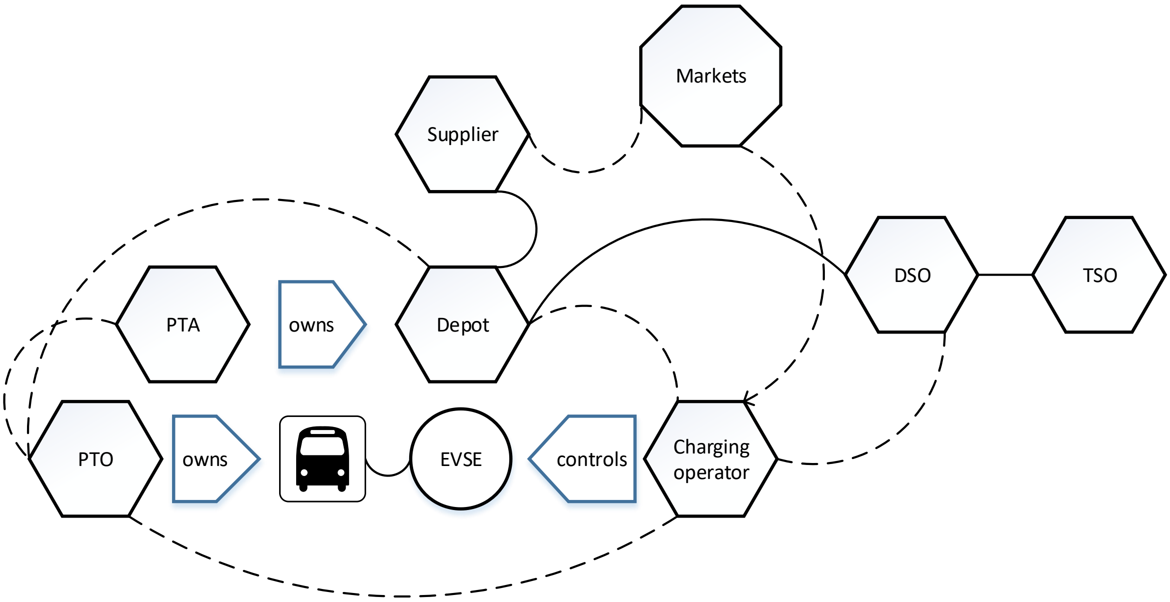

Figure 4: The ownership structure and communication pathways in electric bus flexible charging when the PTA owns the depot and charging equipment.

Figure 4 shows one possible ownership structure and communication pathways between the stakeholders. In this case PTA owns the depot, which is used by many bus operators. The PTO's inform the depot about their charging needs. This information is further sent to the CSO. The CSO inquires the supplier and DSO about their tariffs and control charging equipment accordingly.

3.1.2 Technical capabilities

Standards for electric vehicle charging are developed by IEC technical committee 69. However, we must make a difference between the communication between Electric Vehicles (EV) and the Electric Vehicle Supply Equipment (EVSE), an on the other hand between EVSE and other actors. For example, the standard ISO 15118 specifies the communication between EV and EVSE but does not specify the communication of the EVSE to other actors and equipment.

There is no widespread standard for the upstream communication of the EVSE to other actors and equipment. The Common Information Model (CIM) or Open Automated Demand Response Communications Specification could be used for that purpose. The CSO should be able to receive the following information from the EVSE:

- state of charge of batteries (included in ISO 15118)
- vehicle indentification number (included in ISO 15118)

From the bus operator the CSO must receive the daily schedule of each bus. The CSO can then decide when charging must be ended and possibly also if less than full battery is adequate. Depending on the business model, the CSO must also have automated communication interfaces to the markets where he is participating. In future, the CSO may also have to communicate with the DSO to check possible grid constraints or to sell charging flexibility to the DSO.

The technical implementation of flexible charging may take different forms. Figure 5 shows one possibility where a “flexibility gateway” stands between the CSO and the depot. The task of the flexibility gateway is to provide technical interoperability between different systems, i.e. provide the middleware for technically incombatible systems.

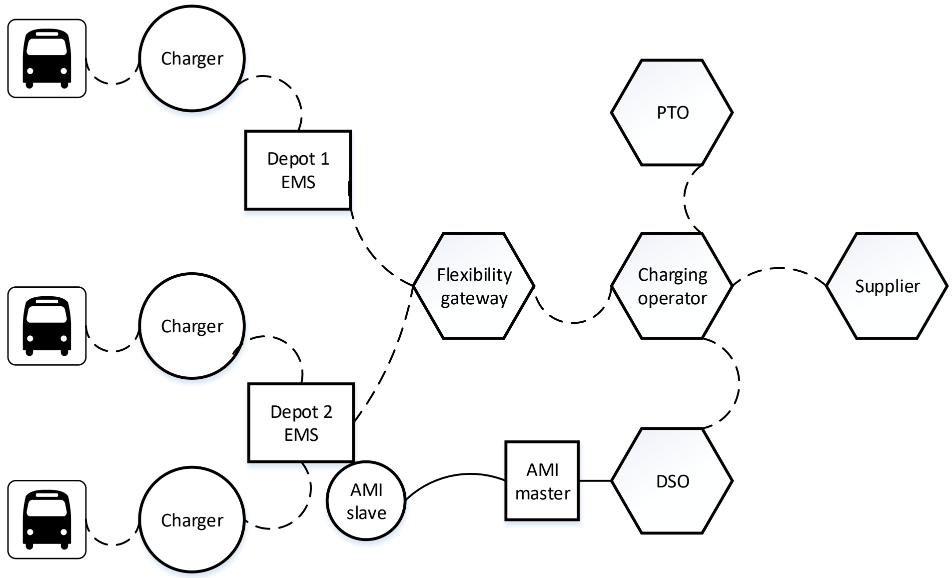

Figure 5: Possible information pathways in the technical implementation of the charging control by CSO.

3.2 Role of the Distribution System Operator (DSO)

3.2.1 The general role

Distribution system operators are responsible for maintaining, expanding and improving the electric network distribution, the grid including cables, transformer stations, supply connections, meters, etc. They are responsible for maintaining the power quality within relevant standards such as EN 50160. In addition, the distributors are responsible for carrying out the meter readings and transmitting them to the supplier that manages the billing. The distribution company is a monopoly and regulated power system participant. In EU, this position was established in the second electricity directive (2003/54/EC), which calls for unbundling of the distribution activities from generation and retail operations.

3.2.2 Responsibilities and priorities, case Spain

Before 2009, the same company distributed and sold the electricity. A separation between both actions was done after the electricity market liberalisation.

The distribution system operators in Spain cannot carry out any activity related to liberalized activities (generation or market). The Spanish law 54/1997, 27th of November, of Electric Sector, establishes that electric energy distribution is a regulated activity, whose economic regime will be subject to regulatory development by the Government of Spain. The following image shows the areas managed by the five distributors that operate in Spain

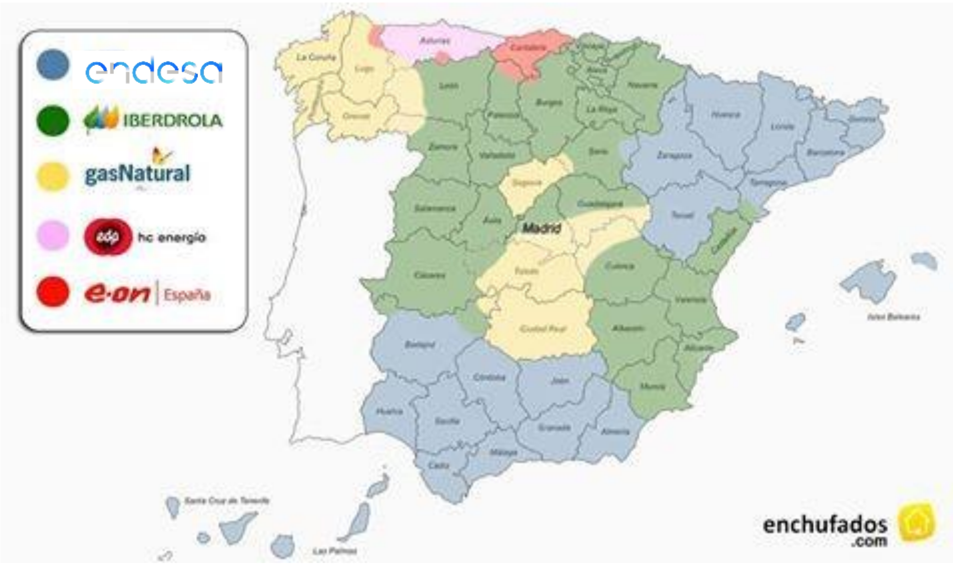

Figure 6: distribution system operators in Spain.

The DSO's functions according to the current regulations are as follows:

- Build, maintain and operate the electrical grids that unit the transmission with the consumption centers.
- Widen the installations in order to attend to new demands for electricity supply.
- Ensure the suitable level of service quality.
- Respond in equality all the demands of electric access and connection.
- Measure the consumption.
- Apply the costs and access fees (grid tariffs) to the consumers.
- Keep the supply points database updated.
- Inform to the agents and customers involved.
- Present annually its investment plans to the Spanish Autonomous Communities.

In Spain, transmission and distribution networks remain under a regulated scheme. For this reason, the grid costs have an effect on each consumer according to its characteristics through access fees, independently its energy contract in the liberalized market or in the regulated market.

