Driving Towards Grid Balance

An Architecture Clarification White Paper

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Summary

Why

In Denmark the shift to renewable energy is a shift from electricity production based primarily on thermal power plants that can be controlled and regulated to an electricity production based on wind and solar power. The future energy system must, to a high degree, abide by weather. As a part of this process Energinet looks into how future electricity consumption is expected to interact with the energy system as a whole, with the goal of identifying possible barriers and inefficiencies and thereby supporting an economically sound green transition with a satisfying security of supply.

In 2035 it is estimated there will be 1.5 million electric vehicles (EVs) in Denmark. As such the charging patterns and the power consumption flexibility will have an impact on the total energy system. The EVs ability and willingness to adapt power consumption to the variable renewable production is in several studies identified as one of the key elements in achieving an efficient transition, with high security of supply, relatively low costs, and high utilization of renewables. Therefore, Energinet has an interest in contributing to an efficient integration of EVs in the electricity system.

The importance of utilizing smart, IoT[1] devices and digital technologies, including EV chargers, is also highlighted in EU's action plan as an essential part in facilitating a clean energy transition[2]. Furthermore, EU's action plan towards a digitalized and green energy system mentions the key enabler to be the availability of energy-related data among different parties, as access to data enables innovative services to be developed. Services from which consumers, public authorities and the private sector will benefit. This paper supports the strategic visions presented in the EU's action plan and will address why these visions are essential for an efficient and smart market using EVs as a showcase.

How

In this paper it is explored how the digital infrastructure and market setups around electric vehicle charging are in Denmark today. Barriers for entry for new market actors, competition in the market and the suitability in relation to adapting charging to power production and to enable electric vehicles to help in balancing the power grid are explored and a suggestion to adjustments of the current data ecosystem is developed.

Proposing a technical framework for changing the current market into a democratized ecosystem, this paper introduces a unified way for any actor engaged in the electric vehicle charging ecosystem to interact with the physical infrastructure as well as the services running the infrastructure. It is made possible for a legal owner to delegate granular control and read access to some piece of infrastructure (i.e., a charge point) to any other designated actor the owner deems should have access. This constitutes a significant change from today's structure, unbundling the otherwise bundled infrastructure layer and service layer.

What

This white paper's contribution to the ecosystem of electric vehicles showcases how the electricity sector and transportation sector can be combined in value streams by having the potential to optimize both sectors. The specific values can be many, but without pointing to any one value, it is

1 Internet of Things

2 Digitalising the energy sector – EU action plan (europa.eu)

relevant to focus on how data can be shared, which regulatory concerns must be met, and how regulation can be a barrier for collaboration between transportation and electricity.

For the proposed framework to reach its societal value potentials, legislative actions are required, which is discussed in the final section. This discussion lays the groundwork for what should be considered when preparing new legislation and shapes the process for how to proceed with legislation that can accommodate the technical framework. In the final section, challenges of implementing the technical framework as well as some concrete potential market innovations, enabled by the framework are elaborated.

Another contribution is the generalization of the access to data and functions of a sectors IoT devices, further enabling an improved coupling to the Data Space initiative. While this paper presents the architecture on a backdrop of EV charging, it can also be utilized for other use cases and other types of IoT devices e.g., heat pumps.

Who

If implemented, the value creation outlined in this paper is significant for mainly the users of electric cars and market actors, as new business models can be developed with the new framework. There is also a potential to lower the total cost of the future green electricity system. The question of who should have the role of owning, developing, and maintaining the proposed framework is not addressed. It is not a decision solely for Energinet to make, since the required governance structure of the ownership is larger than the interests and mandate of Energinet. The paper should be seen as a contribution to the general development of the data ecosystem surrounding EVs and a strong recommendation of initiating the work to enable a democratization of the charging market to benefit both consumers, service providers and the energy system.

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Introduction

Background and context

Energinet is the Danish TSO (Transmission System Operator) for electricity, gas and hydrogen. Being a TSO means that Energinet is responsible for building, maintaining, and operating the physical equipment needed to run a transmission grid, and furthermore, responsible for making sure there is always balance between the electricity demand and supply in Denmark, as visualized in figure 1. This task includes development of the markets, network codes and many other related tasks. As the energy system is developing into a system of systems where several sectors are closely coupled it is increasingly relevant to achieve insight into the new dynamics of a sector coupled system.

