Article

Energy Flexibility from Large Prosumers to Support Distribution System Operation—A Technical and Legal Case Study on the Amsterdam ArenA Stadium

Dirk Kuiken [1],*, Heyd F. Más [1], Maryam Haji Ghasemi [2], Niels Blaauwbroek [3], Thai H. Vo [3], Thijs van der Klauw [2] and Phuong H. Nguyen [3]

[1] Faculty of Law, Groningen Centre of Energy Law (GCEL), University of Groningen, Oude Kijk in't Jatstraat 26, 9712 EK Groningen, The Netherlands; h.fernandes@rug.nl

[2] Department of Electrical Engineering, Mathematics and Computer Science, University of Twente, Drienerlolaan 5, 7522 NB Enschede, The Netherlands; m.hajighasemi@utwente.nl (M.H.G.); t.vanderklauw@utwente.nl (T.v.d.K.)

[3] Electrical Energy Systems Group, Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands; n.blaauwbroek@tue.nl (N.B.); t.vo@tue.nl (T.H.V.); p.nguyen.hong@tue.nl (P.H.N.)

* Correspondence: d.kuiken@rug.nl; Tel.: +31-50-363-4573

Abstract: To deal with the rising integration of stochastic renewables and energy intensive distributed energy resources (DER) to the electricity network, alternatives to expensive network reinforcements are increasingly needed. An alternative solution often under consideration is integrating flexibility from the consumer side to system management. However, such a solution needs to be contemplated from different angles before it can be implemented in practice. To this end, this article considers a case study of the Amsterdam ArenA stadium and its surrounding network where flexibility is expected to be available to support the network in the future. The article studies the technical aspects of using this flexibility to determine to what extent, despite the different, orthogonal goals, the available flexibility can be used by various stakeholders in scenarios with a large load from electric vehicle charging points. Furthermore, a legal study is performed to determine the feasibility of the technical solutions proposed by analysing current European Union (EU) and Dutch law and focusing on the current agreements existing between the parties involved. The article shows that flexibility in the network provided by Amsterdam ArenA is able to significantly increase the number of charging points the network can accommodate. Nonetheless, while several uses of flexibility are feasible under current law, the use of flexibility provided by electric vehicles specifically faces several legal challenges in current arrangements.

Keywords: congestion management; demand side management (DSM); distribution system operation; electric vehicles; energy flexibility; legal framework; storage system

---

1. Introduction

The anticipated integration of large amounts of stochastic renewable energy sources (RES) and energy intensive distributed energy resources (DER) increases the uncertainty in power consumption and production. Especially in distribution networks, more energy intensive appliances, such as climate control, electric vehicles charging points and other electric transportation systems are gradually added, causing increased stress on the system [1]. Meanwhile, another important source of uncertainty in future power systems comes from the intermittency of RES. RES are much harder to predict and schedule than on-demand sources. These uncertainties make it increasingly difficult to: (1) operate the electricity network within secure operation limits; and (2) balance the demand and supply over time [2,3].

Several research projects address possible approaches to exploit flexibility from (large) prosumers and other end-users (see, e.g., [4–6] or one of the many surveys recently published and references therein [2,3,7–9]). While these projects differ according to, for instance, the objective of using customers' flexibility, considered time horizons, and physical constraints considered, this article focusses on answering the research question: how can flexibility from end-users be used to improve efficiency in system operation and how can such flexibility be exchanged between end-users and the system operator? The novelty of the presented work lies in the combined perspectives: it considers potential conflicts between goals of stakeholders through the (feasibility) aspects and a legal analysis of the possibilities to achieve the proposed solutions under current legislation.

While many facets are involved with the efficient operation of a distribution system, the focus in this article is on the reduction of reinforcement needs caused by peak loads resulting from a large number of electrical vehicle (EV) charging points connected to the system. Although the integration of a large number of EV charging points to support electric driving is usually perceived as a positive development towards alternative fuels, a considerable increase in the number of charging points for EVs is likely to cause voltage violations and power congestions in the local grid. On this topic, the Amsterdam ArenA has an interesting setup in place. There are currently several charging stations in the parking garage underneath the stadium (Transferium/P1) with electricity supplied by the network of the municipality (Amsterdam). In the case of major events, all charging points are typically used for charging at a high rate. This causes high power consumption in a short time, leading to peak loads in the distribution system. Currently, the ArenA stadium is planning to install batteries for storage, which offer a 4 MWh total capacity that could be used for lowering the aforementioned peak loads. Throughout this article, we refer to this system as the planned storage system.

By proposing four case studies, the article identifies a set of possible solutions for power congestions and voltage problems that would be caused, for instance, by too many EVs charging at the same time. It does so by looking into technical and legal possibilities for the effective use of the flexibility in the network from, e.g., the planned storage. In the first scenario, a situation where no control is applied to the load profile of the ArenA is simulated and its consequences are calculated; scenario two looks into the consequences of the Arena using its planned storage system to balance its own profile, hence, this scenario illustrates the case when the ArenA does not offer flexibility to the distribution system operator (DSO), but rather uses this flexibility for its own purposes; the third scenario simulates the Arena offering its flexibility to the distribution system in a coordinated fashion with the DSO. From a technical point of view, a fourth scenario is possible, where flexibility for the distribution system would not only originate from the ArenA's planned storage system, but also from the EVs connected to charging points in its parking garage.

In assessing the scenarios within the case study, it is important to stress that this article does not focus on one specific discipline, but presents research results from three different ones: power system engineering, computer sciences, and legal sciences. The results presented aim to open up the flexibility to the relevant markets in the electricity system, facilitating more efficient distribution network operation. As a result, the main contributions of this article are:

- An integrated discussion on the use of flexibility from large customers from both a technical and a legal perspective;
- Identification of potential use cases of flexibility to exploit flexibility values for both system users and distribution grid operators; and,
- Identification of potential legal barriers for the use of flexibility by DSOs.

As such, the article brings further the discussion of the usefulness and applicability of flexibility from large customers under current law.

The rest of this this article is structured as follows: Section 2 describes the methods and methodologies used in this work. Sections 3 and 4 deal with the analysis and results of the proposed case study in all four scenarios; in which, the analysis and results are structured into two different

parts, so that the technical and legal aspects are properly approached. An integrated conclusion and discussion is drawn in the Section 5 of the article, emphasizing the chances and challenges for the use of flexibility for facilitating distribution system operation, discovered in the ArenA case study.

2. Method: DISPATCH Framework and Central Research Questions

The research disseminated within this work falls within the DISPATCH and DISPATCH2 projects [10]. The DISPATCH and DISPATCH2 projects consist of a versatile set of disciplines. Combining these disciplines requires a clear and consistent framework, in order to integrate the research results from these disciplines as good as possible. As such, we define the abstract framework used within the project in this section.

Given the different disciplines involved in the DISPATCH project, it is first of all important to find common ground. As such, the project partners agreed to use a three-layer approach. In this approach, the layers are defined as: (i) the abstract interaction layer; (ii) the concrete interaction layer; (iii) discipline specific research layer. In the first layer, the (current) electricity system is discussed and used as a starting point for further defining which elements (which can be roles (actors), markets, economic relations, and physical relations) are relevant for the problems addressed. The second layer applies the abstract layer to the ArenA case study. Within the second layer the case study is further specified and the research goals are added. Based on the desired optimisations, specific solutions are selected. In the third layer the proposed solutions in combination with the optimisation goals are used as a starting point. Following, the respective researchers active in each discipline present research and propose discipline specific solutions for solving the selected problems.

2.1. Abstract Interaction Layer: The Electricity System

The electricity system as a whole is a complex system integrating many different parties. Those can be identified as acting within the system through various markets and agreements, ensuring a safe and stable operation of its entirety. In this work, we focus on two actors within the electricity system: end-users and system operators. The end-users are parties connected to the physical network of the energy system that use this network to serve their energy need, e.g., supplying their demand. The focus of the study is particularly directed to large customers, as these can potentially offer a large amount of flexibility to the system [2,3]. We would like to stress that a more precise definition of flexibility offered by customers is given below. System operators operate and maintain the physical grid used to transport energy between producers and consumers (which are both end-users). These operators are regulated entities that are required to ensure a safe, secure and efficient operation of the physical networks they control and maintain [11]. In particular, we focus on DSOs, as problems within the distribution grids are foreseen in the (near) future due to the energy transition and specifically the electrification of our energy use [12–14].

The interaction between DSOs and end-users in the current system is limited to a connection and transportation agreement (CTA). This agreement specifies the basis of the use of the connection the end-user has to the network, which is operated by the DSO. Costs are attributed to the end-user through the CTA to compensate the DSO for the costs they incur for transporting and distributing according to the energy needs of the end-user.

As mentioned, DSOs are increasingly facing challenges (e.g., congestion) within their networks, which are expected to worsen in the future. Conventional ways of tackling congestions and other network related issues are through reinforcements. However, such reinforcements are often expensive [15,16]. As an alternative, some end-users, such as large customers, are expected to have flexibility in their consumption in the future. These new sources of flexibility are often considered in the literature as a cheaper alternative to conventional reinforcements [2,13,15]. In this article, we refer to flexibility as: *the ability for an end-user to deviate from their usual consumption pattern to benefit the system*. We note that this is often referred to in the literature as demand response, demand side response or demand side management (DSM) [2,3]. The term DSM is also used in the legal part,

as most legislation refers to flexibility from customers as DSM (in Dutch 'vraagzijdesturing'). While generators and some types of large customers have traditionally been used to support the network in several scenarios [3], this was generally done to ensure balance on the national grid level, through the transmission system operator (TSO). In the future, new opportunities for the use of flexibility from large customers is expected to play a role in solving more local problems (i.e., those experienced by the DSO instead of the TSO). This article aims to study exactly this new interaction between (large) customers and DSOs. Within such a scenario the interactions between a DSO and an end-user are no longer limited to the one-way interaction of the current CTAs, but also flexibility is offered to the DSO that can be used for system operation. An overview of the (future) interactions considered in this article is given in Figure 1.
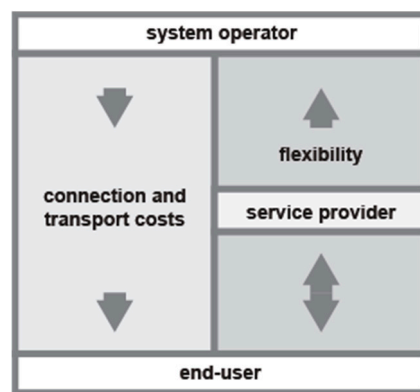

Figure 1. Abstract overview of the interactions between the distribution system operator (DSO) and a customer considered within this article.

Within Figure 1 we note that there is the potential for one or more service providers to interact with the DSO on behalf of an end-user. Such interactions are arranged through contractual agreements that fall into the end-users services market. In this article we only consider direct interactions between the end-users and the DSO. However, any of these interactions can also be done by a service provider and the findings herein should also apply to cases where a services provider acts and an intermediary between the end-user and the DSO instead.

2.2. Concrete Interaction Layer: DISPATCH2 Case Study

For this article, the researchers focus on the ArenA case as defined for DISPATCH2. In this case mainly interactions between the relevant DSO, the ArenA stadium, and the parking garage of the stadium are of interest. The stadium is a large consumer of energy, connected to multiple feeders of the surrounding medium voltage (MV) grid. While the energy consumption of the ArenA is currently inflexible, this is expected to change in the (near) future. One prominent change is the planned installation of a large battery storage system that can act as a resource of flexibility by changing the consumption pattern of the stadium when requested.

The parking garage of the stadium is owned by the municipality and has its own separate connection that currently serves a low load. The load inside the garage is mainly caused by lighting and a small number of electric vehicle charging points. These charging points are operated and maintained by an independent charging point operator (CPO). Charging services are offered at these points by a mobility service provider (MSP). In the future, a large increase is expected in the number of charging points inside the main parking garage of the stadium due to a clear push to electric driving that is happening in the Netherlands, with the new government pushing for all new vehicles sold being electric in 2030 [17]. Furthermore, the ArenA aims to be a frontrunner in implementing smart energy solutions. As such we believe it is likely that a large number of the charging poles for EVs of visitors will be installed in the main parking garage of the stadium (Transferium/P1) in years to come.

Furthermore, almost all of the points are expected to be operated when the garage is fully utilised, such as during large events inside the stadium.