3.2.3 Grid tariffs

Case Spain

The regulated grid tariffs (also called access fees and use-of-system charges) in Spain are composed of a power term and an energy term. In this way, the access cost depends both on the consumer's contracted power and on the actual consumption (variable term). The power term constitutes a demand charge, in other words the consumer is charged for the maximum power he needs. In addition Spanish grid tariffs for medium-voltage customers have been arranged as time-of-use tariffs as shown in Figure 7:

Medium-voltage rates							
	Group of application	Power term [€/kW year]			Energy term [€/kWh]		
		Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
3.1 A	1kV < T ≤ 36kV	59,173468	36,490689	8,367731	0,014335	0,012754	0,007805
	Group of application	Power term [€/kW year]					
		Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
6.1	1kV < T ≤ 36 kV	39,139427	19,586654	14,334178	14,334178	14,334178	6,540177
6.2	36 kV < T ≤ 72,5 kV	22,158348	11,088763	8,115134	8,115134	8,115134	3,702649
6.3	72,5 kV < T ≤ 145 kV	18,916198	9,466286	6,92775	6,92775	6,92775	3,160887
6.4	T > 145 kV	13,706285	6,859077	5,019707	5,019707	5,019707	2,290315
	Group of application	Energy term [€/kWh]					
		Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
6.1	1kV < T ≤ 36 kV	0,026674	0,019921	0,010615	0,005283	0,003411	0,002137
6.2	36 kV < T ≤ 72,5 kV	0,015587	0,011641	0,006204	0,003087	0,001993	0,001247
6.3	72,5 kV < T ≤ 145 kV	0,015048	0,011237	0,005987	0,002979	0,001924	0,001206
6.4	T > 145 kV	0,008465	0,007022	0,004025	0,002285	0,001475	0,001018

Figure 7: Regulated grid tariffs in Spain.

There are six time zones in the regulated time-of-use grid tariffs as shown in Figure 8.

6.X														
Hours / Months	January	February	March	April	May	First fortnight of June	Second fortnight of June	July	August	Sept	Oct	Nov	Dec	Weekends and Holidays
H1 (00-01h)	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
H2 (01-02h)	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
H3 (02-03h)	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
H4 (03-04h)	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
H5 (04-05h)	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
H6 (05-06h)	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
H7 (06-07h)	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
H8 (07-08h)	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
H9 (08-09h)	P2	P2	P4	P5	P5	P4	P2	P2	P6	P4	P5	P4	P2	P6
H10 (09-10h)	P2	P2	P4	P5	P5	P3	P2	P2	P6	P3	P5	P4	P2	P6
H11 (10-11h)	P1	P1	P4	P5	P5	P3	P2	P2	P6	P3	P5	P4	P1	P6
H12 (11-12h)	P1	P1	P4	P5	P5	P3	P1	P1	P6	P3	P5	P4	P1	P6
H13 (12-13h)	P1	P1	P4	P5	P5	P3	P1	P1	P6	P3	P5	P4	P1	P6
H14 (13-14h)	P2	P2	P4	P5	P5	P3	P1	P1	P6	P3	P5	P4	P2	P6
H15 (14-15h)	P2	P2	P4	P5	P5	P3	P1	P1	P6	P3	P5	P4	P2	P6
H16 (15-16h)	P2	P2	P4	P5	P5	P4	P1	P1	P6	P4	P5	P4	P2	P6
H17 (16-17h)	P2	P2	P3	P5	P5	P4	P1	P1	P6	P4	P5	P3	P2	P6
H18 (17-18h)	P2	P2	P3	P5	P5	P4	P1	P1	P6	P4	P5	P3	P2	P6
H19 (18-19h)	P1	P1	P3	P5	P5	P4	P1	P1	P6	P4	P5	P3	P1	P6
H20 (19-20h)	P1	P1	P3	P5	P5	P4	P2	P2	P6	P4	P5	P3	P1	P6
H21 (20-21h)	P1	P1	P3	P5	P5	P4	P2	P2	P6	P4	P5	P3	P1	P6
H22 (21-22h)	P2	P2	P3	P5	P5	P4	P2	P2	P6	P4	P5	P3	P2	P6
H23 (22-23h)	P2	P2	P4	P5	P5	P4	P2	P2	P6	P4	P5	P4	P2	P6
H24 (23-24h)	P2	P2	P4	P5	P5	P4	P2	P2	P6	P4	P5	P4	P2	P6

Figure 8: ToU tariff zones applied by Spanish DSO's. P1 is the highest tariff zone and P6 the lowest.

Case Finland

The grid tariffs in Finland are not set by the regulator but the regulator monitors the level of grid tariffs and connection fees in periods of four years. Not only the tariff levels but also the tariff regimes may vary between DSO's. The current monitoring period covers the years 2016–2019. For medium voltage customers the DSO's normally set an energy fee, which can be different at night (normally 22:00 to 7:00) as well as demand charges for both active and reactive power. The calculation rules of the peak power on which the demand charge is based may vary. For example, a certain level of reactive power is normally free of charge. Table 1 shows two examples of grid tariffs of medium voltage customers of two large DSO's.

Table 1: Grid tariff for customers who wish to connect to the medium-voltage network of two Finnish DSO's (Tampereen Sähkölaitos 2017).

DSO	Daytime energy €/MWh	Nighttime energy €/MWh	demand charge €/kW/month	demand charge for reactive power €/kVAr/month
Tampereen sähkölaitos	11.6	7.1	1.34	1.25
Helen Electricity Ltd.	11.4	6.1	2.90	1.99

3.2.4 Connection fees

Case Spain

As described above, the main activity of a distribution company in Spain is to attend to the requests for new supplies or power extensions as established in Royal Decree 1955/2000 and Royal Decree 1048/2013, in its article 21 of the Spanish Legislation.

When a customer requires a new electric power supply, or extend the power available in an existing one, (for example, TMB depot for the installation of charging points for electric buses), a request for supply must be made to Endesa Distribucion Electrica S.L.U (in case of Catalonia), which will usually lead to the execution of a new electrical connection or the adequacy of the facilities of the network to guarantee the power requested. Once the new connections are put into service, the end-users (in this case TMB) will be able to realize their energy contract with a company of energy trader of their free choice. To summarize, the procedure is:

1) Request of a new supply to Endesa Distribucion Electrica (in this case).
2) Analysis of the request by Endesa Distribucion Electrica.
3) Acceptance of the conditions and payment for the works to Endesa Distribucion Electrica.
4) Execution of the connection and commissioning.
5) Inspection and contracting of electrical energy by the final user.

Registering a new supply represents an economic consideration that must be paid to the corresponding distributing company, which is known as connection charges. Prices are regulated by the Ministry of Industry, Tourism and Commerce of Spain according to article 25 of Royal Decree 1048/2013 in case of facilities to assist new supplies up to 100 kW in low voltage and up to 250 kW in high voltage in urban land. When the power limits established in the previous point for urban land are exceeded, the distribution company in Spain will employ tariffs, which are not public. The connection charges can be broken down into four parts, which are extension, access, connection and verification charges. The verification charges are not listed but are of the same magnitude as connection charges.

Table 2: Extension rights: payment for the necessary electrical infrastructures between the existing distribution network and the first element owned by the applicant.

1) Extension rights:	Tension	Extension rights (Euro / kW requested)
1. High-tension Requested power <= 250kW	V <= 36 kV	15,718632
	36 kV < V <= 72,5 kV	15,343534
	72,5 kV < V	16,334353
2. Low-tension Requested power <= 100kW	Extension rights= 17,374714 Euro / kW requested	

Table 3: Access rights: payment for the addition to the network of a new supply or extension of an existing one.

2) Access rights:	Tension	Access rights (Euro / kW requested)
1. High-tension	V <= 36 kV	16,992541
	36 kV < V <= 72,5 kV	14,727812
	72,5 kV < V	10,700842
2. Low-tension	Access rights = 19,703137 Euro / kW requested	

Case Finland

As mentioned above, the regulator does not set the connection fees in Finland but the regulator monitors their level. Each DSO has published formulas for the cost of most common connection types where the price depends on the subscribed apparent power and possibly distrance from the existing grid. Connections in locations which lie further away from the existing grid are normally priced on case-by-case basis.

Table 4: Connection fees for customers who wish to connect to the medium-voltage network.

DSO	Subscribed power kVA	fixed charge €	variable charge €/kVA
Tampereen sähkölaitos	0–800	32430	0
	> 800	14830	22
Helen Electricity Ltd.	0–1000	18 870	0
	> 1000	18 870	10.23

3.3 Role of the public transport authority

Regulation (EC) No 1370/2007 on public passenger transport services by rail and road is of major importance for the organisation and financing of public transport services by bus, tram, metro and rail in the Member States. Its aim is to create an internal market for public passenger transport services. The Regulation achieves this by complementing the general rules on public procurement (European Commission 2017). The regulation allows variations in how public transport is arranged, and consequently the market and regulatory structure for bus services varies widely across Europe, and indeed within individual countries. As a result, the role of the public transport authority also varies widely in the extent to whicih the PTA is responsible for, and able to influence, bus operations. In some cities the PTA owns the bus operator and is responsible for providing services; while in others it specifies services that are contracted to private operators. Where the market is largely dergulated (for example in the UK), it may have only a 'light touch' regulatory role, with private sector operators determining for themselves the services that they run and the vehicles they wish to use; although they may still contract private operators to run subsidised socially necessary services on their behalf (Butcher 2010; Gwilliam & van de Velde n.d.; KPMG 2016). The types of relationships that might exist between PTAs and operators, according to the regulatory regime in place, are described in greater detail in section 3.4.2.

When considering electrically powered buses that may need to recharge on the public highway, or in public transport facilities provided by the PTA, it is also necessary to take account of the differences between cities in how highway infrastructure is governed. The PTA is not necessarily also the highway authority for the roads on which its bus services operate. For example, in London Transport for London (TfL) is the PTA. It is also responsible for the major roads in London; however the majority of roads are the responsibility of the 31 separate London Boroughs. Hence, the provision of on street charging infrastructure would have to be arranged with London Boroughs. Furthermore, while highway authorities will have experience in working with electricity suppliers for purposes such as street lighting and power for traffic signals they will have little or no experience in the higher power connections, and associated contracts and tariff structures, required for large scale bus charging. The complexities of the different relationships that might exist between PTA, bus operator and energy supplier are described in more detail in 3.4.2

3.4 Role of the bus operator

3.4.1 Responsibilities and priorities

Operation of bus service:

- Delivery of bus service in accordance to regulatory requirements, which will vary between cities and countries (see for example (Butcher 2010; Gwilliam & van de Velde n.d.; KPMG 2016)).
- Meeting punctuality targets (i.e. services on time)
- Meeting reliability targets (i.e. services not cancelled)
- Ensuring that buses are driven safely and with consideration for passengers and other road users
- Minimising fuel costs to maintain competitiveness.
- Managing on-bus ticket checks and sales and participating in any local smart ticketing or 'travel card' arrangements

Vehicles:

- Compliance with emission standards and any local restrictions e.g. a low emission zone .
- Maintenance and cleaning of vehicles to ensure availability of vehicles in suitable condition to operate service and to meet regulatory requirements. Operators will usually have their own bus garages for this purpose, but they may be shared. Specialist maintenance is likely to be undertaken by vehicle supplier.
- Provision of particular types of vehicle to meet any contractually required specification, for example in a local authority awarded franchise or concession.