The work done related to electric vehicles is one example of this and this paper presents only a part of the work.

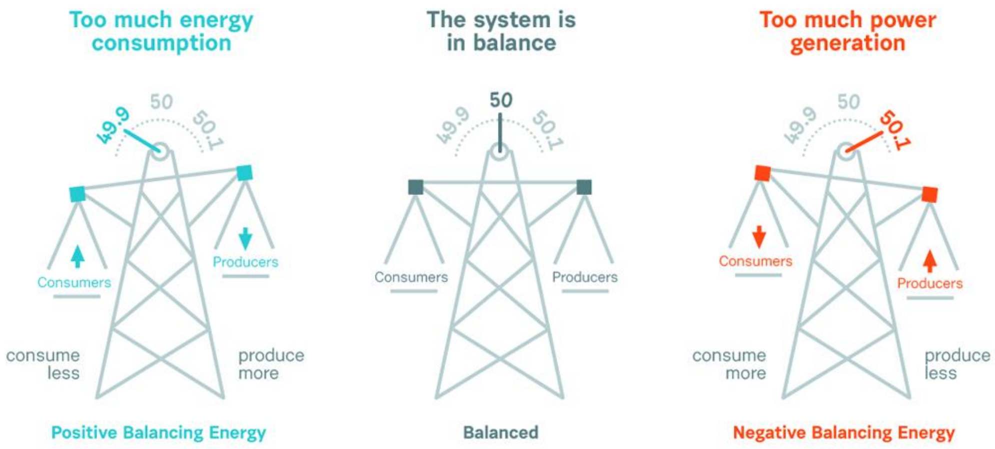

Figure 1 – Visualization of grid balancing
Source: https://nanoenergies.eu/knowledge-base/manual-frequency-restoration-reserve-mfrr

Furthermore, Energinet is tasked with a series of other related activities as e.g., Energinet is responsible for collecting electricity consumption data from all Danish electricity customers, which is done through Energinets Datahub. This data is used by market actors and is an integral part of how the processes behind the electricity market are handled. Furthermore, Datahub enables electricity consumers to gain access to their own data and allows consumers to share data with third party actors to support the development of new and innovative services.

High political ambitions are set in Denmark to move from relying mainly on fossil fuels for our energy needs to a system based on energy from sun and wind resources, which is considered renewable and with a very low CO_2-intensity. In fact, in 2030 it is expected that all Danish electricity will be from renewable sources. Alongside this move away from fossil fuels to cover the traditional electricity consumption, a huge electricity consumption from electrolysers are expected as the need for hydrogen is increasing. The Danish Energy Agency roughly projects a doubling of Danish electricity consumption from around 37 TWh in 2023 to 74 TWh in 2030[3], and the growth is expected to continue to over 200 TWh in 2050.

In the wake of the green transition data is becoming a much-needed resource. The amount of units consuming and producing electricity is increasing rapidly as is the share of variable renewable resources. While the introduction of electrolysers in the energy system is expected to add a

[3] https://ens.dk/sites/ens.dk/files/Hoeringer/af22_-_sammenfatningsnotat.pdf

significant amount of flexibility, there is potential in getting as much consumption as possible to respond to the various price signals generated at the different electricity markets.

Focusing on the electric vehicles they have the potential to react fast and thus contribute to balancing the electricity system in real time – if the data streams, service providers, car battery management system, chargers and so on supports it. Data can also be used to facilitate and enable a better, faster, and more efficient transition to a society with an energy need met 100% by variable renewable energy (VRE). This is true for governments, municipalities, businesses, and citizens. However, it is not only a need driven by the goal of 100% VRE that puts data in demand – data on infrastructure can be a valuable asset for new business models, smarter planning, and better investments.