The relevant interactions for the project are between the DSO and the ArenA and among the DSO, the /CPO/MSP, and potentially EV users. Also, third parties can be involved that act as intermediates between the ArenA, CPO/MSP, or EV users and the DSO. However, for the scope of this article, the roles of these parties are not specifically addressed.

Within the case study it is important to note that the different parties have different goals. Although all parties are first of all involved to gain insights and experiences, ultimately the goal of the DSO is to be able to use the available flexibility present in and around the ArenA to avoid (expensive) network investments. For the case study, we particularly consider the number of EV charging points that can be connected in the main ArenA garage (Transferium/P1) to the network without causing congestion. This number is called the *hosting capacity* of the network. To this end we consider severe loading conditions of the network that occur during events hosted at the stadium and study how using flexibility in several scenarios can increase the hosting capacity. By doing so we can determine how the available flexibility can be used to support the network and its value to the various parties.

In contrast to the goal of the DSO, the main objective for the ArenA is to have a more sustainable, efficient, and affordable (cheaper) energy installation, through effective use of the planned storage system. The main objective for the CPO/MSP is to provide charging points and services to the visitors of the ArenA. In a business-as-usual scenario, the DSO is obliged to ensure the network is capable of handling connection requests of its customers. Hence, if the number of charging points is drastically increased, causing a large peak load during events when many EVs are charged simultaneously, network reinforcements might be required. However, smart coordination of the flexibility provided by the ArenA could increase the hosting capacity of the network surrounding the stadium. Next to this, smart charging strategies could also increase the hosting capacity of the network. Within the technical aspect of this study we investigate if our hypothesis that flexibility can benefit the DSO is correct. If our hypothesis turns out to be true, the DSO might be able to procure the flexibility available to the Arena and/or the CPO/MSP to support the grid using savings obtained from the hypothesised benefits.

The ArenA itself is financially incentivised to use its own flexibility to reduce its peak consumption (without the EVs) and the costs incurred through the connection and transport agreement. About 25% of the monthly connection and transportation costs of the ArenA are based on the maximum transported peak. Such peak moments rarely occur in the ArenA, mainly during events in the stadium (e.g., a football match). Thus, a significant reduction in the monthly costs can be obtained by the ArenA, if flexibility available inside the ArenA (primarily from the planned storage system) is utilised to reduce the maximum monthly peak. While a consumption peak of the stadium and of a large number of charging points is likely to coincide in time (i.e., during an event), they may be of a different nature (e.g., the stadium peak might span a much longer time period) causing a potential conflict between the goals that the ArenA and the DSO have for the use of flexibility.

For the CPO/MSP a larger connection required to host a higher number of EV charging points incurs additional costs through their own CTA. These costs are likely to be added to charging fees set for their customers. This implies that a reduction of these costs likely increases the competitive position of the CPO/MSP.

In this article we show the potential use for flexibility in the considered case study of the ArenA stadium. We combine a technical study of how the envisioned flexibility in the network surrounding the ArenA can benefit the DSO or the system users with a legal study on how the potential use of such flexibility would fit with current legal practice. The technical study includes 4 different scenarios to study the potential use of flexibility:

(1)   a base-case where no flexibility is available;

(2)   the ArenA using the flexibility provided by the planned storage system for peak-shaving its own load;

(3)　　the ArenA coordinating with the DSO to use the flexibility provided by the planned storage system to reduce peak loads in the grid;

(4)　　the DSO coordinating the flexibility provided by the planned storage system in the ArenA and flexibility provided by smart charging of the EVs to minimise peak use in the grid.

In all four scenarios, a weekend with a football match is simulated to mimic peak loading conditions with varying numbers of EVs connected to the charging points to determine the hosting capacity of the network. The technical study determines to what extent a management approach for flexibility proposed in literature suites the considered case. The legal study researches how the methods used in the technical study can be implemented in practice under current legal arrangements. It also considers where potential barriers lie and gives an outlook on possible changes to these arrangements to allow for the proposed solutions in the technical studies to be brought to practice.

This article aims to answer the central research question posed in Section 1 (Introduction) through studying the specific case study of the ArenA and its surrounding network. While the results obtained will be specific to the case study, we believe the implications of the results have a broader application. This is because we study in this article also the combined issues that arise when tackling flexibility use of (large) customers in both the technical and the legal aspects.

2.3. Discipline Specific Research Layer

In this section, we define the research subject and questions for both the technical and legal aspects of the case study individually. We note that the work in the technical parts combines the computer science and power systems engineering fields. Below we first discuss the technical aspects: what the central questions are and how we tackle these questions within these aspects. Next, we do the same for the legal aspects. The details and results of the technical aspects are then considered in Section 3, while those of the legal aspects are considered in Section 4.

2.3.1. Technical Aspects

There are two research questions central in the technical aspect of the case study, which are

-　　*to determine how flexibility provided by the ArenA's planned storage system and the smart charging of EVs can increase the hosting capacity of the network surrounding the Arena, and;*
-　　*to determine how different use of the flexibility in the system aligns with the objectives of the various stakeholders.*

To answer these questions, we conduct detailed simulations of various scenarios defined in Section 2.2. In all scenarios, the first sub-question is addressed through varying the amount of EV charging points connected and using power flow simulations within the Vision software package [18] to determine when the network is overloaded. The second sub-question is answered by a comparison between the cases. We assume that the basic value a large customer can generate from flexibility is through a reduction in maximum transportation peak. Thus, we compare Scenario 2 where the flexibility provided by the ArenA's storage system is used for their own objective with Scenarios 1, 3 and 4.

In the comparison between Scenarios 1 and 2, we get an indication of how much the ArenA would benefit from using the planned storage system for its own benefits. This value is a purely monetary value based on the CTA between the ArenA and its DSO. Similarly, we obtain an indication of the value of smart charging for the CPO/MSP when comparing Scenario 4 with other scenarios. In a comparison between Scenarios 2, 3 and 4, we get an indication of the value of the flexibility of the planned storage system, and also smart EV charging in the comparison with Scenario 4, for the DSO by increasing the hosting capacity. This value is in terms of an increase in the maximum number of EV charging points that can be connected to the network. Indirectly this translates to a monetary value because an increased hosting capacity means that grid investments can be deferred for longer.

2.3.2. Legal Aspects

The central research question of the legal part is to what extent the current legal framework allows for the desired interactions between the DSO and end-users. In order to answer this question, the case studies are analysed in four corresponding subsections. In these sections first the general legal framework for the planned interactions is sketched. For analysing the relevant legal framework, mainly Dutch law is taken into account. Although the EU framework is applicable in the Netherlands, most relevant EU legislation is part of Directives. These Directives provide for minimum standards that have to be implemented into Dutch law. In implementing these Directives, the Dutch legislator has to comply with the minimum standards. If the Dutch legislator has implemented these Directives, the acts implementing the minimum standards from the Directives are the directly binding laws [19]. As such, we focus on Dutch legislation, and only analyse EU legislation when Dutch legislation is ambiguous or inconclusive.

Once the legal framework is clear, the framework is applied to the specific situation of the ArenA. In analysing the interactions between the DSO and the end-user(s), a distinction is made between regulated and non-regulated interactions. The regulated interactions mainly consist of CTAs between the DSO and system users. The non-regulated interactions will mainly consist of (potential) flexibility trade agreements between DSOs and system users. Currently, these agreements are not used. Moreover, in the Netherlands such standard or model agreements are still in an early development phase. Therefore, the options for the agreements are sketched (taking into account the relevant debates and discussions), rather than analysing existing standards or model agreements. It should however be noted that for mobility services (charging) a number of standards are currently used. Of these, the standards used within the scope of the case studies are taken into consideration. Although such standards can be amended, they provide relevant insight on what interactions are relevant and how such interactions could be integrated into legal standards. In the concluding section, the results of the legal part of the case study are presented as a descriptive answer to the research question.

3. Technical Aspects

This section details the technical analysis of the case study of the network surrounding the ArenA. Within this section, we aim to answer the research sub-questions, as stated in Section 2.3, through the analysis of various (futuristic) scenarios. The aim is determining how flexibility provided by the ArenA's planned storage system and smart charging of EVs can benefit the network through an increase in hosting capacity. Also, we aim to determine how the objectives for flexibility use of different stakeholders align.

This section is outlined as follows: we first give a description of the electricity network surrounding the Amsterdam ArenA that is under consideration and details on the used model of the network. After this we discuss the models of the considered flexibility we used in the simulations of the various scenarios. This entails models for both the planned storage system in the ArenA and controllable EV charging as well as a description of the overall coordination mechanism used to steer the use of the flexibility. Next, we present the details of the different scenarios followed by the obtained results within our simulations. Within these simulations, we obtain detailed power profiles for the various important players in the network, i.e., the planned storage system and the steerable EVs. Also included are the results of the power flow analyses of the network using the loads obtained in our simulations used to determine the hosting capacity of the network. Finally, we present a discussion on the obtained results.

3.1. The ArenA Network

This section discusses the network surrounding the ArenA stadium that we used for simulating the various scenarios we define below. First, we discuss the network topology. This is followed by a

short discussion on the load profiles used for the network analysis. Finally, we discuss the simulation software used for the power flow analysis.

3.1.1. Network Topology

For the power flow simulations, we use data of the actual 10.5 kV network surrounding the Amsterdam Arena. This network consists of 30 outgoing feeders and is currently managed by Liander. Of these feeders four run towards the stadium using a three-ring structure. However, under normal operation the network is operated radially with two feeders supplying the stadium. The relevant feeders consist of 100% underground cables, of which the type and length of each cable section, together with the topology of the network is shown in Figure 2. In this figure we depict the normal operational configuration of the DSO with the transformer tap position at 1.025 p.u. This position is chosen to prevent voltage drops, while maximizing the voltage rise headroom in the down-stream. In the figure it can be observed that the Arena stadium and the neighbourhood are currently supplied by the 150/10.5 kV Bijlmer Noord substation at the far end of the two relevant feeders. These feeders will be referred to as the upper and lower feeder respectively. The ArenA itself is supplied by 8×1000 kVA and 2×630 kVA transformers. Based on their locations, the transformers are divided into three groups A, B and C. The specifications of the transformers are listed in Table 1. The main conductors being used in the two relevant feeders are listed in Table 2. For the case study in this paper, no data is available on the exact reconfigurability of the network. As such, we assume the network topology to be fixed.

Table 1. Specifications of the transformers used to supply the ArenA stadium from the 10.5 kV grid.

Gr.	Provider	No.	Ratings	u_k (%)	P_0 (kW)
A	Pauwels	2	10500/400 V—1000 kVA	5.8	1.1
	HOLEC	2	10250/400 V—1000 kVA	6.3	1.1
B	Smit	2	10250/400 V—1000 kVA	6.0	1.1
	IEO	2	10500/400 V—630 kVA	3.8	0.9
C	Smit	1	10250/400 V—1000 kVA	5.1	1.4
	IEO	1	10500/400 V—1000 kVA	5.7	1.1

Table 2. Specifications of the cables used in the ArenA network.