Charging equipment:

- Installing and operating charging facilities at operator- owned sites such as bus garages and dedicated bus stations (usually via a contract with the equipment supplier, but potentially via a CSO, should such a business model develop in the future) at suitable locations where they can be operated safely and efficiently (i.e. ensuring they are accessible to vehicles)
- Ensuring facilities are maintained (most probably via a service contract with equipment provider)
- Ensuring that staff are trained and encouraged to use the charging facilities correctly
- Working with (i.e. agreeing contracts defining tariffs, payment processes, availability of facilities etc) third-party charging providers that buses may need to use, in particular those on the public highway or at publically owned bus stations.

Electricity supply:

- Arranging for suitable commercial power supply connection (with DSO) and contract with an electricity supplier, to provide for vehicle charging in addition to existing workshop/ depot requirements (lighting, heating, workshop equipment), unless a separate CSO is involved.

- Payment of charges to electricity supplier.
- Undertaking any monitoring/ analysis of electricity consumption data from supply company and on site meters.

3.4.2 Relationships with other stakeholders

City/ local transport authority

There is a wide range of different structures for operating bus services both between and within different European countries. For example, in some cities buses are operated directly by the local authority, in others the operator may be a subsidiary company, or they may be run under contract by private bus operators, providing tightly specified services, or even, (as in the UK outside London) by competing private operators running commercially determined services with little regulation (Butcher 2010; Gwilliam & van de Velde n.d.). Furthermore, the local authority will have overall responsibility for any charging equipment provided on the highway or at local authority bus stations and interchanges (i.e. on public land). This means that there are the following potential relationships that the bus operator may have with the local transport authority:

- The bus operator might be part of the local transport authority
- The bus operator might run services specified under contract to the local authority (i.e. the local authority specifies timetables and fares, taking the commercial risk)
- The bus operator might run commercial services regulated by the local authority (i.e. the local authority regulates roadworthiness, emissions, punctuality etc, and may coordinate integrated ticketing, but the operator sets the timetable and fares it considers to be commercially viable)
- The bus operator might use bus garages or other facilities provided by the local transport authority (as is the case in London)
- The bus operator might use charging infrastructure provided by the local authority, on the public highway or bus stations (and in turn, this could be either as a direct relationship with the authority or with a charging provider that works for the local authority)

This wide range in the nature of the relationships between operators and local authorities means that their involvement in the electricity supply market, and the extent to which they might benefit from flexible charging business models, will vary significantly between locations according to how bus services are delivered, funded and regulated. In particular it influences how the costs and benefits of flexible charging business models will affect different organisations, which will have an impact on the way cost-benefit of such services would be perceived by the bus operator and thus affect which services it may be most interested in. For example, an operator that runs services as a commercial operation may have a different attitude towards energy costs than one that runs a local authority service with electricity costs fixed as part of its contract.

Electricity suppliers

Bus operators are not ordinarily large consumers of electricity, their requirements being primarily lighting, space heating, workshop equipment and vehicle washers. So without the requirement for EV charging they would normally have a relatively low power "light commercial" electricity supply and relatively simple contracts and tariff structures. Awareness of energy management will vary considerably between operators – while some may undertake regular energy monitoring to support energy efficiency measures, it is unlikely that this will be a business priority for many and few will work with energy management specialists or have significant in-house expertise in this area. This does therefore provide a potential opportunity for specialist providers to enter the market and manage the more complex requirements and higher value energy contracts that EV charging involves. Such an organisation is the CSO. This would have similarities to the contract energy management companies that serve energy users in other sectors. For example in the UK there are Third Party Intermediaries (TPI) which provide advice on energy efficiency, tariffs and procurement. They exist under a number of different models, usually specialising in particular sectors (OGEM 2015). It would be expected that the TPI sector would need to expand and develop specialised services for bus operators if this market is to become more widespread.

Depending upon the structure of the electricity supply industry in the country concerned, the bus operator would not necessarily have a direct relationship with the DSO for on-site electricity provision, rather they might have a contract with an energy vendor/ supplier who in turn contracts with the DSO for the grid connection. The DSO may also however be the same organisation as the electricity supplier. Furthermore, if a separate CSO were to become involved then contracts for vehicle charging would potentially be via the CSO rather than the bus operator's usual electricity supplier. Regardless of the supply structure, it is important to note that the contract for charging would be significantly different, and more complex, from those the bus industry would traditionally have with suppliers for depot and workshop supply alone.

.Where charging is undertaken both at bus operator and local authority premises, or on the street, a bus operator could potentially have to interact with two or more separate CSOs.

3.4.3 Opportunities and Barriers

The potential to become involved in various forms of flexible charging offers bus operators the benefit of additional income streams, or at least reduced electricity prices through more favourable tariffs. On the other hand, bus operators' primary responsibilities and business priorities are all related to delivery of a bus service to passengers and complying with whatever regulatory requirements they are subject to in their area. A summary of the opportunities and barriers for different forms of charging management is given below.

Opportunities

- Reduced electricity supply prices (better tariffs) from maximising off-peak electricity and being able to offer short-term demand reductions.
- Avoidance of maximum-demand (i.e. peak apparent power) charges.
- Avoidance of Triad charges
- Additional income from demand-management services as per the models being considered, potentially including vehicle to grid.

- Avoiding the need for capital expenditure by bus operators if CSO's are able to provide charging facilities, potentially even the batteries, as part of a service paid for according to usage.

Barriers

- There is no scope for flexible charging during operating hours unless batteries and charging equipment are significantly over-specified for the route being serviced by the buses
- Flexibility in overnight recharging is likely to be short-term only (i.e. for power stabilisation over periods of a few minutes) unless charging equipment (and grid connection) is specified for higher power ratings so that less recharging time is required in total.
- Vehicle to grid capability (effectively doubling the maximum impact of demand management alone) would require greater equipment costs and could potentially cause additional battery degradation.
- More complex energy contracts would require greater management expertise and time and understanding of the potential risks of not being able to operate an electric service if the buses are not being sufficiently charged at night.
- Volatility in short-term electricity prices and in the market for back-up generation capacity exposes the operator to greater commercial risk and uncertain benefits.
- If the bus operator has to work with more than one CSO (for example for both on-site and on-street charging) contractual arrangements could become very complicated.
- There may be unintended consequences from the financial incentives to delay or avoid charging, for example if payments encourage the bus operator to make greater use of diesel, particularly if this occurs at peak times when vehicle emissions are of greatest concern.
- There may be unintended impacts on real or perceived battery degradation and subsequent insurance and warranty costs caused by greater utilisation and cycling of the bus batteries.

3.5 Retailer

The retailer (also called supplier) acts as a link between the power market and the consumer. The retailer procures the electricity from the wholesale market and sells it forward to consumers. The retailers handle the electric supply contracts with the customers and establish the rates and offers for the end-customer. The retailer can also act as the balance responsible party (or load balance responsible, LBR) but in some cases several retailers use the same balance responsible party.

3.6 Balance responsible party

The main task of the balance responsible (BRP) is to make a plan of the consumption and generation for the upcoming day and try to achieve a balance between them. Retailers and generators may outsource their balance responsibility to a BRP (Figure 9). The BRP may use resources such as DR and flexible charging to reduce imbalances in their consumption and generation. An effect, which also bears importance to the BRP is the rebound or payback effect of flexible charging. This effect arises from the fact that modulating charging during one period will invalidate also the planned future charging schedule, causing imbalances for the BRP.

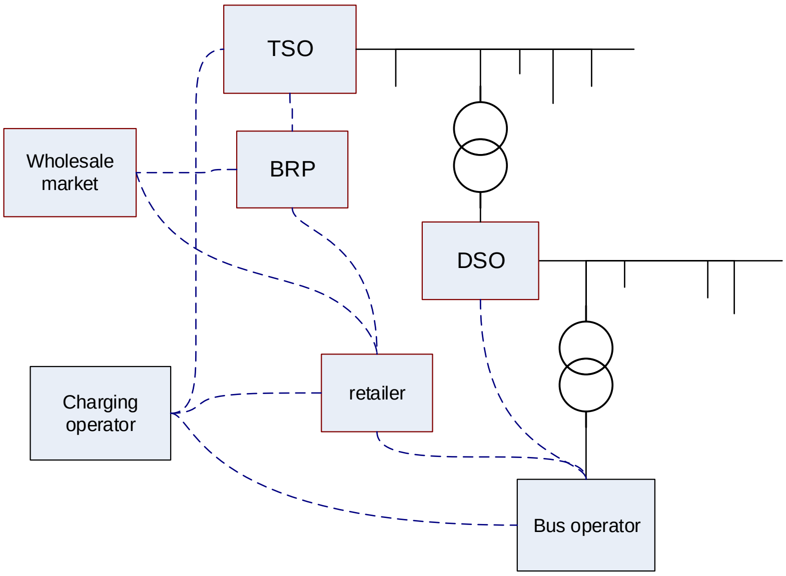

Figure 9: Position of the balancing responsible party among the power system participants.

4. BUSINESS MODELS FOR FLEXIBLE CHARGING

” Business model is generically intended as a framework for the description of the commercial relationships among market entities for creating value to the whole chain of the electricity market. According to Drucker “A business model is nothing else than a representation of how an organization makes (or intends to make) money (Drucker 2006). Here it is intended as a logic of creating value (such as profits to the company, tax income, benefits to consumers, power quality and improved environment), including description of the stakeholders and of their roles and the most important transactions. The core ingredients of a business model are (Ikäheimo et al. 2010):

- actors, such as different companies involved and their roles;
- products, services, such as load modification in certain load area;
- contractual relationships between the actors, including pricing and penalties;
- transactions and flows between the actors: energy flow, information flow, economic flow;
- enabling technologies (non-ICT and ICT), such as sufficient communication links;
- values/benefits for the actors, such as ability to integrate distributed and uncontrolled generation;
- drivers and barriers to the implementation, such as regulatory constraints, to the adoption.