One example of imbalance in the electricity system is individual clouds moving past a solar park. The production can change fast as illustrated in Figure *2*. The individual clouds are very hard to predict since it is such a local weather phenomenon, and even if they were predictable to a very high degree, it would still require Energinet to activate other energy resources that can stabilize the fluctuations generated by these drifting clouds. The batteries in electric vehicles would be a fine match to balance this kind of fluctuation and if the data ecosystem gets matured it should be possible to find and activate the flexibility in EVs where it, at the time, makes little to no difference to the user if the car charges in a fluctuating pattern. In comparison, reducing the electricity consumption of an electrolyser would result in less production of hydrogen. Energinet is expecting the need of balancing services to increase with the increase in variable renewable consumption. See more details in Scenarierapporten, published by Energinet, where you will find an explanation behind an expected increase in fast reserves between 4-8 times over the years between 2022 and 2032.

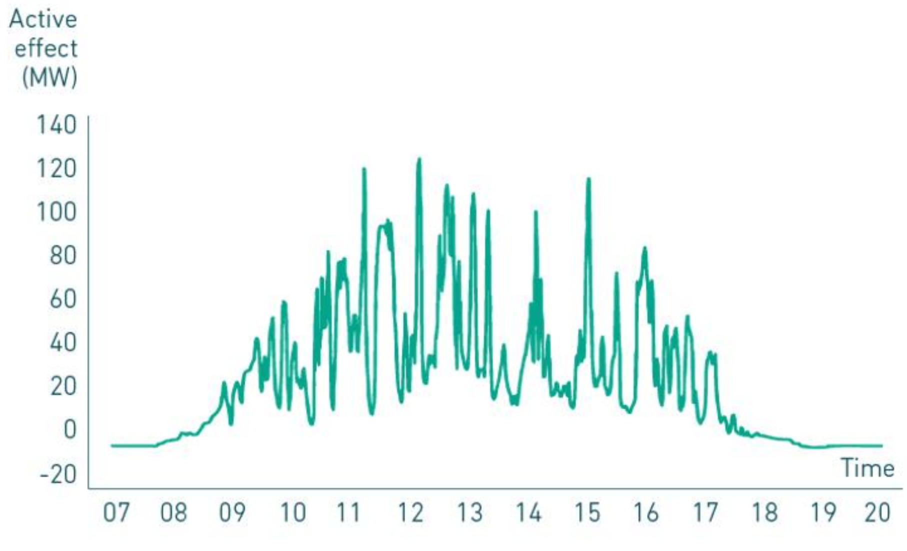

Figure 2 - Drifting cloud over a PV park creates big fluctuations in power production minute by minute.
Figure from Energinets annual magazine: https://en.energinet.dk/about-our-reports/reports/annual-magazine-2022/

To sum up; more renewable energy means higher costs for the activities supporting the same security of supply if we continue to use the current mechanisms. Furthermore, for Energinet to economical efficiently solve the problem of how to balance an energy system with as much VRE as possible, it is key that new technologies and methods are considered and put to the test to ensure that energy system is kept cheap, green and with high security of supply.

Empowerment of active con- and prosumers

Historically, electrical consumers have had the luxury of being able to consume power with little thought to prices or system demands. The phenomenon of electricity consumers adapting their use of electricity to match the electrical systems' needs is generally called flexibility, or in a more technical term; DSR (Demand Side Response). Going even deeper, DSR can come in several forms, as it can be price-flexibility of the hour-to-hour prices of electricity that is known between 24-36 hours ahead of time or it can be in the form of ancillary services. The difference between the former and the latter is, respectively implicit and explicit DSR.

Implicit response is choosing to move some consumption from hours with high prices to hours with low prices. The monetary benefit is seen on the electricity bill. Billing requires information about the electrical power needed in the immediate future, an algorithm to optimize when to place the needed power and the ability for at least part of the total consumption to act on a scheduled power plan. In short, as a consumer you simply follow the market; when supply is low, prices are high and when supply is high, prices are low.

Explicit response is a much more time-sensitive and critical part of maintaining grid balance since the flexibility of producers and consumers of electricity is traded on different markets. Where implicit response is handled on a resolution of an hour, explicit responses are handled in lower time resolutions both in minutes and seconds. The different markets requirements are defined such that there are products with fast reaction times and low energy amounts, and slow reaction times and large energy amounts.