Type	R_0 (mΩ/km)	X_0 (mΩ/km)	R_0/X_0
150Al (3 × 150Al VGPLK 10 kV)	229	78	2.94
150Al X (6/10 kV 3 × 150Al + as70)	265	93	2.85
240Al (3 × 240Al VGPLK 10 kV)	139	74	1.88
240Al X (6/10 kV 3 × 240Al + as70)	162	98	1.65

3.1.2. Load Profiles of Other Loads in the Network

The urban neighbourhood around the Amsterdam Arena mainly composes of commercial buildings (entertainment centres and shopping malls), light transportation industry and residential buildings. Figures on the peak load and simultaneity of the loads, are provided by Liander. To determine detailed load profiles, we assume that the allocation of other loads (besides the stadium) in the network is 50% from commercial, 20% from industrial and 30% from residential loads. Typical normalised daily load curves of these loads are obtained from the Vision software (Version 8.10.4, Phase to Phase B.V., Arnhem, The Netherlands, see Figure 3). For the Arena stadium, detailed load figures were recorded and provided by BAM Techniek B.V. (Bunnik, The Netherlands). The provided measurements are 10-min averages of the aggregated power consumption of the entire ArenA stadium.
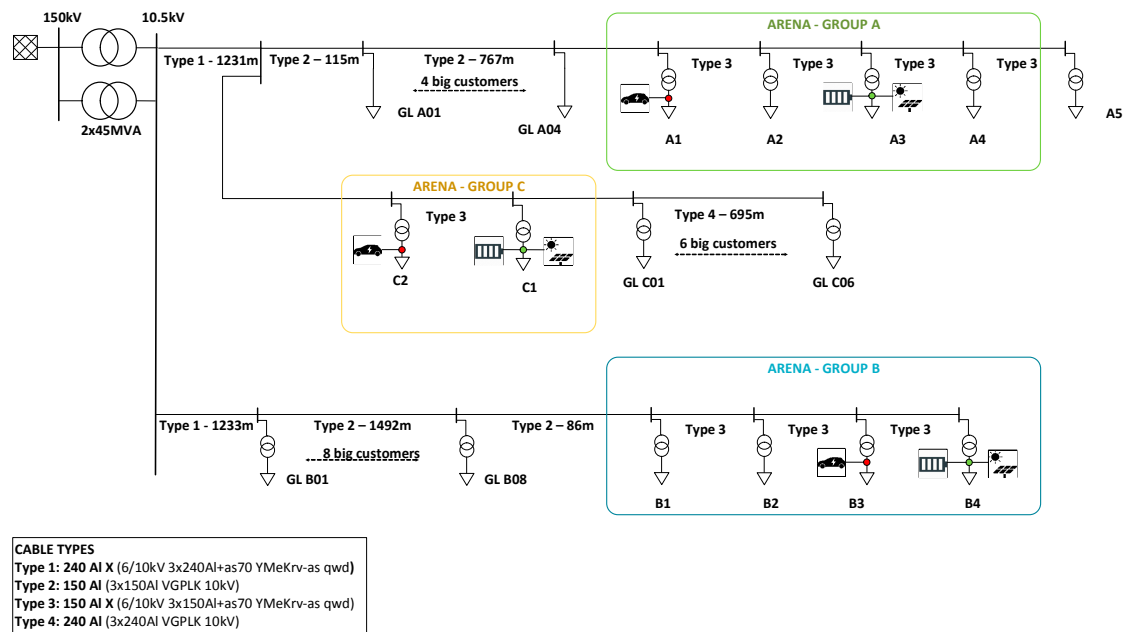
Figure 2. Single line diagram of the network supplying the ArenA. This is the network topology that is used during normal operation, with 3 groups of transformers (A–C) supplying the ArenA.
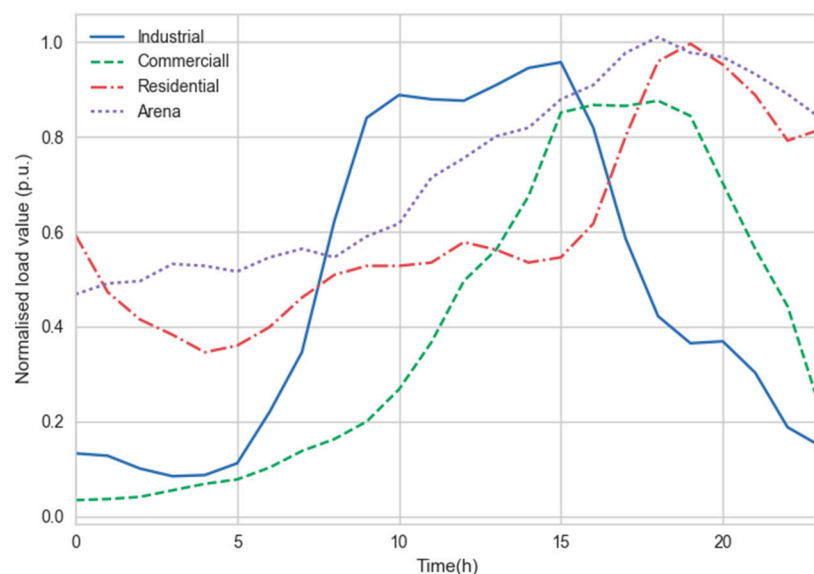

Figure 3. Normalised load profiles used for the other loads in the ArenA network in the simulation studies.

3.1.3. Power Flow Simulation Platform

To determine the hosting capacity of the network, we use the network topology and load profiles as described above as input with the support of the Vision software package [18]. As the ArenA's provided load profile is in 10-min values and the Vision software packages uses 15-min data as input, we use interpolation to obtain data for 15-min values. The used profile is typical for peak loading scenarios. These scenarios occur around events that take place inside the stadium (e.g., a football match). The used profile is depicted in Figure 4. The load is divided over the two feeders supplying the ArenA according to a division of 55% of the load on the upper feeder and 45% on the lower feeder. This division is based on the maximum peak load observed in each of the feeders from the ArenA. Furthermore, we assume that the load of the ArenA on each feeder is equally divided over the transformers supplying the ArenA connected to that feeder.
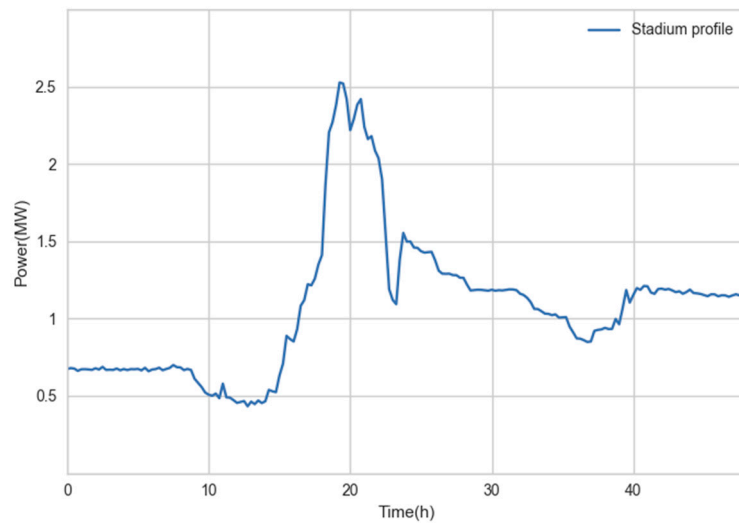
Figure 4. The load profile of the ArenA stadium used in the simulation studies.

3.2. Flexibility Models and Profile Steering

Within the case study of the ArenA network, two sources of flexibility are considered as possibilities to increase the hosting capacity. The first source is a planned electrical energy storage system using old Nissan LEAF batteries with a capacity of 4 MWh at the maximum charge/discharge rate of 4 MW (see also Section 1). The second source is the option for smart charging of the EVs in the ArenA's parking garage. Below we introduce the models used for these sources of flexibility. The models define how the flexibility can be used to alter the load profile of the ArenA and its parking garage to reduce stress on the network. These models are used within a decentralized energy management (DEM) approach. This DEM approach is described at the end of this section.

To match data available from measurements inside the ArenA and the input requirements of the power flow analysis, we work with simulations using discrete time steps of 15 min. Thus, within our models we consider a time horizon $H = \{1, 2, \ldots, T\}$ of T time intervals, each of 15 min. Our flexibility models determine the feasible load profiles of the sources of flexibility (the storage system and the EVs), i.e., the set of feasible load profiles of the appliances that offer flexibility. These sets of feasible load profiles are then used as input for the chosen DEM approach. This DEM approach determines for each source of flexibility a load profile (from its set of feasible profiles) such that together all sources of flexibility work towards a common goal.

First, we consider the planned storage system of the ArenA. This storage system is planned to be installed in late 2018, consisting of 4 MWh of second-life Nissan LEAF batteries. The goal is that the system can operate at a rated power of 4 MW, which suffices for peak shaving the ArenA's load and for serving as a backup in case of contingencies in the network. The storage system can provide flexibility by absorbing energy from the network when there is a surplus of energy or the load is low, and discharging the absorbed energy back to the network during periods of high demand (e.g., when many EVs are charging). It is important to note that the use of the storage system can directly affect the costs incurred by the ArenA by altering the peak load.

To model the planned storage system, we use a linearised model which disregards losses, i.e., the system is modelled as an ideal storage system. We recognise that in the process of implementation input/output efficiency and stationary losses are relevant for an accurate operation of the storage system. Nonetheless, in order to provide a simpler and feasible setting, this will not be taken into account for this article. We model the charging and discharging of the storage system for a time interval $t \in H$ using the variable x_t, where a negative value indicates that the system is discharging energy. The value of x_t is given in W and should not exceed the limits of the storage system. This leads to the following constraint in our model:

$$x^{\min} \leq x_t \leq x^{\max} \quad \forall t \in H, \tag{1}$$

where $x^{\min}$ and $x^{\max}$ are the discharging and charging limits of the system. Next to the charging and discharging of the battery energy storage system (BESS) we also need to determine the state-of-charge (*SoC*) of the storage system. The *SoC* for time interval t is modelled by SoC_t and is related to x_t and SoC_{t-1} as:

$$SoC_t = SoC_{t-1} + \frac{x_t}{4} \quad \forall t \in H. \tag{2}$$

where SoC_0 is the state-of-charge of the BESS at the beginning of the time horizon, which we assume to be known. At all times, the *SoC* of the battery should be between zero and the maximum capacity of the storage system, leading to the constraint:

$$0 \leq SoC_t \leq SoC^{\max} \quad \forall t \in H, \tag{3}$$

where $SoC^{\max}$ is the maximum storage capacity of the system. Because it is uncertain at this time how the storage system will be connected exactly, we modelled the planned storage system of 4 MW/4 MWh as being split according to a 2:1 ratio between the upper and the lower feeder. To accomplish this, we effectively modelled two systems, one connected to the upper feeder with a capacity of 2.67 MWh and a maximum (dis)charging rate of 2.67 MW and one connected to the lower feeder with a capacity of 1.33 MWh and a maximum (dis)charging rate of 1.33 MW.

Next to the storage system, flexibility can also be provided by smart charging of EVs connected to charging points inside the ArenA parking garage. A clear boost to electric driving is happening in the Netherlands, with the new government pushing for all new vehicles sold being electric by 2030 [20]. Furthermore, as the ArenA aims to be a frontrunner in implementing smart energy solutions we assume that a majority of the charging poles for EVs of visitors will be present in the main parking garage of the stadium (Transferium/P1). As discussed in Section 2.2 this load is separately connected to the network from the stadium's load, thus it does not contribute to the costs incurred by the ArenA from its CTA. However, with a significant penetration of EVs, grid congestions can be expected, which smart charging strategies can help to prevent [12,14,21].

To determine what smart charging of an EV entails, we need to determine the flexibility provided by an EV. This flexibility comes from the fact that most EVs do not need to be charging at full power for the entire duration they are parked to satisfy their energy demand. We assume that the EV users only require that their vehicle is fully charged by the time they want to depart (e.g., at the end of an event in the ArenA). To determine the flexibility provided by the EVs we define the set of EVs as $D = \{1, 2, \ldots, M\}$, with a total of M EVs to be charged at the ArenA garage. For EV $m \in D$, we need to ensure that the EV is charged appropriately during the time that it is parked. To ensure this we model the charging of EV m in time interval t by y_t^m and add the following constraints to our model:

$$0 \leq y_t^m \leq y_{\max}^m \quad \forall t \in H : t_a^m \leq t \leq t_d^m, \tag{4}$$

$$y_t^m = 0 \text{kW} \quad \forall t \in H : t < t_a^m \wedge t > t_d^m, \tag{5}$$

$$\sum_{t=t_a^m}^{t_d^m} y_t^m = R^m \quad \forall m \in D. \tag{6}$$

where $y_{\max}^m$ is the maximum charging rate of EV m, t_a^m and t_d^m specify the first and the last interval that the EV is plugged in and available for charging respectively, and R^m specifies the amount of energy the EV has to charge before departure. As the ArenA parking garage is also supplied by the two feeders that supply the stadium during normal operation, we split the load of the EV charging points in the same manner over the feeders as the planned storage system. This means that for every three EVs

that are modelled, two are assumed to be connected to the upper feeder and one is assumed to be connected to the lower feeder with a three-phase balanced charging points configuration.

To steer the available flexibility provided by the planned storage system and the parked EVs in and around the ArenA stadium, we use the profile steering DEM approach [21–23]. As the problem of finding optimal use of flexibility within the energy management setting is mathematically difficult (NP-hard), we use a heuristic approach [21,22]. Profile steering is an iterative scheduling approach that attempts to determine the best use of the available flexibility locally (i.e., at the device level) using target profiles to achieve a common goal among all devices. A target profile can for instance be a flat profile to steer the flexible devices towards (local) supply and demand matching and reduction of import and export peaks, or it can be a profile that was traded on an energy market. As a scheduling approach, it relies on predictions of future states in the system, such as the load of the uncontrollable devices in the ArenA and the required energy to charge into an EV and its parking duration.