A business model description normally includes also a quantitative evaluation of the costs and income flows of the business. Thus, some people call business model “a story backed with numbers”. Below we first list and then analyze the possible business models for the CSO.

4.1 Possible business models

The CSO must control the charging process within the limits dictated by the transportation need. Most importantly the bus battery must be full enough at the time when the bus leaves according to its schedule. In case of overnight charging the battery must be nearly full in the morning. There are also other limitations which will be discussed below. Within these limitations the CSO can offer the charging flexibility to be used in different applications in the power system. Table 5 lists some possible applications where charging flexibility can offer value. Note that the “scope” for each application in this table could be also defined differently. For example, customers can also participate in frequency and voltage control.

Table 5: Applications in the power system where energy storage can add value (Olivier et al. 2014; Lew 2016)
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	Scope			
	Conventional Generation	Transmission	Distribution	Customer Level
Applications	black start	frequency control	voltage control	peak power cutting
	energy arbitrage	synthetic inertia	contingency grid support	energy arbitrage
	bridging & ramping	improving angular stability	intentional islanding	continuity of energy supply
	capacity		investment deferral	compensation of reactive power
				increased self-sufficiency

- Black start: local storage can provide auxiliary power and help in the process of restoring a power plant to operation. For bus charging this application is generally not possible because the charging station is located in the distribution network.
- Arbitrage: battery storage optimally selects the production/consumption moments according to energy market prices to minimize costs. This is possible both for customer level storages and large centralized storages.
- Bridging and ramping: battery storage can pick up fast load variations giving enough time for a given generator to ramp its production level according to technical limits. This is related to reduction of imbalance costs as explained below.
- Capacity: battery storage could relieve capacity for several hours during peak hours by postponing charging. For bus charging this could be difficult if hybrid buses are not used.
- Frequency control: battery storage can help to maintain the instantaneous balance between system generation and demand. Various different contracts have been defined for this purpose where the response time may be few tens of seconds or more and the response may last up to one hour.
- Synthetic inertia: battery storage simulates rotating spinning mass and feeds or takes out power with very fast response to slow frequency deviation after a contingency event.
- Angular stability refers to the ability of individual synchronous generators of an interconnected power system to remain in synchronism after being subjected to a disturbance.
- Voltage control: battery storage can adjust charging or feed power to the distribution grid to correct poor voltage levels. Alternatively the battery storage can consume or produce reactive power.

- Contingency grid support: : battery storage can provide capacity/voltage support to reduce the impacts of the loss of a major grid component, for example during severe weather.
- Intentional islanding: battery storage can provide voltage/frequency support in case a part of the distrubution grid is isolated from the rest of the grid and continues operating.
- Investment deferral: storage units with a capacity of discharge in few hours can be valorised
- Peak power cutting: battery storage is able to reduce charging or even feed power at times when the depot's total consumption is highest, and thus reduce the demand charges paid to the DSO.
- Continuity of energy supply: battery storage is able to substitute the network for the depot in case of short service interruption.
- Compensation of reactive power: battery storage can supply reactive power and thus reduce the reactive power charges paid to the DSO.
- Increased self-sufficiency: battery storage can store part of locally produced electricity when it would otherwise be fed into the grid. Feeding power to the grid is under current tariff and tax regimes usually not economically lucrative compared to using the power on-site.

When the offered product is demand response, it is often most convenient to distinguish business models according to the markets where the product is offered. Markets do not exist for all the applications which were listed above. In that case it is difficult to know the price which the CSO could receive for providing the service, which hinders quantitative business model analysis. We thus concentrate on services for which markets currently exist. These include energy arbitrage and provision of frequency control reserve.

4.2 Energy arbitrage

Energy arbitrage means consuming energy when it is cheapest and selling it back when it is most expensive. If the charging depot has no vehicle-to-grid capability or it is too expensive, then naturally feeding power back to the grid is not possible; in this case charging is limited to minimum when energy is most expensive. Naturally the limitations set by the normal busines operation of the PTO must be respected.

The retailer of the charging depot must procure the electrical energy for charging from the wholesale market. The CSO can be same company and the retailer but it can also be a third party. In this case the CSO still controls the charging process, which ultimately determines the consumption of the depot during each settlement period which the retailer must procure. Thus, the CSO must in all cases consider the costs from the retailer's point of view because the retailer will try to pass the procurement costs to the consumer (depot). The retailer generally faces a varying power price, which changes from one settlement period to another and may manifest large fluctiations during one day. Consequently possibilities exist for cost minimization.

Similarly, when calculating energy price, the CSO must take into account the variable part of the grid tariff. Distribution tariffs vary from one European country to another and can be e.g. in the form of time-of-use tariff or flat tariff. In the future more dynamic network tariffs are also possible. Energy arbitrage should be distinguished from avoiding other grid frees. Often demand charges, which depend on the maximum power withdrawal, are also included in distribution tariffs. For example, in the project, one demonstration location used a separate battery storage in order to store power during daytime, having then enough capacity for overnight charging.

4.2.1 Market environment

Here we separate two cases: one where the CSO is the retailer and another where the retailer is a separate company. In the first case the CSO operates directly on the wholesale market, whereas in the second case it takes the retail rate structure given by the retailer as given. In both cases, the market environment affects the CSO's energy arbitrage business either directly or indirectly.

The two cases are also linked to two different types of demand response (Eurelectric 2017):

- Under explicit demand response schemes, the result of a demand response action is sold upfront in the electricity markets or as network service to system operators, either directly (for large industrial customers) or through demand response service providers/aggregators (supplier or a third party). Consumers receive a specific reward in exchange for their flexibility.
- Under implicit demand response schemes, consumers can choose to be exposed to time-varying electricity prices that intend to reflect the value and cost (real or expected) of electricity in different time periods. Armed with this information and with the possibility to control their load through automation, consumers can decide to shift their electricity consumption away from times of high prices. They are rewarded for their flexibility by reducing their electricity bill.

Especially the implicit charging flexibility could be implemented by an EMS at the depot without the need for CSO. Explicit charging flexibility is more beneficial to the power market and benefits from the presence of CSO.

The temporal granularity of the retail rates varies. Whereas for small customers, time-varying retail rates are available in relatively few European countries (notably Finland, Norway and Estonia); for medium-sized customers (above 30–100 kW peak power) they are more commonplace. We should, however, note that the time variance can take many forms. The retailer e.g. may offer a time-of-use tariff, which consists of several temporal price zones during the day or week. In France so-called critical peak pricing is available. The depot peak power would easily exceed 500 kW even for a small depot. We can thus assume that the retail rate for the depot varies hourly or with higher granularity.

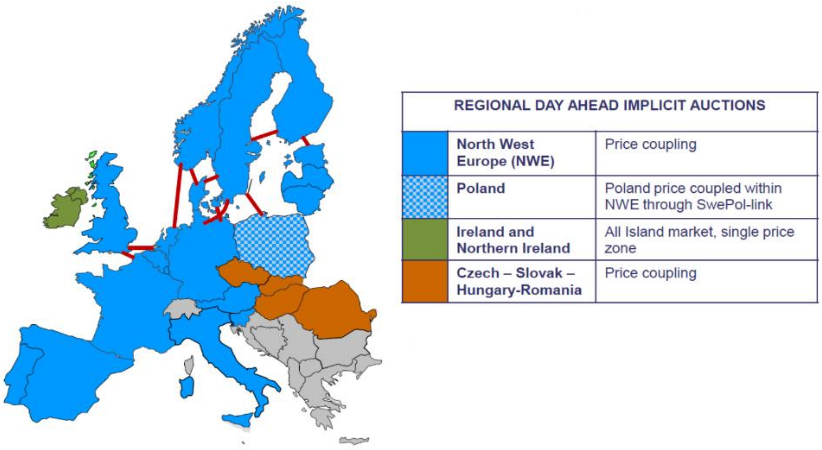

Figure 10: Day-ahead power market price coupling in the EU (Offenberg 2016).

In March 2017 a committee with representatives from all EU member states decided to harmonize the imbalance settlement period in the EU to be 15 minutes. The timeframe of the harmonization has not yet been decided but it will be after 2020. The imbalance settlement period (ISP) is also generally the shortest period at which prices are determined on organized wholesale markets. The ISP is not necessarily reflected in retail pricing. The time periods applied in retail pricing can be longer than the ISP if typical load profiles are used to convert convert the meter readings into the shorter ISP time scale, although the most straightforward procedure is to use the same time period in all stages of the supply chain. If retail pricing granularity is also harmonized to the ISP, this would mean changes to energy arbitrage in many countries.

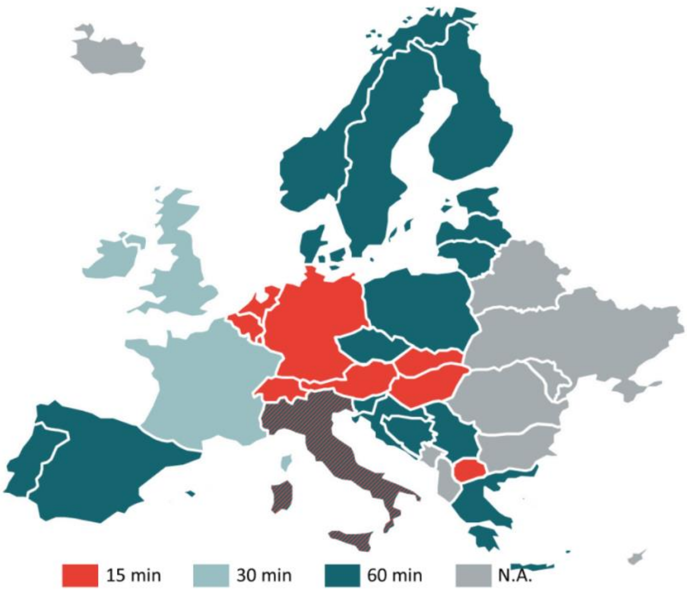

Figure 11: The current imbalance settlement periods in European countries. Italy has a 60-minute ISP with the exception of Balancing Service Providers (BSPs) that are required by regulation to have a 15 minute ISP (Frontier Economics 2015).