What the future exactly will look like in regard to DSR is an open-ended question, but electric vehicles are deemed to have a great fit – that is, both in terms of explicit and implicit DSR. While some of the EVs in Denmark today are active in the electricity markets many are not. Some consumers are not aware of the opportunities, some have a charger that does not support demand response, some are locked to a service provider that does not manage the EV as a flexible resource etc. Ensuring the continuous development of new, innovative market products for consumers and the free competition in the charging market is essential for EVs in Denmark to participate in the electricity markets. In this paper, we investigate the potential possibilities and barriers of the electric vehicle charging ecosystem in Denmark compared to the vision of a seamless and efficient sector integration between the electricity sector and the EVs inspired from the EU Action Plan[2] with focus on creating maximal value for society. We propose a set of capabilities and principles with an accompanying software architecture that can fulfill some of the electric vehicle's potential to be a helping hand in the green transition and we elaborate on the regulatory considerations that are needed to implement such an architecture.

Why are electric vehicles and charge point data an important use case?

In Denmark there are currently a total of around 2,8 million active vehicles. That number might change slightly over the coming years, but we are already seeing a major shift towards electric vehicles.

As of April 2023, there are 136,998 electric vehicles (not including the 111,298 plugin hybrids) in use. According to Figure 3, that means there has been a doubling of the total number of active electric vehicles in Denmark in 15 months. A trend that seems to continue.

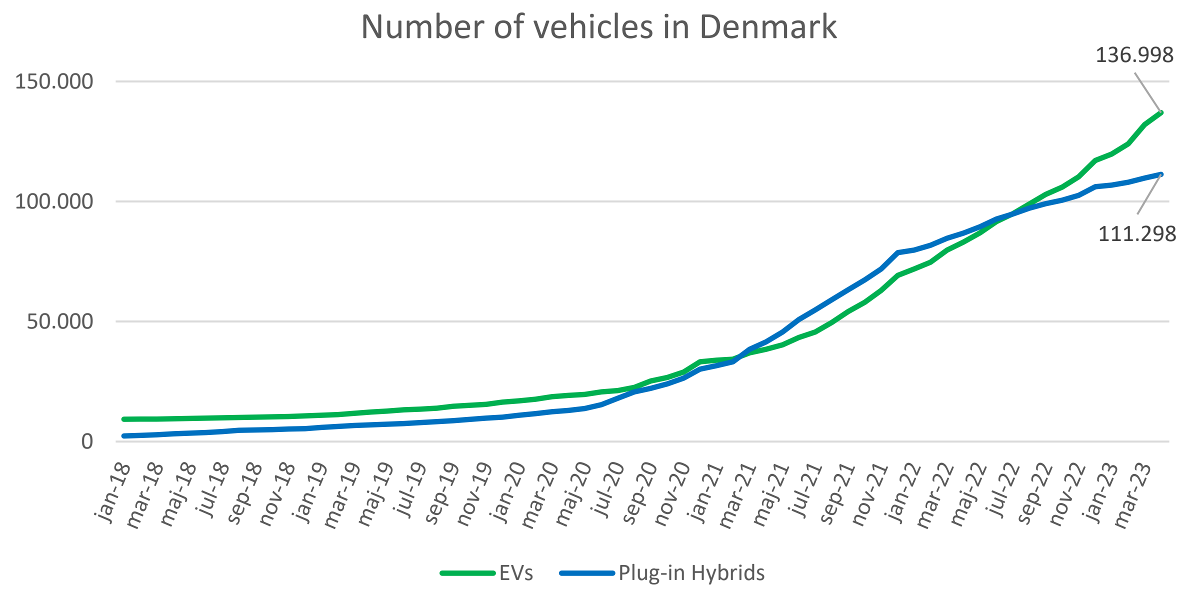

Figure 3 – Graph of EVs and plug-in hybrids in Denmark
Source: dst.dk ([BIL54](BIL54))

Predictions estimate 1.5 million electric vehicles by 2035 in Denmark[4]. Whether there will be upwards of 1.5 million electric vehicles in Denmark by 2035 depends on car manufacturers, regulation, incentive schemes, and many other factors. However, even if the goal isn't reached by 2035, this project isn't invalidated – it simply means that the scale of potential payoffs is delayed. While the Danish adoption of electric vehicles depends on a multitude of external factors, this paper can have a positive influence on the rate of adoption due to increased transparency, simplicity and lowering of Total Cost of Ownership for electric vehicle owners. More on that later.