The profile steering approach works in two phases. In the first, called the initial phase, only the load profiles of the inflexible devices are assumed to be known. Initial schedules for the devices are made that best fit the target profile. For example, in case the target profile is a flat profile, the EVs are scheduled such that they spread their energy consumption as much as possible over the time that they are parked. These initial schedules for the devices are combined into a single aggregated schedule for all the devices (flexible and inflexible) combined. Then, in the second phase, called the iterative phase, the flexible devices are asked to suggest updates for their scheduled load profile that change the aggregated profile to better fit the target profile. Flexible devices that suggest beneficial updates are selected and subsequently update their schedule to match the suggestion until the aggregated profile matches the target profile or no significant improvements can be obtained. The profile steering approach is implemented in the DEMKit simulation platform that simulates scenarios like our case study of the ArenA in Python programming language. For more detailed information we refer the reader to [22,23].

In our simulations profile steering has been used to aim at local energy balancing by using the zero profile. In other words, the desired profile for the flexibility is one that balances consumption and production within the ArenA network at all times. While the production capacity within the network is very limited compared to the consumption, using this profile guarantees that flexibility is used to flatten out the load profile in the network. Since higher peaks are more heavily penalised in the method through a quadratic objective, flexibility is used for the goal of peak shaving and valley filling. This is the most beneficial strategy to increase the hosting capacity. We assume that the bus bar supplying the feeders in the network is extremely unlikely to be the bottleneck in the network. This means both feeders in the network can be considered independently. Therefore, we ran the profile steering approach separately for both the upper and lower feeder with the available flexibility specified per feeder.

3.3. Specifics of the Scenarios

In this section, the four different simulated scenarios to determine how different sources of flexibility can assist the network through increasing its hosting capacity are described:

Scenario 1. This scenario is the base case in which we do not consider any flexibility. This means that the planned storage system is disregarded and the EVs that are connected charge as fast as possible.

Scenario 2. This scenario serves to determine the value of the flexibility from the planned storage system for the ArenA. In this scenario, the storage system is steered to compensate for the load caused inside the stadium, i.e., it does not consider the load put on the network by the charging points.

Scenario 3. This scenario serves to determine the value of the flexibility from the planned storage system for the DSO. In this scenario, the storage system is steered to compensate for the load in the entire network (instead of just the load of the ArenA in Scenario 2).

Scenario 4. This scenario serves to determine the value of coordinating multiple flexible sources together to achieve the goals of the DSO. Flexibility provided by the storage system and by smart

charging strategies of the EVs is combined to increase the available flexibility even further than in Scenario 3.

To be able to simulate the various scenarios, various input data are required. The description of the used input data for the ArenA's inflexible load as well as the other loads in the network can be found in Section 3.1. For the EVs we use a US survey on driving data to determine the required charge of an EV arriving [24]. This survey details data on trips from and to work, giving a discrete distribution on the required charge for an EV upon connection to a charging point. This discrete distribution is constructed over various bins of charge requirements, i.e., 0–3 kW, 3–6 kW, 6–9 kW, etc. and is depicted in Figure 5.
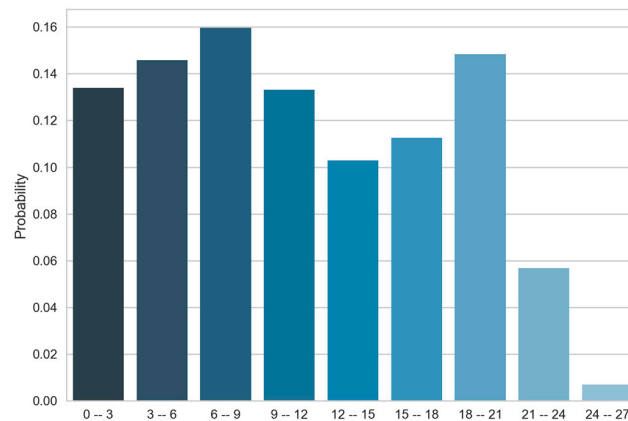
Figure 5. Probability density of the required charge of the electrical vehicle (EV) upon arrival at the ArenA.

To determine the required charge for an arriving EV (i.e., the value of R^m, see Equation (6)), we use the discrete distribution given in Figure 5 to determine the bin and sample uniformly at random from the integers inside this bin to obtain a required amount of energy to be charged in kW's. As we expect that people are inclined to travel further for events inside the ArenA, we add another 3 kW (about 15 km of driving at an efficiency of 0.2 kW/km) to the charging requirement of each EV.

Unfortunately, no accurate data was available to determine the arrival and departure times of the EVs (given by t_m^a and t_m^d, see Equations (4) and (5)). For the simulations, we assume that visitors are likely to arrive shortly before the football match that occurred during the weekend for which we took sampling data of the ArenA profile and are expected to leave shortly after. We constructed our own distribution function to determine the arrival time and duration of stay (which in turn gives the departure time), which are given in Figures 6 and 7. As the simulations use time intervals of 15 min, we use a discrete distribution over these time intervals.
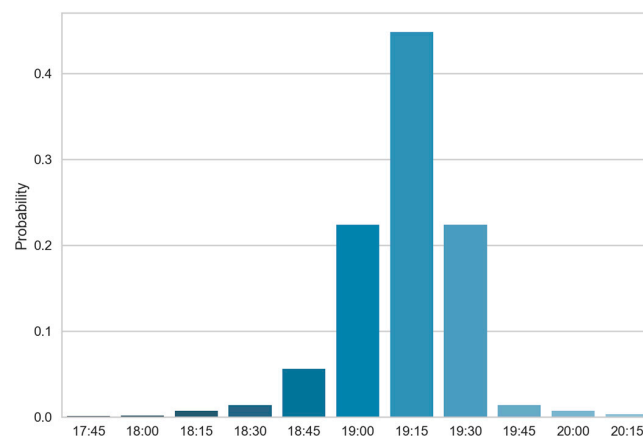

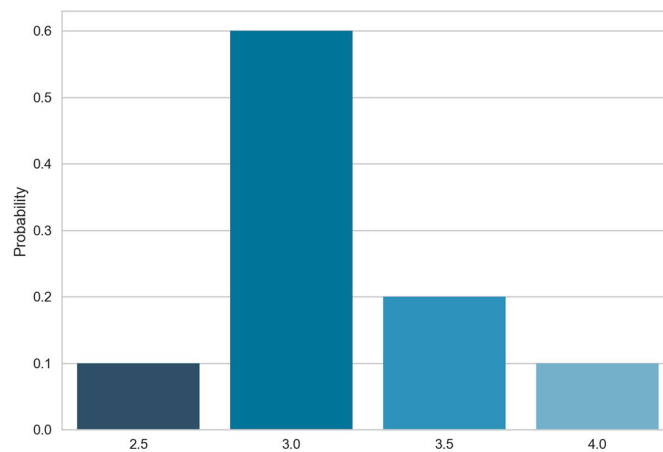**Figure 6.** Probability density of the arrival time of an EV at the ArenA.

Figure 7. Probability density of the duration of stay of an EV at the ArenA.

Each of the four scenarios described above is simulated repeatedly, with an increasing number of EVs. In each subsequent simulation the number of EVs connected to charging points is increased by 50 and data are generated for each of the new EVs according to the process described above. Data for the other EVs are kept the same to ensure consistency between the simulated scenarios.

3.4. Results

This section provides an overview for simulation results for each of the four scenarios defined in Section 2.2.

3.4.1. Scenario 1

In this scenario no flexibility is assumed to be available. This means that the battery is disregarded in this scenario and the EVs are charged as fast as possible upon arrival at the stadium. This causes a massive peak in both the upper and the lower feeder, especially when the number of EVs is large. The loads in both feeders follow a similar pattern. This is to be expected due to the symmetry between the used data and available flexibility for the two feeders. Figure 8 depicts the maximum cable loading per time interval for different numbers of EVs. As can be seen, the large peak caused by the uncontrolled charging of the EVs in the total profile of the ArenA causes significant stress on the network, even with a relatively low number of EVs connected. The results obtained for cable loading match the obtained load profiles and are similar for the two feeders. However, the cable load in the upper feeder is higher, implying that this feeder is the bottleneck for the hosting capacity. The result is that the hosting capacity of the network is only about 300 EV charging points before the upper feeder becomes overloaded (the feeder is already very stressed with 300 charging points present).
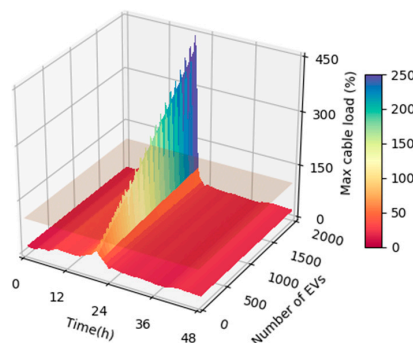

Figure 8. The maximum cable load in Scenario 1 in the upper feeder for different numbers of EVs.

The profile of the ArenA without the load of the EVs is given in Figure 4 above (see Section 4.1). The peak of this profile is 2.53 MW.

3.4.2. Scenario 2

In this scenario the flexibility provided by the ArenA storage system is used for peak shaving the stadium load (i.e., the load of the ArenA without considering the EV charging point load). The maximum cable loading of the upper feeder is given in Figure 9. Note that due to similarity again only the results for the upper feeder are plotted. The peak load of the ArenA during the event logically coincides with the EV charging point peak and is only slightly reduced compared to Scenario 1. This is because the peak consumption of the stadium (excluding the EVs) persists for a much longer time than the peak caused by EV charging (see Figure 4 in Section 4.1). Thus, to reduce the peak demand of the stadium alone, the storage system is inclined to discharge energy slower over a much longer period. This means that the peak caused by the EV charging points is not significantly reduced and the hosting capacity barely increases. In this scenario minimal overloading of the upper feeder occurs with 350 charging points connected, implying that the increase in hosting capacity between Scenarios 1 and 2 is minimal.
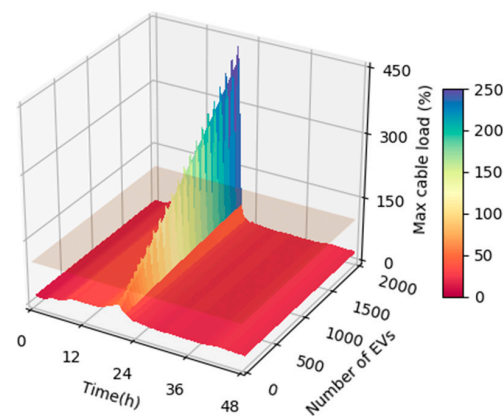

Figure 9. The maximum cable load in Scenario 2 in upper feeder for different numbers of EVs.

The adjusted profile of the stadium itself, which is changed because of the flexibility provided by the storage system, is depicted in Figure 10. The used profile steering approach ensures that the load profile is flattened out as much as possible over the considered time horizon. Thus, the storage system is used for simultaneous peak shaving and valley filling. The peak load of the stadium is reduced to 1.38 MW.
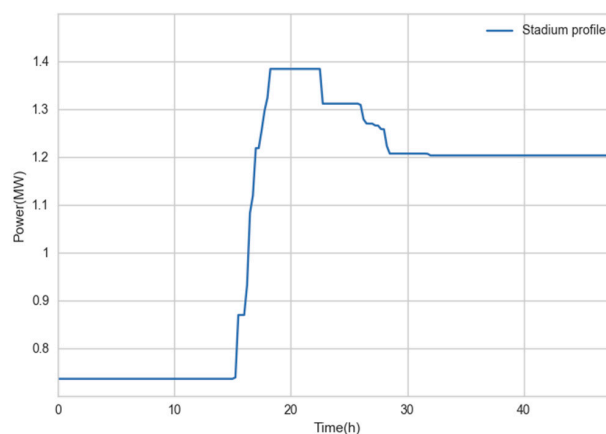

Figure 10. The total load profile of the ArenA stadium in Scenario 2. Note that this profile is the same for any number of EVs present.