4.2.2 Barriers

There is currently no specific European-wide regulatory framework for energy storages. For example storages are not mentioned in Electricity Directive (Directive 2009/72/EC). In Renewable Energy Directive (Directive 2009/28/EC) storages are briefly mentioned in article 16, according to which member states should take the appropriate steps to develop storage facilities and the electricity system. According to Voss (2017) the lack of clear definition for energy storage results in a lack of coherence in the classification of storage facilities into generation and/or consumption across EU member states. It is leading to a series of unintended barriers and thereby creating an uncertain investment environment. In practise, the problem for storage operation may be e.g. that during charging the electricity tax is levied but it is not refunded during discharging.

If the batteries do not feed power back to the grid, from the regulatory point of view the charging flexibility is treated as demand response. European legislator voiced its strong support for Demand Response in the Efficiency Directive 2012/27/EU enabling consumer participation in retail but also wholesale, balancing, reserves and other system services market. For example, according to the Energy Efficiency Directive, article 15 distribution tariffs should not hamper Demand Response.

4.2.3 Income flows

Income flows in this business models come from the price differentials in wholesale price or grid tariffs. The wholesale price variation at night is normally quite low. Figure 12 shows the average diurnal profile of the day-ahead power price in the Nordic countries. We see that the average price during the night when overnight charging takes place is almost flat. The average price, though, does not tell the full story. Examining the night prices from midnight to 6:00 when overnight charging is most active, we find that during 150 nights in 2016 the price differential between the cheapest and most expensive hour was more than 3 €/MWh and during 50 nights the price differential between the cheapest and most expensive hour was more than 5 €/MWh. If buses can be charged during the day, the price differentials are much larger. But on the other hand, daytime charging can offer large reductions in battery capacity, which is a much larger benefit.

As discussed in Section 3.2, the ToU grid tariffs also vary by a few euros per megawatt-hour. In Spain the differential between tariffs P2 and P6 is about 10 €/MWh, and can be applicable in some overnight charging cases.

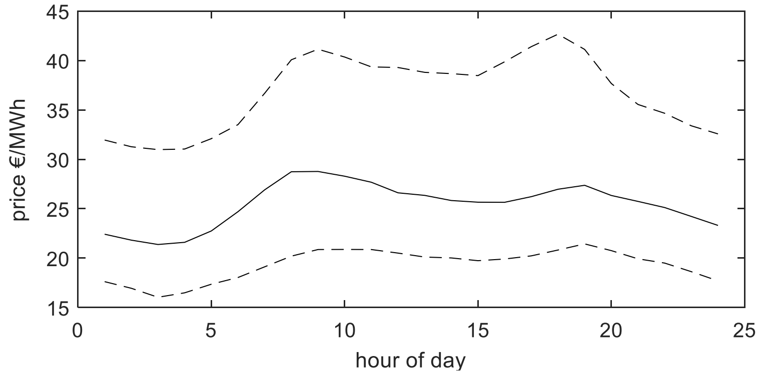

Figure 12: Median and 10 % and 90 % fractiles of the system price in the Nordpool Elspot day-ahead market in 2016 (Nordpool 2016).

Often the price differentials cannot be fully exploited if the utilization rate of chargers is high. In Chapter 5 the income flows are simulated quantitatively.

4.2.4 Technical requirements

The technical requirements of this business model are low. The CSO needs to implement functions, which retrieve the relevant retail and grid tariffs, and optimize the required charging periods according to the tariffs. Assuming that that the CSO already has an automated charging scheduling system, this additional functionality can be implemented in software without further hardware investments. As mentioned above, the CSO also needs information about the charging need of each bus. For some buses, balancing charging might be needed, and this information is also needed in planning charging schedules.

4.3 Operation on balancing power markets.

The bus depot may provide balancing services for the system operator. In this report we define balancing markets as all services, which may be requested and paid for by the system operator during the period of power delivery. This is opposite to organized power markets, which are operated in advance of the delivery period by unregulated companies.Thus the definition includes frequency-controlled reserves and e.g. regulating power markets in Nordic countries.

4.3.1 Market environment

The implementation of balancing power markets varies from country to another. Also the terminology is lacking clarity. Terms such as spinning reserve, standing reserve, operating reserve, minute reserve, load frequency control, automatic generation control, etc. are used sometimes as synonyms and sometimes to mean slightly different services in different countries. ENTSO-E has started the process of harmonizing balancing markets in Europe. As a first step they have defined the three categories for balancing services, which are compared against the control reserves in the continental Europe synchronous grid.

Table 6: Categories of control reserve in the UCTE region and the corresponding ENTSO-E categories (Elia 2013).

Old term	Term by ENTSO-e	Purpose
Primary reserve	Frequency Containment Reserves (FCR)	Contain the system frequency after the occurrence of an incident or imbalance within the Synchronous Area. Frequency Containment is a joint action of all the TSOs of the Synchronous Area.
Secondary reserve	Automatic Frequency Restoration Reserve (FRR-A)	Reserves with an activation time less than 15 minutes which are used to restore the ACE of the control block to zero, restore the system frequency and relieve FCR.
Tertiary reserve	Manual Frequency Restoration Reserve (FRR-M)	Relieve automatic FRR for further imbalances.
Slow tertiary reserves	Restoration Reserve (RR)	Optional reserves with an activation lead time exceeding 15 minutes that have to prepare the FRR for further imbalances.

In Nordic countries the markets for control reserves are somewhat different. There are two types of frequency containment reserves (FCR), one of which is reserved mainly for power plant or transmission line tripping. These are supplied by each TSO separately. Traditionally for frequency restoration reserves (FRR) the regulating power market have been used, which is common to all Nordic countries.

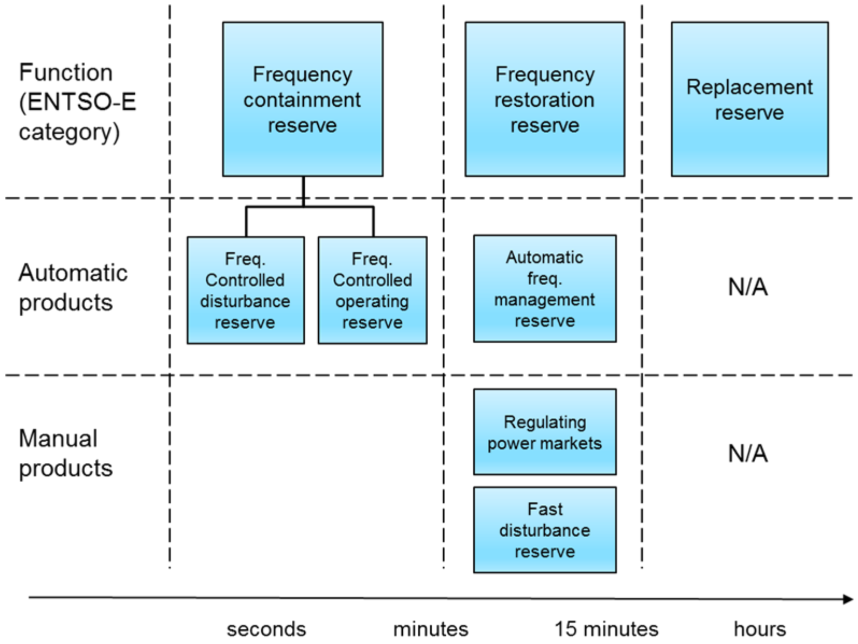

Figure 13: Reserve types for frequency control in Nordic countries.

4.3.2 Technical requirements

Because this business model includes a number of different services which vary from country to another, the technical requirements also vary. In all cases, however, the requirements are higher than for energy arbitrage. For FCR provision the CSO must have access to accurate and rapid grid frequency measurement. Alternatively, the frequency measurement can be done in EVSE and the CSO only sets the relevant control parameters beforehand. If the CSO provides FRR, it should be able to receive the control signals from the TSO. Providers of control reserves normally undergo a technical prequalification to examine whether they meet the technical criteria required to guarantee the necessary quality of the provided control reserve. TSO's normally also require that near real-time time-stamped measured values for consumption (or generation) of the individual resource via online transmission must be provided.

4.3.3 Income flows

The types and levels of available payments vary greatly from one country to another and one market category to another. In addition, the payment levels have shown large variance over time in the recent years. For example, Figure 14 shows the price development of frequency-controlled disturbance reserve in Finland during the past few years.

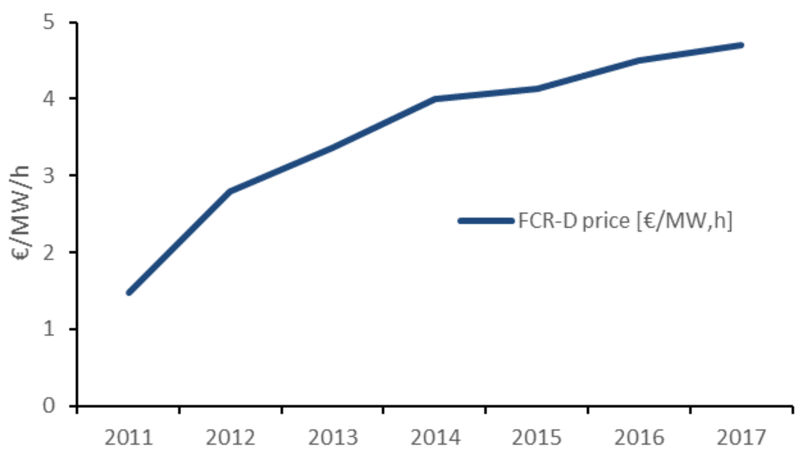

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Figure 14: Price development of the frequency-controlled disturbance reserve in Finland (source Fingrid Oyj).