3.4.3. Scenario 3

In this scenario, the flexibility provided by the ArenA storage system is used for peak shaving the load of the stadium and the EV charging points combined. The resulting cable loading in the upper feeder is given in Figure 11. In this setting, the battery discharges much energy during the peak load times of the EV charging points to compensate. This results in a significantly reduced peak, increasing the hosting capacity of the network up to 600 EVs. The stadium profile (including the planned storage system) now also depends on the number of EVs present. As the planned storage system attempts to compensate for the large EV charging peak, the load profile of the planned storage system changes very slightly between scenarios where a significant number of EVs is present. As a representative curve, we plot the load profile of the stadium with 1000 EVs present in Figure 12. Note that the planned storage system is still used to flatten out the load profile of the ArenA when it is not required to support the EVs, i.e., before and after the event finishes and the ArenA's load profile turns to normal. The maximum transported peak of the ArenA now depends on the number of EVs present and is depicted in Figure 13. In this figure, it is visible that a peak reduction of about 0.1 MW can be obtained by the ArenA in this scenario with a low number of EVs present. However, the peak reduction is reduced with a higher number of EVs present. We believe it is likely that the minor variations existing between the cases where 1500 or more EVs are due to randomness in the generated data, and are unlikely to realise in practice.
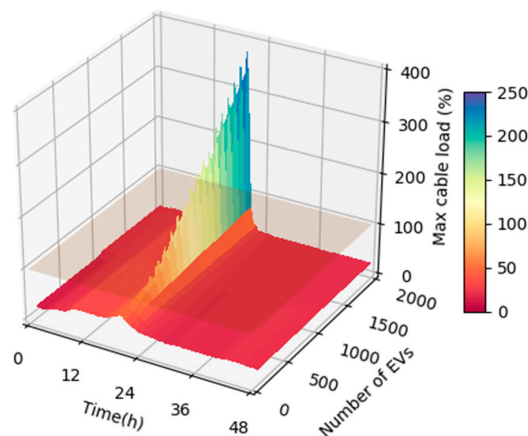

Figure 11. The maximum cable loading in Scenario 3 in the upper feeder for different numbers of EVs.
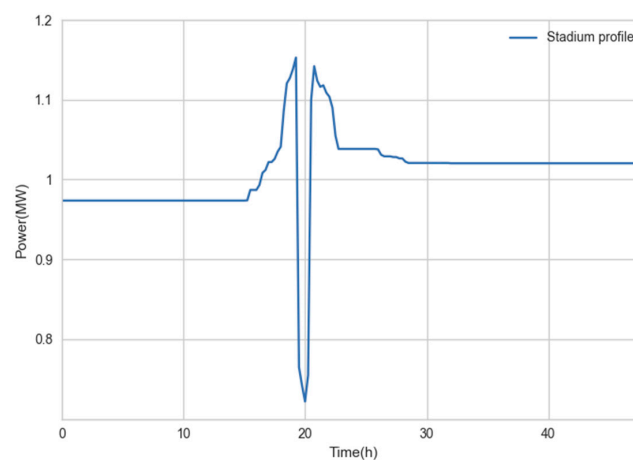

Figure 12. The total load profile of the ArenA stadium in Scenario 3 with 1000 EVs present. Now, the stadium is a net exporter of energy when the majority of the EVs are charging to compensate for their energy need and to support the network.
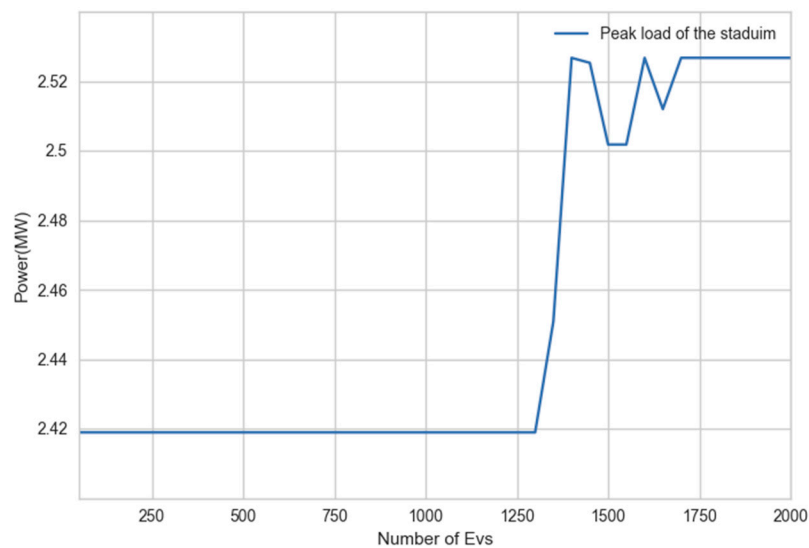
Figure 13. The maximum peak load of the stadium in Scenario 3 for different numbers of EVs. Note that the storage system is steered to best compensate for the load profile occurring in the entire feeder in this case.

3.4.4. Scenario 4

In this scenario both the flexibility from the planned storage system and the smart charging of EVs is considered. The maximum cable load in the upper feeder is given in Figure 14. Because of the applied smart charging strategies and a significant contribution of the planned storage system to the energy needs of the EVs, the peak load is further reduced in this case. This results in a hosting capacity that far exceeds that of the other cases of about 1200 EVs.
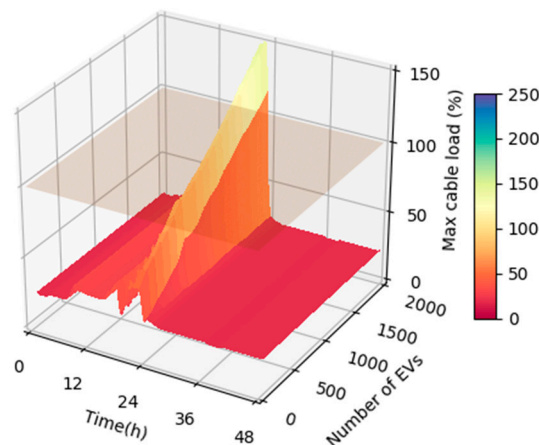

Figure 14. The maximum cable loading in Scenario 4 in the upper feeder for different numbers of EVs.

In Figure 15 the maximum peak load of the stadium (without the EVs) is given for different numbers of EVs present. It may seem counter-intuitive that the peak load of the stadium is highest when the lowest number of EVs is present. This can be explained by looking at the profile steering approach we used and the load profile of the ArenA. The approach is applied from a grid perspective in this case, meaning that it only cares about load balancing of all the loads combined on a feeder. When a smaller number of EVs is considered, the storage system can fully compensate for their peak load and other peak loads in the grid, meaning it does not discharge energy shortly after the end of the event when the peak load of the stadium is still high and nearly all EVs departed. When the number

of EVs increases, smart charging is also applied, meaning that EV charging is delayed and spread out as much as possible to lower the peak. This means that when smart charging is applied the peak load of the charging points better matches the peak load in the stadium, resulting in a discharging strategy for the battery that better aligns with the stadium peak. Finally, when the number of EVs becomes even larger (and the network is significantly under stress), the number of EVs that have to be charged fast and depart before the stadium peak decreases also becomes large. As the peak caused by these inflexible EVs becomes significant compared to the load in the rest of the network, the storage system shifts to a strategy that compensates for this high, short-duration peak. As this peak again does not cover the whole peak consumption of the stadium, the peak load of the stadium again increases.
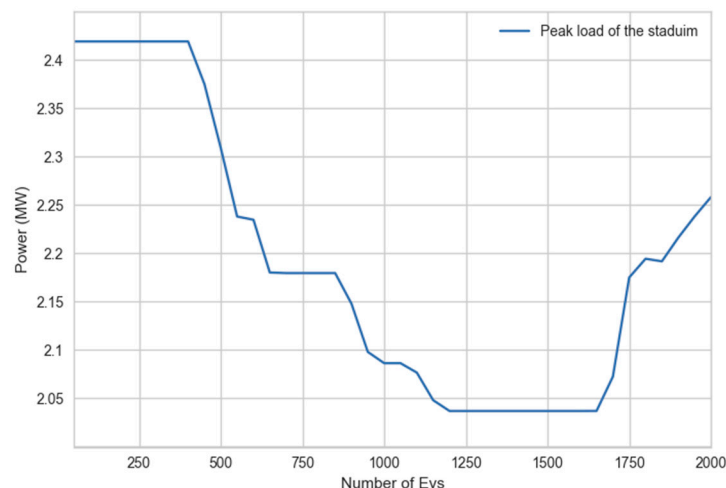

Figure 15. The maximum peak load of the stadium in Scenario 4 for different numbers of EVs. Note that the storage system is steered to best compensate for the load profile occurring in the entire feeders in this case.

On the other hand, the maximum peak of the EV charging points load profile goes down for any number of EVs when smart charging is applied, as depicted in Figure 16. However, the ratio of the peak with smart charging applied to the peak when the EV charging is uncontrolled improves when the number of EVs increases, as shown in Figure 17. This implies that, in this scenario, the peak load caused by the EVs charging is more effectively reduced when a larger number of charging points is considered. Thus, the use of flexibility for the network gives a larger percentage cost reduction for the CPO/MSP/EV user with a larger number of charging points, and hence an increased amount of flexibility, present in the system.

3.5. Discussion on the Simulation Results

As expected, the hosting capacity of the network increases significantly in the scenarios in which flexibility is used to assist the network (Scenarios 3 and 4). Nevertheless, the results indicate that the goals for which flexibility can be used by the different stakeholders do not necessarily align. For example, the reduction of the peak load of the ArenA in Scenario 3 is very limited, while a significant reduction can be obtained when the flexibility of the planned storage system is used specifically for this goal (Scenario 2). This shows that, while a system that uses flexibility from (large) consumers is technically feasible, improvements are likely required to bring such a system to practice. The approach used currently only considers a single goal. If a system or approach (like profile steering) using flexibility from customers is to be implemented, consumers are likely to be compensated for the flexibility they provide. As such, a comparison between the (expected) compensation received for aiding in achieving the overall objective and the local objectives is a required improvement for profile steering or other DEM approaches.
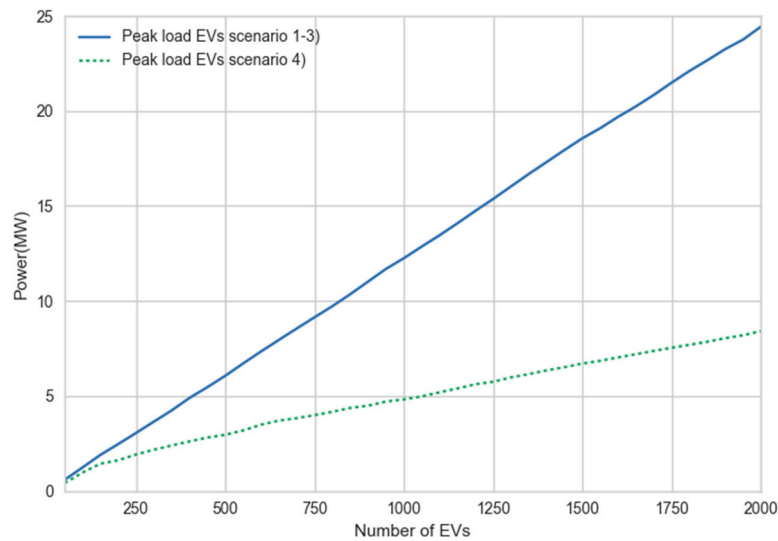
Figure 16. The maximum peak load of the EVs for both Scenarios 1–3 (no smart charging) and Scenario 4 (smart charging).
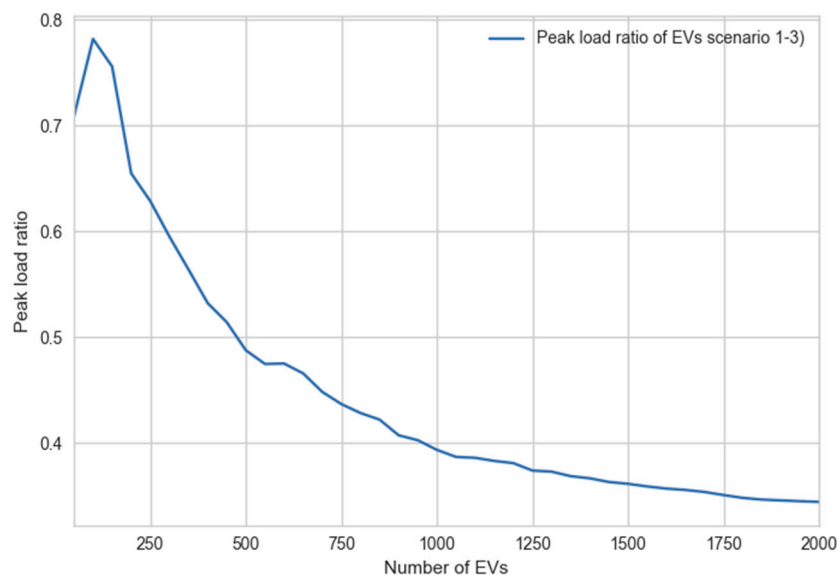

Figure 17. The ratio between the maximum peak of the EVs charging Scenario 4 and the peak of the EVs charging in Scenarios 1–3. This indicates potential savings on the costs for the charging point operator/mobility service provider (CPO/MSP) of their maximum peak load.

Within the simulation studies presented, the used profile steering approach uses abstract models of the available flexibility. These abstract models might not reflect all constraints present inside the physical components the models represent. Furthermore, some data within the simulation studies presented could be improved by basing it on actual measurements. However, in general, the results and conclusions should remain valid when taking more component specific constraints and measurement data into account. Furthermore, the profile steering approach requires predictions to schedule the use of flexibility provided by the various devices simulated. In the simulated scenarios we assumed perfect predictions are available (e.g., EVs arrive and depart exactly as predicted). Extensions to the approach exist that account for prediction errors that allow it to follow the scheduled plan quite closely [25]. Therefore, we believe that the results obtained here in, e.g., peak reduction, can also be obtained in a scenario where perfect predictions are not available.

4. Legal Aspects

Considering the case studies described in the method section, this section discusses legal issues regarding those in four subsections. Section 4.1 deals with the first case study, in which the ArenA does not perform DSM. In this subsection, the general legal framework is introduced. The second subsection discusses the second case study, in which DSM is only applied to optimize the electricity portfolio of the ArenA internally. In this setting, flexibility is only used by the ArenA to optimize its own electricity costs without taking into account the potential value of DSM for the DSO. The third subsection focuses on ArenA's flexibility and potential for solving network issues. There, a general legal framework for flexibility trade between the ArenA and the DSO is discussed. Subsection four discusses a setting in which the EVs located in the parking garage are used for solving network issues during events at the ArenA.

In order to develop the subsections, it is first necessary to understand the existing relations set between EV users, CPOs, potential service providers (e.g., MSPs), the owner of the parking garage (connection) and the DSO. Further within these relations, it is then important to understand who holds the connection(s) with the electricity system, which rights are transferred and, ultimately, who detains control over the loads in order to utilize EVs' potential to solve network issues. Finally, this section ends with conclusions drawn based on the findings of the above-mentioned interactions.

4.1. Basic Setting: Legal Framework

In order to understand the legal arrangements and interactions implied in these case studies, it is important to first analyse the relevant legal provisions established in the Dutch (and EU) legal frameworks for the electricity system. In the Netherlands, most of the electricity system is regulated by the Electricity Act (E-Act) [26,27]. The E-Act implements the basic rules defined by the Electricity Directive (E-Directive) [28], and specifies the actors and their roles in the electricity system. For the case studies considered in this article, the definitions of system users and connections are extremely relevant. A customer or system user (other than the E-Directive, the E-Act does not make a distinction) is defined in Article 1 of the E-Act as anyone having a connection to a network. In short, a connection is defined as the physical connection between a network and an immovable property. Networks are defined as the equipment and connections used for transporting electricity. Networks are operated by system operators, and more specifically, distribution networks are operated by a DSO. DSOs are to be independent from supply and production and as such are not allowed to be involved in the production, supply or trade of electricity (art. 10b E-Act). The general task of the DSO is to ensure secure, reliable and efficient electricity networks, and is further specified throughout the E-Act and more specific network codes (art. 16(1) E-Act). In order to allow consumers to make use of these networks, DSOs should offer connection and transport services to all (potential) system users by a CTA (in Dutch 'Aansluit-en transportovereenkomst'—ATO). This Agreement includes the terms and conditions for the physical connection to the distribution system and the transport services required for using such a connection. All these terms and conditions can be found in the electricity codes applicable in the Netherlands.

For the ArenA, the above setting implies that the ArenA pays a fee for the electricity it consumes, that it receives a price for the electricity it produces, and that it pays network tariffs charged by the DSO. The network tariffs are defined in the CTA and are regulated by the Tariff Code [29]. According to the Tariff Code, 50% of the network tariff for the ArenA is based on the amount of capacity it consumes (kWh), and 50% on the total peak of its consumption. For its peak-consumption, 50% (25% of the total tariff) of the ArenA's tariff is based on a contracted peak (the expected peak), and 50% (25% of the total tariff) on the actual peak, which should be below the contracted peak (art. 3.7.9 Tariff Code). If the actual peak exceeds the contracted peak, the latter will be adjusted to the highest actual peak and fixed for a period of one year (art. 3.7.11 Tariff Code). Assuming that the ArenA does not apply DSM and is unwilling to let its activities be guided by optimizing its electricity costs, the ArenA will

have little to no control over its network costs. As such, in the base case the ArenA will be paying for a relatively high peak (see Section 3.4 Scenario 1).

4.2. Demand Side Management for Optimizing Electricity Portfolio

In the E-Act, no definition of DSM can be found. However, DSM is defined in the E-Directive as influencing the amount and timing of electricity consumption (article 2(29) E-Directive) (also see Section 2.1 and for further details [30]). Although DSM could be used for achieving different goals, the DSM in the second case study aims at optimizing the ArenA's own electricity costs. In this setting, the ArenA would be interested in adjusting its costs for electricity consumption and its network costs. To optimize the costs of its electricity consumption, the ArenA would need an electricity supply agreement in which flexible prices that reflect the actual wholesale market prices are integrated. For optimising its network charges, it could reduce its costs by lowering the contracted and actual peak by spreading its consumption. Also, it could try to consume as much of its own produced electricity as possible to lower the capacity consumption charge. In the technical study performed above we specifically considered optimising towards network charges, as these are currently in place (see Section 4.1). Such part of the study has, therefore, shown that the current legal framework does not pose any obstacles for the ArenA to apply the strategies proposed there.

4.3. Demand Side Management for Solving Network Issues

For the third case study, a setting in which the ArenA would trade DSM with the DSO is considered. For trading flexibility between system users, in our case study, the ArenA and the DSO, several trade arrangements can be used [31–34]. The most obvious option is using the CTA. Because it is already present, it seems easy to include DSM into the CTA. For example, it could include a flexibility component in which the system user could utilize its capacity in a flexible manner. However, in the Netherlands the CTA as used today has a binding formula which does not allow for flexibility trade to be included. Currently, the peak is set on the basis of a one-month period, and all components only take into account the connection size and the amount of capacity used, not the time of usage (see Section 4.1). To allow flexibility to be integrated into the CTA, also timing of consumption needs to be taken into account.

Other options for trading flexibility between the ArenA and the DSO are to use dedicated bilateral trade agreements or trade platforms. Bilateral trade agreements (hereafter referred to as DSM agreements) can either be based on standardized agreements or be tailor made. Trade platforms are an indirect form of trading where DSOs and system users make their bids and, at the end, the market price is set and the market is cleared (by the market operator). Such trade platforms can be accessed directly by system users, or could be accessed by service providers (e.g., aggregators) on behalf of system users.

Using DSM agreements and trade platforms is not restricted by fixed contract terms. However, general rules of electricity system regulation (e.g., balance responsibility requirements [35]), and also, from competition law and trade regulation (e.g., transparency requirements from the Regulation on wholesale energy market integrity and transparency (REMIT) [36]) apply. These rules might pose restrictions to DSM agreements and to the use of trade platforms. It is, therefore, well possible that the proposed solutions in Scenario 3 of the technical simulation study (see Section 3) are currently not possible to achieve from a legal perspective. However, it is beyond the scope of this article to assess all potential limitations stemming from these regulations. Also, the restrictions might be very different from case to case.

4.4. Demand Side Management from Electrical Vehicles

For the fourth and last case study, a more complicated setting exists. In this setting a significant number of (potential) actors are active: EV users, MSPs offering charging services, the operator of the charging point, the CPO, the system user, possessing the connection of the parking garage,

and the DSO. In order to analyse these relations, current standard agreements and terms and conditions between the actors in the case, Allego and Vandebron and the customers (EV users) are used by the authors as a base to explain the situation in the ArenA and to make a reflection on the options at hand for using the EV-fleet for DSM purposes by the DSO.

The above helps in identifying who might have control over the load-pattern of the EVs once connected to the electricity system. However, it does not provide an exclusive answer as to who is able to decide how the load-pattern of the EVs is defined. In order to answer which party eventually has control over the EV-loads, two questions arise. The first question regards the relation of the EV customer with the electricity system: who should be identified as system user? In order to find the answer to this question, it is first of all important to understand how the EV is connected to the electricity system. Eventually, the system user should be considered the person 'in control' of the system connection. The second question regards the relation between the EV customer and the MSP: how should the services (charging) of the MSP be defined in the framework of the E-Act? The answer to this question defines how service agreements between EV customers and MSPs could or should look like (and who is in control of how the system connection might be used).

Firstly, considering the questions 'who should be considered as the system user' and 'how the EV is connected to the electricity system', a number of observations can be made. The first is that an EV is connected to a charging point. In turn, this charging point can either be connected directly to the electricity system, or to another installation (which is the legal term for properties connected to the electricity system) [37].

This is also illustrated by Figure 18. In the first case, the charging point is an installation. In the second, the charging point is part of an installation, that is, not the whole installation itself. It is, hereby, important to note that a connection can only exist between the system and an immovable property (art. 1(1)(b) E-Act and art. 16(a)–(e) *Wet waardering onroerende zaken*) [38]. As such, the connection between the charging point and the EV cannot be considered as a connection as defined in the E-Act. The second observation is that the entity 'having' the connection can either be the owner of the charging point, the owner of the installation to which the charging point is connected, or the MSP that is using the charging point (art. 24 E-Act). According to the E-Act, the entity 'having' the connection should be considered the customer (art. 1(1)(c) E-Act). More specifically, this does not necessarily mean the entity owning the connected installation, but rather the entity that possesses the connection to such an installation. For example, tenants neither own a house, nor a connection, instead, they possess the connection, as they have the right to freely decide how to use it, and are able to pass this right on to other persons [39]. In this setting, the entity having the connection also has a contract with the DSO, the CTA. Turning to the question of who has control of the connection, the answer depends on what has been agreed between the owner of the installation and the person using the connection. In principle, the owner of the installation can (either implicitly or explicitly) grant the right to possess (have) the connection to other parties. Even further, these parties too, could, in principle, transfer the right to possess the connection to others. Hence, also the EV customer could be provided the right to have the connection. Despite that the connection between the charging point and the EV cannot be considered as a connection as defined in the E-Act, the EV customer could still possess the connection of the charging point itself.

Regarding the system connection in the setting of this study, the charging points are part of an installation (the parking garage) and use the connection of this installation. In the future, however, the charging points can be technically sharing the connection with the parking garage, but still be considered as a separate installation (and be considered as such). This can be arranged by creating a virtual transfer point (as if there is a separate connection) for each of the charging points and the network, or a group of charging points [40]. The virtual transfer point also enables the DSO to incentivize those in control of the connection to provide DSM services. Given the different interests and goals of the parties involved in EV charging, it is necessary that specific incentives are provided indivually to each of the parties. Once the charging points are (virtually) separated from the installation

with which they share the connection, it creates the possibility for one, or a group of charging points to be separately controlled. For example, only then the customer, most likely the CPO or the MSP, will be able to limit the use of the connection by including terms in the agreement with the MSP or EV customer, respectively. For example, the customer, most likely the CPO or the MSP, can limit the use of the connection by including terms in the agreement with the MSP or EV customer, respectively.
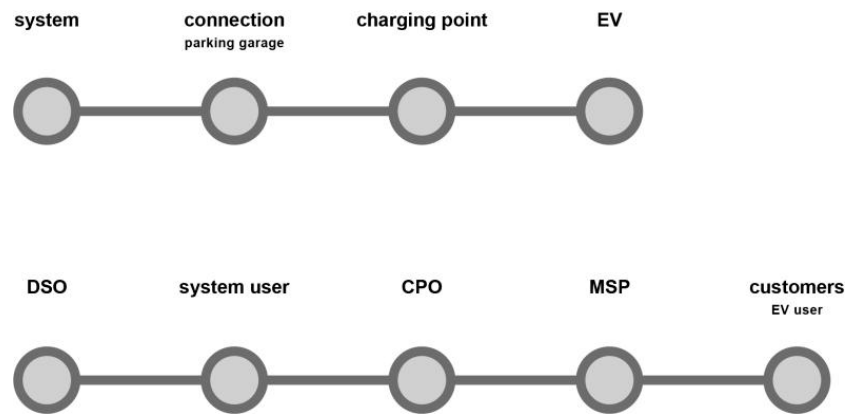

Figure 18. In this figure you can find the above described chain of relations. The upper sequence represents the 'physical' components as recognized by law, the lower sequence represents the actors.