4.4 Peak power reduction

As mentioned in Section 3.2, DSO's set demand charges, which are determined based on the highest power consumed during a measurement period (which can range from 15 min to 1 hour) during a monitoring period such as one month or one year. The CSO can reduce demand charges by charging the buses as slowly as possible (Gallo et al. 2014). Sometimes it is not possible to plan charging with full accuracy and more power is needed. The CSO can then take advantage of higher power allowance during the rest of the monitoring period for other business models such as energy arbitrage.

Reduction of so-called triad charges in UK, which are levied on electricity sretailers based on the three highest demand half-hours in winter months, could also be a possible business model. The retailer should purchase the service from the CSO.

4.5 Services for local network operator (distribution or transmission network).

Controlling the process of charging ebuses (shifting the charging period, modulating the charging power or providing reactive power) and taking advantage of their flexibility to support their cost efficient integration into the system has clear benefits, such as full exploitation of grid capacity and cost savings. In practise, bus depot could provide services such as active voltage control, power quality improvement, voltage dip mitigation or temporary islanded operation of local grid area as shown in the following table.

Table 7: DSO activities that can be supported by flexible EV services (Coppola et al. 2012).

Parameter	Time horizon	Possible processes	Implementation
Overvoltage	Pseudo-Real time (< 1 min.)	Centralized power flow control	Start battery charging
Undervoltage			Reduce power or stop battery charging
Congestion			Q control
Reactive power compensation			Q control
Smart emergency load shedding		Centralized – Upstream order	Reduce power or stop battery charging
Foreseen overvoltages	Short term (from some hours to some days)	Centralized or decentralized power control	Management of he battery charging time slots (ToU, dynamic tariff…)
Foreseen undervoltages			
Foreseen congestion			
Phase balancing*			
Optimization: reduction of losses…	Same as foreseen constraints with a lower priority		

*Way of implementation to be studied

One important point of the provision and acquisition of ebuses flexibility services is its activation time-scale. Some services are agreed in advance (from several months until day-ahead) and some near real time. The interaction of these services with other business models such as energy arbitrage must be considered.

However, the services cannot be provided without the implementation of the appropriate regulatory framework, market design and technical infrastructure. These are all still developing. Consequently, services for the local network operator is not currently a possible business model.

4.6 Local storage (e.g. with second-hand batteries) or local generation

The CSO may in cooperation with depot owners install electricity storages, such as used traction batteries, at the depots. These may be used to provide additional flexibility for the charging process and thus support other business models such as energy arbitrage, provision of balancing power and reduction of demand charges. Round-trip efficiency loss as well as costs of cycling the energy storage should be taken into account and reduce the available profits.

5. PROFIT ANALYSIS OF THE BUSINESS MODELS

5.1 Simulation methods

Flexible bus charging was simulated by optimizing the charging times of a set of buses against a series of power prices, considering the constraints of the normal bus operation and available charging power. Therefore, the simulated business model was energy arbitrage combined with reduction of demand charges and the needed charging capacity. As a second business model, provision of frequency containment reserves was also studied. Because the subject of this report is flexible charging business models at the depot, the analysis was concentrated on overnight charging. The possibility for opportunity charging on the route was also studied. However, it is difficult to determine similar cost parameters for opportunity charging as for overnight charging at the depot. This is because the provider of opportunity charging, which may be e.g. PTA, would possess a number of charging spots and chargers, used possibly by many bus operators with unknown utilization rates. The on-route chargers can also be located under several connection points of service, for which the grid tariffs and demand charges are levied separately.

5.2 Assumptions

There are a number of parameters, some of which can dramatically affect the results. We defined a so-called base case set of parameters, which is a starting point of the simulation. Below we list the main assumptions

5.2.1 Buses

The analysis considered one bus line which was served by three buses. The buses are listed in Table 8. More buses and bus lines could be added in a straightforward manner if the timetables are known. The example buses do not attempt to represent any single real bus line. If real bus timetables were used, several bus lines should be modeled to gain any improvement in accuracy of results. This would increase the simulation work and still the results would be somewhat specific to the chosen depot. The possibility to switch buses between bus lines would introduce an additional degree of freedom.

A relatively high base value 600 €/kWh for the battery investment cost was used. Currently the manufacturing cost of traction batteries has fallen to 200–300 €/kWh or even below but large batteries also have to be transported with the bus and they take space, to which cost can be associated. The cost of high-power batteries (including but not limited to lithium-titanate batteries) remains much higher (Olivier et al. 2014). The battery investments were amortized to annual level by applying 7 % interest rate and 12 years' lifetime. Lifetime for the investment calculation is difficult to determine exactly: cycle life and calendar life vary from battery model to another.

Table 8: Buses included in the simulation.

Bus	Description
Bus 1	Taking care of the base load on the route from 6:00 to 23:00
Bus 2	Taking care of the base load from 7:00 to 24:00
Bus 3	Serving rush hours from 6:00 to 12:00 and 15:00 to 22:00

The buses were mainly charged as overnight charging at the depot, although depending on the case, some opportunity charging was also allowed, as shown in Table 9 case value is thus quite low. The effect of delays caused by opportunity charging on the main business of the bus operator were not accounted for.

Energy consumption of the electric bus was assumed to be 1.3 kWh/km, which is a fair value for easy routes. For hilly routes the consumption is greater. The bus model of course affects the energy consumption (Zhou et al. 2016). The average speed depends on the route; 15 km/h, the average speed in London area (Transport for London 2017), was assumed here. Thus during 16 hours' daily operation the bus would consume 312 kWh. It was assumed that temperature does not affect the consumption. In cold climates for example, most buses are supplied with fuel-powered cabin heaters. On the other hand, air conditioning may increase consumption by 10–25 % (Zhou et al. 2016), which should be accounted for in a more detailed analysis.

Table 9: Opportunity charging in the base case.

Bus	Opportunity Charging availability	Opportunity Charging power
All buses	3 min each hour	1 C

5.2.2 Depot power consumption

Other power consumption at the depot, such as lighting and air conditioning were not considered when calculating the peak power. It is likely that they vary considerably from one case to another. They could also be contractually assigned to a different connection point of supply. All the bus chargers were assumed to be under the same connection point of supply and thus contribute to the same demand charges.

5.2.3 Chargers and grid connections

Investments into chargers, network connection capacities and traction batteries were not constrained for the depot but costs were assigned for their expansion. The associated costs are listed in Each bus was limited to charging at maximum 1 C rate, although for overnight charging the resulting rates were normally lower. Charger efficiency was assumed to be 95 % in all cases. This is an optimistic value and in practise EVSE efficiency could be far less than 90 %, especially if it is operated at currents which are far below the design current (Zhou et al. 2016). Charger power could be fully modulated from zero to nominal capacity. Were this not possible in practise, the same result could be achieved by charging at full power for part of the hour. This applies only when demand charges are based on hourly measured consumption and control reserves (balancing services) are not offered. Vehicle-to-grid operation was not allowed in any case. Thus taking account the battery degradation due to cycling was not necessary. Deep cycles in grid-to-vehicle operation also cause more battery wear; this effect was not accounted for.

The investments were amortized to annual level by applying 7 % interest rate and 15 years' lifetime for the chargers and 30 years lifetime for the grid connection.

Table 10 and are based on Section 3.2. Each bus was limited to charging at maximum 1 C rate, although for overnight charging the resulting rates were normally lower. Charger efficiency was assumed to be 95 % in all cases. This is an optimistic value and in practise EVSE efficiency could be far less than 90 %, especially if it is operated at currents which are far below the design current (Zhou et al. 2016). Charger power could be fully modulated from zero to nominal capacity. Were this not possible in practise, the same result could be achieved by charging at full power for part of the hour. This applies only when demand charges are based on hourly measured consumption and control reserves (balancing services) are not offered. Vehicle-to-grid operation was not allowed in any case. Thus taking account the battery degradation due to cycling was not necessary. Deep cycles in grid-to-vehicle operation also cause more battery wear; this effect was not accounted for.

The investments were amortized to annual level by applying 7 % interest rate and 15 years' lifetime for the chargers and 30 years lifetime for the grid connection.

Table 10:Base values of parameters determining the cost of peak power consumption at depot.

Parameter	Value	Unit
Charger investment and installation cost	300	€/kW
Grid connection cost	30	€/kW

5.2.4 Market wholesale prices and DSO tariffs

The applied grid tariffs and demand charges in the base case are based on Section 3.2 and shown in Table 11. The demand charges were only levied for charging at the depot.

Table 11:.Base values of parameters determining the cost of peak power consumption at depot.

Parameter	Value	Unit
daytime grid tariff	11	€/MWh
nighttime grid tariff	7	€/MWh

DSO demand charge	2.5	€/kW/month

Two different series of wholesale prices were used in the simulation (Table 12). The historical market prices from the Finnish price area in 2015, and a simulated time series of power prices in a 100 % renewable power system in 2050. The price series was obtained by applying the *WILMAR* unit commitment and economic dispatch simulation tool to the North European region (Ikäheimo & Kiviluoma 2016). Figure 15 shows the future price curve as function of time. The reader may note that the future simulated price level is a bit lower and the price variation is considerably higher compared to current prices.

Table 12: The power price scenarios used in the simulation.

Scenario	Description	Mean price €/MWh	Standard deviation €/MWh
Current	Nordpool Elspot 2015 Finnish area prices	29.7	14.5
Future	Simulated 2050 spot prices for Finland in 100 % renewable power system	24.8	30.2

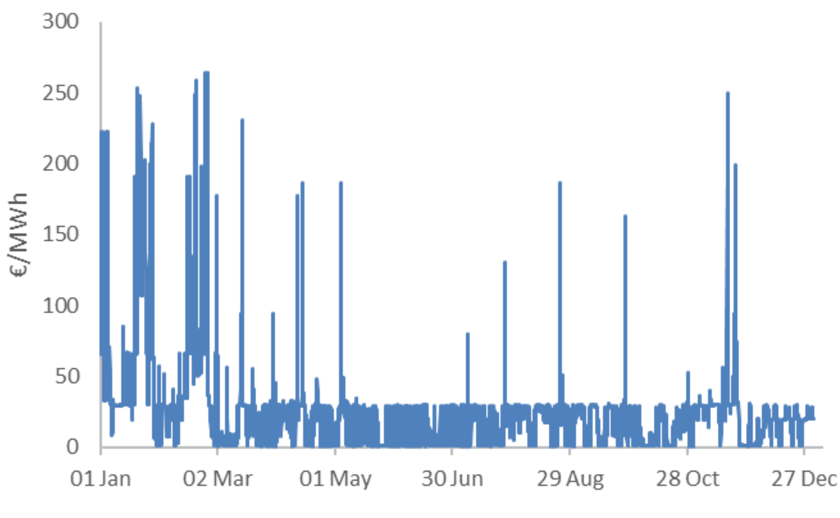


Figure 15: The simulated 2050 spot prices for Finland in 100 % renewable power system.

Electricity taxes or other surcharges were not considered in the final electricity price. If they remain constant with respect to time, they do not affect the results.

5.2.5 FCR

The Nordic FCR-D market was included in the simulations. Normally FCR-D is intended to be the first reserve category which is launced during disturbance within 5 seconds and is superceded by regulating power and automatic frequency restoration reserve in a few minutes. Therefore it is fair to expect that calling of the service would only produce a minor disturbance in the charging schedule, which is easy to correct during the same or the next hour. However, the additional charging capacity must be available. In our simulations we reserved the additional charging energy of 6 minutes times the offered power for the hour when reserve capacity was offered. This is reasonable because this type of reserve is called quite rarely and when called, is replaced quickly by resources which are offered on the regulating power market. If the reserved charging capacity is increased, revenues decrease monotonously. The price for annual contracts of FCR-D provision with Fingrid in 2016 was 4.7 €/MW/h. We used 5 €/MW/h.

Table 13:.Parameters for FCR-D provision.

Parameter	Value	Unit
Energy payback reservation	6	min
FCR-D price	5	€/MW/h

5.3 Results

5.3.1 Base case

To study the profitability of flexible charging, which is based on market prices or reduction of demand charges, we ran simulations where price variations and demand charges were neglected. The cases are designated as “no price control” and “no demand control”. These were compared to the case where price variations and demand charges were taken into account in charging optimization.

Figure 16 shows the resulting energy costs (including grid tariffs) and power-related costs (including charger infrastructure and grid connection costs) relative to electrical energy consumption of bus charging. In the case where price variations were not exploited in charging optimization, the costs were 2.7 % higher and in the case where demand charges were not exploited in charging optimization, the costs were 1.2 % higher than in the optimal case. If both price variations and demand charges were neglected, costs did not increase further. The profit from price flexibility is well aligned with profit of price flexibility of storage electric heating (Leksis 2009). Storage electric heating resembles overnight charging because in both cases a storage must be charged during the night and is discharged during the day.

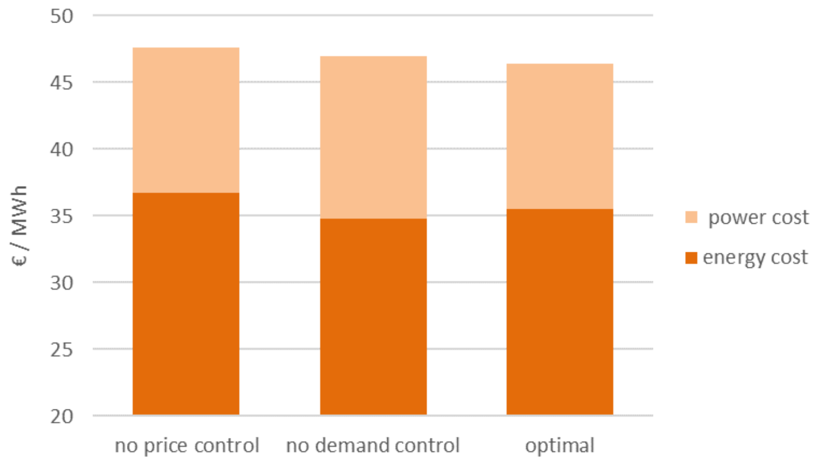


Figure 16: Energy and power-related costs in the base case when current prices were applied.

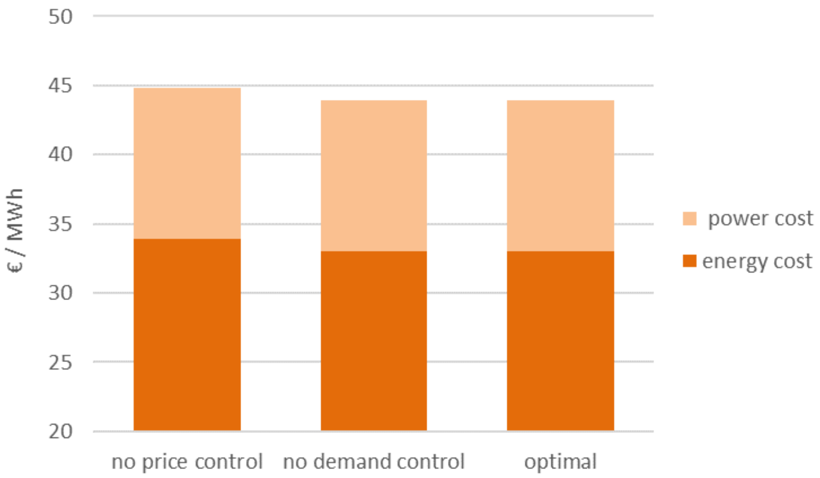


Figure 17: Energy and power-related costs in the base case when future prices were applied.

5.3.2 Variations in opportunity charging

In the base case, the allowed opportunity charging time for each bus was 3 min each hour. Below in Figure 18 the results for the case where only depot charging was allowed. In practise this means sole overnight charging except for bus 3 which was able to visit the depot at noon. The resulting saving from price control was 4.9 % of energy and power costs when current prices were applied. When the future price time series was applied, the saving was reduced to 2.9 %. Considerably larger batteries were needed in this case.

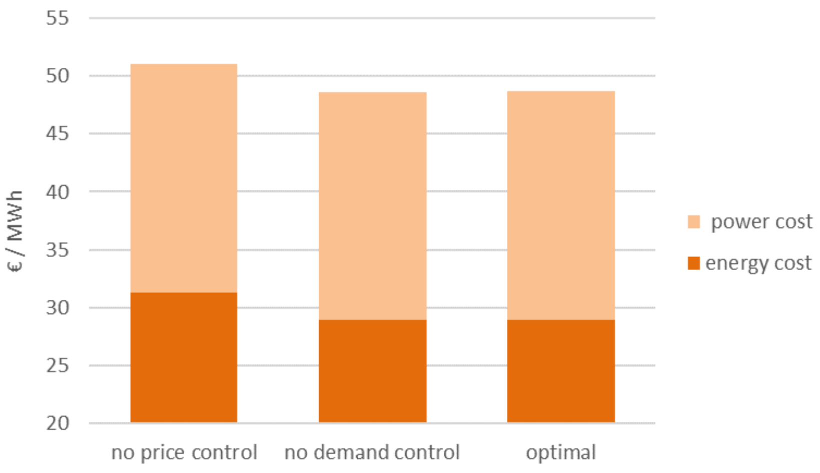
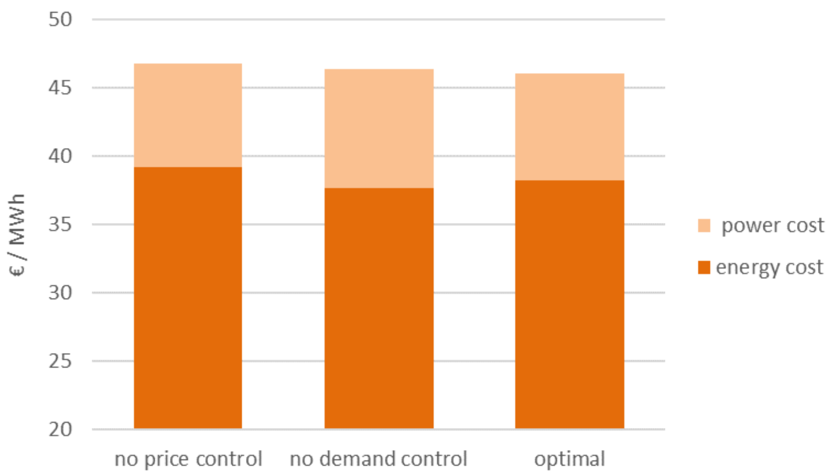


Figure 18: Energy and power-related costs in the depot charging case when current prices were applied

Figure 19 shows the results in the case where opportunity charging speed for each bus was increased to 2C with battery cost remaining the same. The saving from price control was 1.6 % of energy and power costs when current prices were applied and the saving from demand control (avoiding demand charges) was 0.8 % of energy and power costs.

Figure 19: Energy and power-related costs in increased opportunity charging case when current prices were



applied.

Comparing the optimal energy and power costs in the three cases of depot charging only, base case opportunity charging and increased opportunity charging (2C rate), we see a uniform increasing trend of energy cost and decreasing trends of power cost. Naturally the battery costs also decreased dramatically with increasing opportunity charging (Figure 21). The trends are similar when future power prices are used.

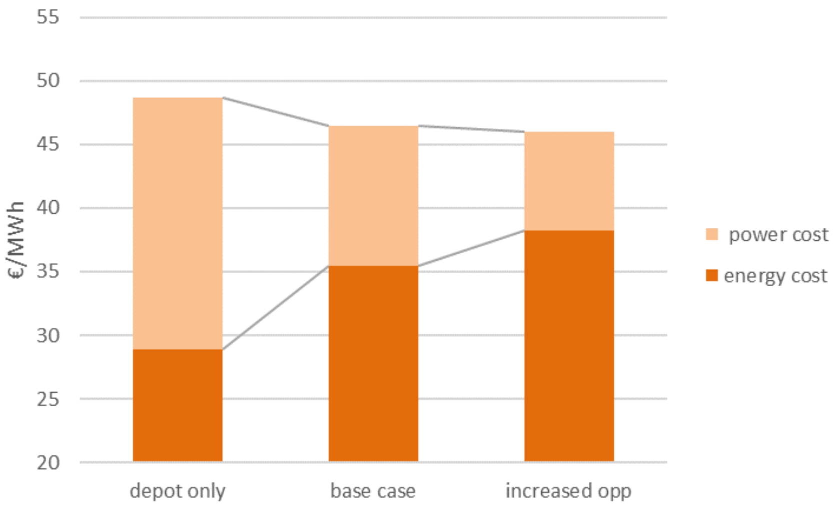


Figure 20: Energy and power-related costs as function of allowed opportunity charging (none/ 1C /2C) when current prices were applied.