Secondly, when analysing charging within the framework of the E-Act, it is relevant to define whether charging can be defined as 'supply'. If not, charging falls completely outside the scope of the E-Act. In defining 'charging' and 'supply' it is important to note that when the E-Act was introduced its intended scope was system-bound supply. This means the E-Act aimed at regulating electricity supply to consumers that are connected to the electricity system (system users). The goal was to exclude non-system bound supply of electricity, such as the sale of alkaline batteries, and the resell in installations (e.g., guests using and paying for electricity in hotels etc.). Nevertheless, despite that the E-Act defines 'suppliers' and 'customers', the E-Act does not include a definition for supply itself. When looking beyond the E-Act, the E-Directive does provide a very general definition of supply: supply takes place between suppliers and consumers of electricity (art. 2(19) E-Directive).

The question whether charging could be classified as supply as defined in the E-Act was also addressed by the Dutch national regulatory authority (NRA), the ACM [41]. The NRA has presented the following line of reasoning in the case of the CPO (Allego) where it was brought to discussion whether its activity towards EV users were to be considered as the supply of electricity. The NRA understood that the CPO was not the system user because it was not actually consuming the electricity itself. That is, the electricity taken from its connection was not dissolved by use but, instead, it was entirely passed on to the EV user. Therefore, in this case, the NRA considered that electricity is being supplied from the charging point to the EV.

Provided that charging should be considered as 'supply', a follow up question arises: what are the consequences of this conclusion? In order to answer this question, it is relevant to define who can be considered a 'customer' according to the E-Act. Supply to customers and supply to others, both, as defined in the E-Act, need to be performed by an entity that should be defined as a supplier. However, different rules apply to suppliers when supplying customers as defined in the E-Act or when supplying customers that are not defined as customers (art. 1(1)(c) E-Act). If a supply agreement with a customer is in place, all requirements of the E-Act are applicable. Potentially, even the most stringent requirements, those applicable to small consumers, might apply (art. 95a(1) E-Act). Therefore, we assess which of the parties can be defined as 'customer' as defined in the E-Act. Potentially, the CPO, MSP and the EV customer could be defined as customer.

When turning to the E-Act, as mentioned above, the 'customer' (which is also the system user, since the E-Act makes no distinction) is the person that 'has' the connection. If the charging point is part of an installation, the CPO can use the connection, but does not necessarily possess the connection. However, again, possession can be transferred to other actors. For example, the operator of the garage could give the CPO the right to possess part of its system connection. This right can be further transferred to other parties, such as to the MSP and, in its turn, from the MSP to the EV customer. Hence, the customer would potentially be the last party to have received the possession of the connection.

Linking the above theory to the case study, we identified the following situation. At the ArenA parking garage, the charging points are operated by 'Allego' [42]. By default, the charging services provided at these charging points are provided by 'Vandebron', a Dutch electricity supplier and MSP [43]. In this setting, Vandebron uses the infrastructure of Allego to provide 'mobility services' (charging). The terms for this use are largely stated in an interoperability agreement [44]. In turn, Vandebron will have an agreement, e.g., to use a charging card with the EV customer. This agreement is subject to the general terms and conditions applicable to the charging card, used by the EV customer to activate the charging point [45]. In these terms and conditions, it is stated that the terms of the CPO (Allego) are applicable (art. 3.7), and that Vandebron cannot be held liable for malfunctioning of charging points, or interruptions of the charging (art. 13.2). Also, according to the interoperability agreement, Allego cannot be held liable for indirect damages of the malfunctioning of charging points (7.1 Interoperability agreement). In principle, this means that users cannot claim damages if a charging point is not working. More specifically, Allego has more or less the discretion to decide how and if the point is active; users merely have a right to access the point (art. 1.3 Interoperability agreement).

In finding the party that will eventually have control over the loads of the charging point, it seems like Allego is able to impose terms and conditions that allow it to control the loads. The current interoperability agreement does not define how charging should take place, or that charging implies the right to always use maximum power from the charging point. Even if the agreement would be interpreted as to provide such a right, the agreement is only valid for two years (art. 4.1 Interoperability agreement), meaning that it could be amended after that period. Also, Vandebron could, within the availability of the charging point, control the load of the charging. Ultimately, also the EV customer could control the load, up to the extent that Allego and Vandebron have not already done so. Assuming that both Vandebron and Allego do not control the charging by controlling power at the charging point, the EV customer has control. However, this cannot be passed on to third-parties without prior consent of Vandebron (art. 12.2 general terms and conditions).

Now turning to the arrangements that could be made trading DSM between the DSO and the entity in control of the loads at the charging point, similar questions arise as to the case of the ArenA providing DSM to the DSO. The CTA, although currently limited (see Section 4.3), could be considered. However, the CTA can only be used between the system user and the DSO. In the case of the ArenA, most likely, the system user will be the operator of the parking garage, as a connection is made between the installation of the garage and the electricity system. Currently, the charging point is not considered as a separate installation (although it can be in the future). Obviously, the mobility service agreement, between the MSP and the EV customer could be used to integrate terms that allow for DSM trade between the DSO and the MSP. However, this would not be a trade instrument to be used between the DSO and the MSP. In this case, the mobility service contract would only facilitate such a trade. Alternatively, DSM agreements between the MSP and the DSO could be considered as an option. Yet, it would only be possible to assume that the MSP can enter into agreements and deliver if it has control over what happens at the connection. This would equally be the case for trade platforms (see Section 4.3).

4.5. Conclusions

Currently, the DSO is a regulated entity in the electricity system with the task of operating, maintaining and developing efficient electricity distribution. However, with the changing aspects of the electricity system, such as an increasing participation of renewables, new technologies and actors, also the way in which the DSO performs its tasks could be adjusted to ensure an efficient electricity system in the future. One way of doing so would be to use DSM. Different actors such as large customers (e.g., the ArenA), CPO, MSP, and EV customers can potentially contribute to solving network issues by means of DSM.

The offer of flexibility that would assist the system operator in the future could be facilitated by currently existing agreements. The CTA between the DSO and system user, and the mobility service agreement between the MSP and the EV customer, are considered by the authors as viable legal instruments, if alterations to the standards currently used would be made. Regarding the potential of EVs, and the position of the CPO, MSP and EV customers, it is important to have clearly identified in the agreements who possesses the connections, and which rights with regard to the use of such a connection are passed on and to whom. Moreover, the agreements between CPO, MSP and EV customer are relevant in order to assess which of these parties has the ability to deliver the DSM. Only then, parties will be able to meet their legal obligations in e.g., the CTA, a DSM agreement or a trade platform to trade DSM with the DSO. In any case, for the ArenA it is currently possible to trade DSM with the DSO by using both DSM agreements and trade platforms.

5. Discussion and Conclusions

Within this article, we looked at the technical and legal aspects of using flexibility from large customers to support the local electrical network. Specifically, we considered the network surrounding the Amsterdam ArenA in a case study where futuristic scenarios involving a large number of EV charging points are analysed. In the scenarios presented, we varied the available flexibility and the way it is used in order to answer the research question using this case study. The hosting capacity of the network is used as a key performance indicator of the provided flexibility value.

As expected, using flexibility to specifically reduce the peak loads in the network significantly increases the hosting capacity of the distribution system. This means there is a clear benefit to the DSO for using flexibility. This indicates that facilitating the trading of flexibility between the DSO and the ArenA (and potentially the CPO/MSP) has beneficial implications for the electricity system as a whole.

An important aspect that remains is defining the value of flexibility for the various parties. For the ArenA and the CPO/MSP, a portion of the value is clearly determined through the connection and transport agreement. For large customers, about 25% of the monthly electricity bills comes from their monthly maximum transported peak (see Section 4.1). Assuming that the conditions simulated are maximum loading conditions, and other peaks in loads of the stadium occur under similar conditions, we find a reduction in the peak of 55%, resulting in a cost reduction due to the CTA of about 14%. Yet, this reduction is completely lost when the storage system's flexibility is used to compensate for EV charging in the parking garage.

Regardless of the specific conditions, smart charging EVs should reduce the connection and transport costs of the CPO/MSP (see Figures 16 and 17). However, the findings suggest that the percentage reduction in cost is much smaller that when a small number of EVs is present, similar to the results obtained for the ArenA. This supports the conclusions reached before (see Section 3.5) that local objectives also need to be considered when using flexibility of (large) customers to ensure their participation.

The value of flexibility for the DSO is given in terms of the hosting capacity instead of a monetary value. A translation from hosting capacity to monetary value is highly dependent on the conditions of the network (e.g., expected remaining lifetime of the assets and type of cables and transformers used) as well as many other variables (e.g., expected load increase in the system). If an approach such as profile steering is to be used to increase the hosting capacity, a more detailed analysis of the value of

the flexibility for the DSO is required. It is important that the DSO gains more value from the system than the ArenA loses in extra costs for its connection and transport agreement, as the ArenA will surely need to be compensated for these costs to be inclined to participate.

The above discussion along with the results brought by the simulation studies indicate that, given sufficient value of flexibility for the DSO, a system that uses flexibility from (large) customers is technically and economically viable. From a legal point of view, despite that the current CTA cannot be used, other options for trading flexibility between the DSO and (end) users are present. Nevertheless, limitations for trading flexibility might still be found in the efficiency of such agreements. Also, trade agreements are subject to requirements from electricity market regulations. These regulations could hinder at least some forms of DSM-trade. From a more general perspective, also the role of the DSO should be taken into consideration. Taking into account the unbundling requirements, it can be debated whether the DSO should be active in utilizing flexibility. Provided that utilizing flexibility might also change the dynamics of the current electricity market, and that current access conditions might also be changed, it can be questioned whether the DSO is currently expected or even allowed to cause such changes.

Applying a broader perspective to the above discussion, and taking it to the system level, one more issue becomes evident: the reallocation of system costs. As identified from the Arena case-study, Scenario 3, although the ArenA would be participating in assisting to reduce the costs of the distribution system, this behaviour would be creating extra costs for the ArenA itself. Even of further concern is the fact that once users providing DSM services to the DSO need to be rewarded for their contribution in increasing system efficiency with the counter effect that users not providing DSM would not be rewarded. Consequently, non-DSM providers might end up paying relatively higher network tariffs. System costs are normally shared amongst all system users. Because more system users are divided into more different classes, the existing user classes become more segregated. Consequently, a redistribution of costs and benefits in the existing user classes is bound to happen [46]. Ultimately, in the scenario when not all system users start providing DSM, those not providing DSM will not only be unable to reduce their own system costs, but also are likely to share in the costs for compensating the costs made by the DSO in purchasing DSM from DSM providing users. Hence, the difference between the system costs becomes higher [47]. This effect needs to be taken into account when defining the 'reward' DSM providers receive when providing their flexibility to the DSO.

In that context, it is also relevant to mention that although different tariffs for current classes of system users (that are considered to be equal system users) are seen as an option to incentivise load peak reductions and might provide an efficient tariff scheme, under certain tariff designs they might be perceived as 'unfair' by the system users. As discussed by Neuteleers et al. the concrete tariff implementation plays an important role in setting prices that clearly associates with revenues needed to maintain the grid, in providing predictable prices, and in using clear arguments [48]. In setting such tariffs for the future electricity system, this is likely to result in a complex puzzle.

Finally, focusing on a more general perspective, there is the issue of how energy policy can integrate and protect both flexibility from DSM providers which supports the distribution system to have sufficient capacity, and non-DSM providers and/or vulnerable consumers which for various reasons (e.g., technical, based on their location in the network topology, or economic reasons based on their income) might be unable to participate. On the one side, fostering participation of consumers in offering flexibility is an efficient way of improving performance of the electricity system. On the other side, consequences of rewarding active consumers should be studied as they are likely to impact the connection and transport costs of all electricity consumers.