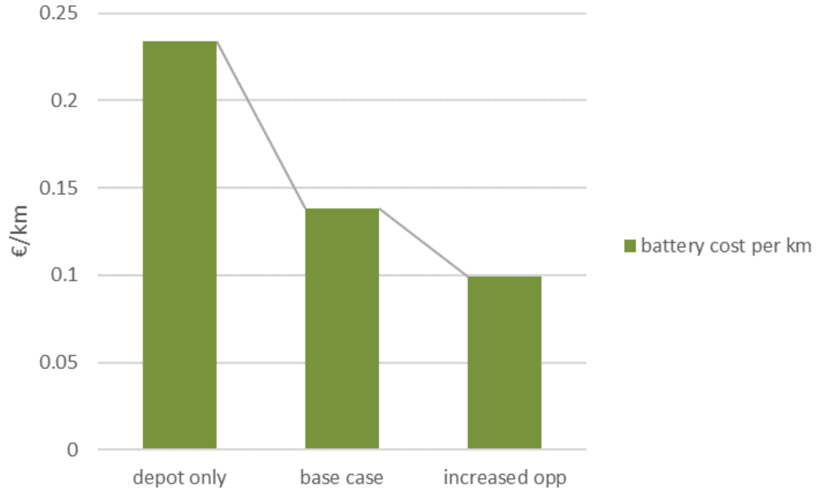


Figure 21: Battery costs in euros per driven distance as function of allowed opportunity charging (none/ 1C /2C) when current power prices were applied.

5.3.1 Variations in charger costs

When charging infrastructure investment cost was decreased from the base case value 300 €/kW to 150 €/kW, the optimal charging schedule or savings from price control did not markedly change. The saving from demand control at 2.2 % was significantly higher than in the base case. The reason is that demand charges are relatively higher when the charger costs, which also depends on peak power, is lower.

5.3.2 Service charge for on-route chargers

In the previous results the provider of the on-route charging points did not charge anything for the infrastructure and possible demand charges were not passed to bus operators. As mentioned above, there are many ways in which the costs could be passed to bus operators. If a surcharge is added to the electrical energy, it can be quite high before it affects optimal charging schedules. 20 €/MWh surcharge would probably be enough to cover charging infrastructure costs and demand charges but had little effect on charging schedules in our case.

5.3.3 Provision of frequency containment reserve

The provision of the Nordic frequency controlled disturbance reserve (FCR-D) was simulated. This is a positive reserve, which in bus charging would mean reduction of the charging power for a certain period. FCR is fundamentally different from other services (energy arbitrage and reduction of demand charges) included in the model. This is because of the stochasticity of FCR operation: during each provision period the service may be called or not. If the service is called, bus charging must be rescheduled. Naturally, all possible outcomes cannot be tracked and simplications must be made. At the same time, we should make sure that the regular business of the bus operator is not disturbed. Also, provision of FCR-D sets the power for each hour but the provided energy (if the service is called) is unknown.

In Figure 22 we show the resulting income from provision of the FCR-D by depot charging. The revenue relative to energy cost (including grid tariff) and power cost (including the cost of charger infrastructure and grid connection) is shown. We see that the revenues are quite significant and clearly higher than those available from energy arbitrage. Two cases with different power ratings of opportunity charging are shown. Base case values were used for other parameters.The revenues in the case with higher-power opportunity charging are lower because in that case opportunity charging is exploited more and the disturbance reserve provision was only possible at depot.

Figure 22: Relative income from the provision of frequency controlled disturbance reserve by bus charging. Two different power ratings of opportunity charging are shown. Also two different cases of wholesale prices (current and simulated future) are shown.

Notice that the reserve income does not fully reduce the costs of the base case because of the resulting higher peak power. However, the FCR clearly reduce total costs as shown in Figure 23.

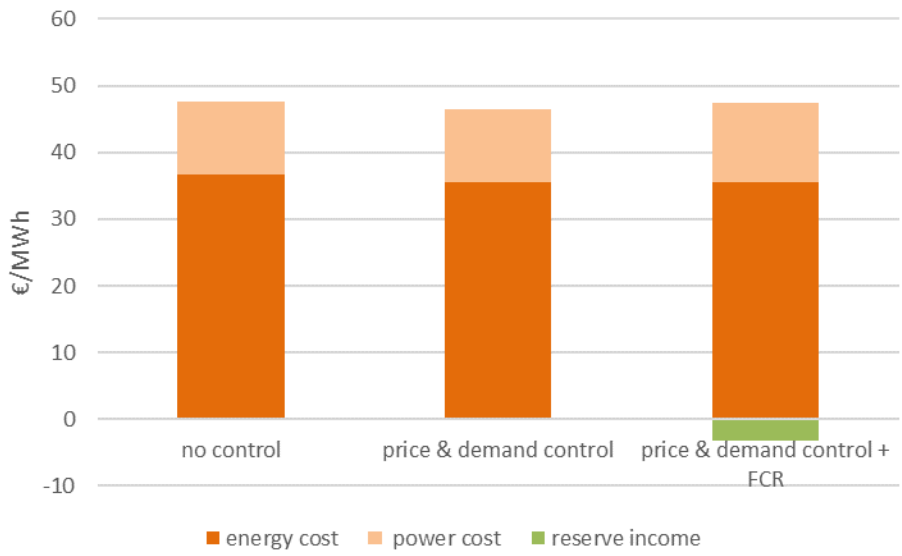


Figure 23: Total energy and power costs of the bus line in case where demand or price control is not applied, price and demand controls are applied, and in case where also FCR-D is offered.

6. EXTRAPOLATION OF THE BUSINESS CASE TO OTHER REGIONS

In previous chapter the business model in Nordic conditions was simulated. Simulation model created for this purpose was used. The model was based on minimization of wholesale electricity cost, grid charges, grid connection cost, charger investment cost, buses battery investment cost. In other words, the purpose was to minimize

$$\min z = \sum_{bus,time} (electricity\ cost + grid\ charges - reserve\ income)$$
$$+ \sum_{bus} (battery\ cost) + charger\ and\ grid\ connection\ cost$$

The minimization was subject to the condition that the buses always have sufficient energy for operation. The detailed market rules such as timeframes, trading blocks, reserve product symmetricity, or stochasticity of market prices was not modeled. While this reduces the accuracy of the simulation it also greatly simplifies performing the study in other areas.

Performing the revenue simulation of the business case in other regions, which could be e.g. countries or wholesale market price zones in its simplest form involves redefining the parameters listed in Section 5.2. While technical parameters such as battery cost do not change from one region to another, market prices and distribution tariffs and connection fees can manifest large differences.

Balancing markets differ between European countries (Verpoorten et al. 2016), which may in some cases require changes not only in the input data but also in the model structure. In some countries load access to balancing markets is altogether restricted, (Verpoorten et al. 2016; SEDC 2017).

Above we discussed the quantititave simulation of the business model. The results concerning the business model can also be *qualitatively* extended to different national contexts using the methodology presented in the EU-DEEP and SEESGEN-ICT projects (EU-DEEP 2009; Ikäheimo et al. 2010). The methodology involves identifying parameters which significantly influence the profitability of the flexible charging business model. The parameters can be related to regulation, or energy trade or bus operation and can be expressed on arbitratry numeric scale. Naturally these parameters include those presented in Section 5.2 but also parameters which are defined on an arbitrary numeric scale can be included. Examples of such parameters are

- variability of electricity market prices
- price level of balancing market products
- number of balancing markets for which loads are eligible
- number of balancing markets for aggregated loads are eligible
- the maximum time a load resource is required to provide service in the balancing markets
- demand charge level in distribution tariffs
- presence of ToU distribution tariffs
- level of connection charges in distribution networks

After the parameters have been identified, the present value of each parameter is obtained for a given region. Expert involvement is beneficial in this stage. The analysis must include several regions because the parameter values are not necessary meaninful in isolation. A weighed average of the parameters is then calculated.

7. SUMMARY AND CONCLUSIONS

A number of business models for flexible charging of electric buses at the depot exist. The exact form and profitability of these business models is country-specific for two reasons: power markets are different; and also the public transport has been arranged in different ways in different European cities, creating different risks and opportunities for CSO's in different countries. The market categories for charging flexibility, their pricing and technical requirements vary from one European country to another. Furthermore, there is an on-going process of harmonizing the relevant markets in EU and the technical requirements are constantly changing with the attempt to bring demand-side resources into the markets. In some cities PTO acts as a monopoly, also owning the depots. In this case the CSO faces different types of challenges than in the case where multiple PTO's are present.

A number of market-based simulations of optimal scheduling of bus charging were run to evaluate the revenue potential of different business models. We found that energy arbitrage combined with reduction of demand charges resulted in modest savings for the CSO. Charging capacity availability and low price differentials reduced the savings. Possible savings from avoiding the demand charge was generally lower than the saving from energy arbitrage. This is because in a deterministic model minimizing the needed charger and grid connection power also contributes toward minimizing the demand charge. Provision of the frequency controlled disturbance reserve generated a much higher revenue, reaching eight percent of the energy and power costs. Of course, this depends directly on the price level of reserve services, which vary greatly. The future price level of frequency controlled disturbance reserve or other reserve products is difficult to predict.

The savings from price-controlled charging (energy arbitrage business model) were greatest when only overnight charging was allowed. However, in this case the battery cost was extremely high. Allowing opportunity charging lowered the total cost. Thus it is evident that the higher power prices at daytime are clearly compensated by the reduced battery and charger costs. This was even true if a service charge was added to the opportunity charging energy price to cover the infrastructure costs. Provision of frequency containment reserve took place only at the depot, opportunity charging thus reduced the revenue. The savings from price-controlled charging were greater with current market prices compared to simulated future prices, although the overall variance in the future prices was greater.

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