Author Contributions: Performance of the simulation studies presented within the technical aspect of the article was carried out in collaboration among Maryam Haji Ghasemi, Niels Blaauwbroek, Thai H. Vo and Thijs van der Klauw. The legal studies were performed by Dirk Kuiken and Heyd F. Más. Supervision of the project was carried out by Phuong H. Nguyen. The article was written jointly by Dirk Kuiken, Heyd F. Más, Maryam Haji Ghasemi, Niels Blaauwbroek, Thai H. Vo and Thijs van der Klauw. This article is prepared in a joint research consortium, all authors have contributed equally to this publication and are listed according to the alphabetical order of first names, except for the corresponding author and supervisor.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

CPO	Charging Point Operator
CTA	Connection and Transportation Agreement
DEM	Decentralized Energy Management
DSM	Demand Side Management
DER	Distributed Energy Resources
DSO	Distribution System Operator
EU	European Union
EV	Electrical Vehicle
RES	Renewable Energy Sources
MSP	Mobility Service Provider
NRA	National Regulatory Authority
TSO	Transmission System Operator

Nomenclature

H	Set of time intervals used within the simulations.
x_t	Charging or discharging value of the planned storage system for interval t.
$x^{\min}$	Minimum charge/discharge value for the planned storage in any time interval.
$x^{\max}$	Maximum charge/discharge value for the planned storage in any time interval.
SoC_t	State-of-charge of the planned storage system in interval t.
$SoC^{\max}$	Maximum state-of-charge of the planned storage system.
D	Set of EVs used within the simulations.
y_t^m	Amount of energy charged into EV m in time interval t.
$y_{\max}^m$	Maximum amount of energy charged into EV m in any time interval.
t_a^m	Time interval EV m arrives at the stadium.
t_d^m	Time interval EV m is schedules to leave the stadium.
R^m	Amount of energy that needs to be charged into EV m while parked at the stadium.

References and Note

1. Nykamp, S.; Bosman, M.; Molderink, A.; Hurink, J.L.; Smit, G.J.M. Value of distributed storage—Competition or cooperation of stakeholders? *IEEE Trans. Smart Grid* **2013**, *4*, 1361–1370. [CrossRef]
2. Siano, P. Demand response and smart grids—A survey. *Renew. Sustain. Energy Rev.* **2014**, *30*, 461–478. [CrossRef]
3. Deng, R.; Yang, Z.; Chow, M. A Survey on Demand Response in Smart Grids: Mathematical Models and Approaches. *IEEE Trans. Ind. Inf.* **2015**, *11*, 570–582. [CrossRef]
4. Kok, K. The PowerMatcher: Smart Coordination for the Smart Electricity Grid. Ph.D. Thesis, Vrije Universiteit, Amsterdam, The Netherlands, 2013.
5. Iacovella, S.; Ruelens, F.; Vingerhoets, P.; Claessens, B.; Deconinck, G. Cluster Control of Heterogeneous Thermostatically Controlled Loads Using Tracer Devices. *IEEE Trans. Smart Grid* **2017**, *8*, 528–536. [CrossRef]
6. Mohsenian-Rad, A.H.; Wong, V.W.S.; Jatskevich, J.; Schober, R.; Leon-Garcia, A. Autonomous demand-side management based on game-theoretic energy consumption scheduling for the future smart grid. *IEEE Trans. Smart Grid* **2010**, *1*, 320–331. [CrossRef]
7. Alam, M.R.; St-hilaire, M.; Kunz, T. Computational Methods for Residential Energy Cost Optimization in Smart Grids: A Survey. *ACM Comput. Surv.* **2016**, *49*, 2. [CrossRef]

8. Barbato, A.; Capone, A. Optimization models and methods for demand-side management of residential users: A survey. *Energies* **2014**, *7*, 5787–5824. [CrossRef]

9. Vardakas, J.S.; Zorba, N.; Verikoukis, C.V. A Survey on Demand Response Programs in Smart Grids: Pricing Methods and Optimization Algorithms. *IEEE Commun. Surv. Tutor.* **2014**, *17*. [CrossRef]

10. NOW. Distributed Intelligence for Smart Power routing and mATCHing (DISPATCH). Available online: https://www.nwo.nl/en/research-and-results/programmes/URSES+-+Uncertainty+Reduction+in+Smart+Energy+Systems/distributed+intelligence+for+smart+power+routing+and+matching (accessed on 30 November 2017).

11. Krüger, H. *European Energy Law and Policy*; Edward Elgar: Cheltenham, UK, 2016; ISBN 9781786430359.

12. Hoogsteen, G.; Molderink, A.; Hurink, J.L.; Smit, G.J.M.; Kootstra, B.; Schuring, F. Charging electric vehicles, baking pizzas, and melting a fuse in Lochem. *CIRED Open Access Proc. J.* **2017**, *2017*, 1629–1633. [CrossRef]

13. Nykamp, S.; Rott, T.; Dettke, N.; Küppers, S. The project "ElChe" Wettringen: Storage as an alternative to grid reinforcements—Experiences, benefits and challenges from a DSO point of view. In Proceedings of the International ETG Congress on Die Energiewende, Bonn, Germany, 17–18 November 2015; pp. 521–526.

14. Clement-Nyns, K.; Haesen, E.; Driesen, J. The impact of charging plug-in hybrid electric vehicles on a residential distribution grid. *Power Syst. IEEE Trans.* **2010**, *25*, 371–380. [CrossRef]

15. Strbac, G. Demand side management: Benefits and challenges. *Energy Policy* **2008**, *36*, 4419–4426. [CrossRef]

16. Humayun, M.; Degefa, M.Z.; Safdarian, A.; Lehtonen, M. Utilization improvement of transformers using demand response. *IEEE Trans. Power Deliv.* **2015**, *30*, 202–210. [CrossRef]

17. Government of the Netherlands. *Coalition Agreement 'Confidence in the Future'*; Government of the Netherlands: The Hague, The Netherlands, 2017.

18. PhaseToPhase Vision Network Analysis. Available online: http://www.phasetophase.nl/nl_products/vision_network_analysis.html (accessed on 27 December 2017).

19. Craig, P.; de Búrca, G. *EU Law: Text, Cases, and Materials*, 6th ed.; Oxford University Press: Oxford, UK, 2015; ISBN 9780198714927.

20. Government of the Netherlands. Problem-Free Electric Driving in the Benelux. Available online: https://www.government.nl/topics/environment/news/2017/12/07/problem-free-electric-driving-in-the-benelux (accessed on 27 December 2017).

21. Gerards, M.E.T.; Toersche, H.A.; Hoogsteen, G.; Van Der Klauw, T.; Hurink, J.L.; Smit, G.J.M. Demand side management using profile steering. In Proceedings of the 2015 IEEE Eindhoven PowerTech, Eindhoven, The Netherlands, 29 June–2 July 2015. [CrossRef]

22. Van Der Klauw, T. Decentralized Eneergy Management with Profile Steering. Ph.D. Thesis, University of Twente, Enschede, The Netherlands, 2017.

23. Hoogsteen, G. *A Cyber-Physical Systems Perspective on Decentralized Energy Management*; Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO): Enschede, The Netherlands, 2017. [CrossRef]

24. Idaho National Laboratory. *Workplace Charging Case Study: Charging Station Utilization at a Work Site with AC Level 1, AC Level 2, and DC Fast Charging Units*; Idaho National Laboratory: Idaho Falls, ID, USA, 2014.

25. Hajighasemi, M.; Hurink, J.L.; Smit, G.J.M. Planning Based Real-Time Control Using DEMKit. In Proceedings of the PowerTech, Manchester, UK, 18–22 June 2017.

26. Elektriciteitswet 1998 (Electricity Act), Stb. 1998. Available online: http://wetten.overheid.nl/BWBR0009755/ (accessed on 27 December 2017).

27. Roggenkamp, M. Energy Law in the Netherlands. In *Energy Law in Europe*; Roggenkamp, M., Redgwell, C., Ronne, A., del Guayo, I., Eds.; Oxford University Press: Oxford, UK, 2016; ISBN 9780198712893.

28. Directive 2009/72/EC repealing Directive 2003/54/EC of the European Parliament and of the Council concerning common rules for the internal market in electricity (Electricity Directive) [2009] OJ L211/55.

29. Tarievencode Elektriciteit, 21 April 2016 (Tariff Code), Stcrt. 2016, 21426. Available online: http://wetten.overheid.nl/BWBR0037951/ (accessed on 27 December 2017).

30. Leal-Arcas, R.; Lesniewska, F.; Proedrou, F. Smart Grids in the European Union: Assessing Energy Security, Regulation & Social and Ethical Considerations. *Columbia J. Eur. Law.* **2017**. Forthcoming; Queen Mary School of Law Legal Studies Research Paper No. 263/2017. Available online: https://ssrn.com/abstract=3062957 (accessed on 27 December 2017).

31. Eid, C.; Codani, P.; Perez, Y.; Reneses, J.; Hakvoort, R. Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design. *Renew. Sustain. Energy Rev.* **2016**, *64*, 237–247. [CrossRef]

32. Ramos, A.; De Jonghe, C.; Gómez, V.; Belmans, R. Realizing the smart grid's potential: Defining local markets for flexibility. *Util. Policy* **2016**, *40*, 26–35. [CrossRef]

33. Koliou, E. Demand Response Policies for the Implementation of Smart Grids. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2016.

34. USEF: The Framework Explained. Available online: https://www.usef.energy/download-the-framework/ (accessed on 27 December 2017).

35. Nobel, F.A. *On Balancing Market Design*; Technische Universiteit Eindhoven: Eindhoven, The Netherlands, 2016.

36. Mäntysaari, P. *EU Electricity Trade Law: The Legal Tools of Electricity Producers in the Internal Electricity Market*; Springer International Publishing: New York, NY, USA, 2015; ISBN 9783319165127.

37. Baljon, L. Juridische aspecten van het plaatsen van laadpalen voor elektrisch vervoer. *Nederlands Tijdschrift Voor Energierecht* **2015**, *2*, 66–74.

38. Wet Waardering Onroerende Zaken, 15 December 1994, Stb. 1994. Available online: http://wetten.overheid.nl/BWBR0007119/ (accessed on 27 December 2017).

39. Reehuis, W.H.; Heisterkamp, A.H.T. *Goederenrecht*; Kluwer: Deventer, The Netherlands, 2006.

40. Codebesluit Meerdere Leveranciers op een Aansluiting, 17 July 2017, Stcrt. 2017, 39821. Available online: zoek.officielebekendmakingen.nl/stcrt-2017-39821.html (accessed on 27 December 2017).

41. ACM. ACM/DE/2016/2005880V, 15.0772.53 Afsluiting Onderzoek Activiteiten Allego. Available online: https://www.acm.nl/sites/default/files/old_publication/publicaties/15461_brief-acm-afsluiting-onderzoek-activiteiten-allego-2016-02-08.pdf (accessed on 27 December 2017).

42. Allego. Available online: https://www.allego.eu/?sl=eu (accessed on 27 December 2017).

43. Vandebron (only in Dutch). Available online: https://energie.vandebron.nl/elektrisch-rijden-pr (accessed on 27 December 2017).

44. Allego. "Overeenkomst Met Betrekking tot Interoperatibiliteit Openbare Oplaadpunten Elektrisch Vervoer" (Interoperatibility Agreement). Available online: https://www.allego.eu/wp-content/uploads/2015/07/Allego-vs-MSP-InteroperabiliteitsContract-Standaard-v.201507.pdf (accessed on 27 December 2017).

45. Vandebron. "Algemene Voorwaarden Laadpas" (General Terms Charging Card). Available online: https://vandebron.nl/assets/pdf/Algemene_voorwaarden_Laadpas_2017.pdf (accessed on 27 December 2017).

46. Pérez-Arriaga, I.J. *Regulation of the Power Sector*; Pérez-Arriaga, I.J., Ed.; Power Systems; Springer: London, UK, 2013; ISBN 978-1-4471-5033-6.

47. Diestelmeier, L.; Kuiken, D. Smart Electricity Systems. *Eur. Compet. Regul. Law Rev.* **2017**, *1*, 40. [CrossRef]

48. Neuteleers, S.; Mulder, M.; Hindriks, F. Assessing fairness of dynamic grid tariffs. *Energy Policy* **2017**, *108*, 111–120. [CrossRef]