On the other hand, it is not inconsequential if the fleet of electric vehicles – to a large extent – simply uses the needed electricity for charging with the single objective of lowering cost and complexity for the end user. With that said, careful considerations must be taken to find a good balance between what can be expected from a consumer and which grid needs EVs are sought to solve. In other words, there are potential tradeoffs between the EV delivering value for the grid or for the driver. A good and efficient integration of EVs into the electric grid will not happen by itself, and if not integrated smoothly there is a multitude of problems that follow.

Electric vehicles can for the purpose of this paper be seen as batteries on wheels that connect to the electric grid via a charge point. Hence, the flexibility from an electric vehicle is based on the energy present in the battery pack as well as the charger's power draw.

The Battery Management System (BMS) of the EV can in conjunction with the charger, deliver flexibility to the electric grid in the following ways:

1. Charging can be stopped and started, based on a pre-planned charge plan (implicit DSR)
2. The charging rate can be increased or decreased, based on a pre-planned charge plan (Implicit DSR)
3. A combination of (1.) and (2.) where charging can be stopped, started and while the charging is active the charging rate can be increased or decreased based on a pre-planned charge-plan (Implicit DSR)

[4] https://ens.dk/sites/ens.dk/files/Basisfremskrivning/kf23_hovedrapport.pdf

4. Explicit DSR where the charge plan for a short period is paused, and the actual charging deviates from the plan to deliver an energy service to some form of system operator or other party that needs the charge to differ from the planned scenario
5. Vehicle-to-X where the energy direction is reversed, so that the battery discharges and delivers its energy to "X" (either being a home, a single load or to the grid). The V2X options of single load, does not benefit the grid in any way as this is an off-grid specific use case. (V2X can be both implicit and explicit DSR)

V2X is not in focus for this paper since very few electric vehicles and chargers available on the European market are compatible with this technology. However, V2X is not explicitly incompatible with the principles, architecture, and direction of this paper, and can by all means turn out to be an important concept to help Energinet to establish electrical security of supply in a system with vast amounts of VRE. In other words, V2X can be added as a feature either before or after an implementation of the contents this paper.

Potential of EVs as a flexibility service

The job of providing affordable, green, and reliable electricity always to every consumer is no easy task. Infrastructure, markets, ancillary services, electricity producers, traders, aggregators, neighboring countries, regulators, and other aspects must be working in unison to operate and optimize this incredibly complex system of systems. Put differently, if you change a single thing it can have consequences for all the other aspects as well. However, this also means that optimizing one aspect can bring value and stability for the system as a whole, as well as the many individual aspects.

The problems solved through an optimal integration of EVs into the grid can be:

- Lower Total Cost of Ownership for EV owners
- Faster integration of more VRE into the grid
- Improved security of supply
- Less or delayed build-out of both transmission and distribution grids
- Lower CO_2-emissions

With the adoption of EVs, and their inherent flexibility, there is a potential for EVs to become a big problem solver by balancing the grid if a significant number of EVs end up supplying implicit and explicit DSR.

The scale of EVs contribution to DSR is hard to quantify, especially as it varies on a yearly, monthly, daily, and even hourly basis. This is due to the changes of

- How many EVs are active on the Danish roads.
- How many EVs are participating in delivering ancillary services to the grid.
- How much each EV needs to charge.
- How many kWh can be changed to another time of charging.
- How many hours until the charging must be finished.

If we see all the participating EVs as one big hypothetical battery and take a snapshot of one of the most important parameters namely batteries ability to provide ancillary services to the grid, while also taking the EVs different flexibility functions into considerations, we get a plot that looks somewhat like this.

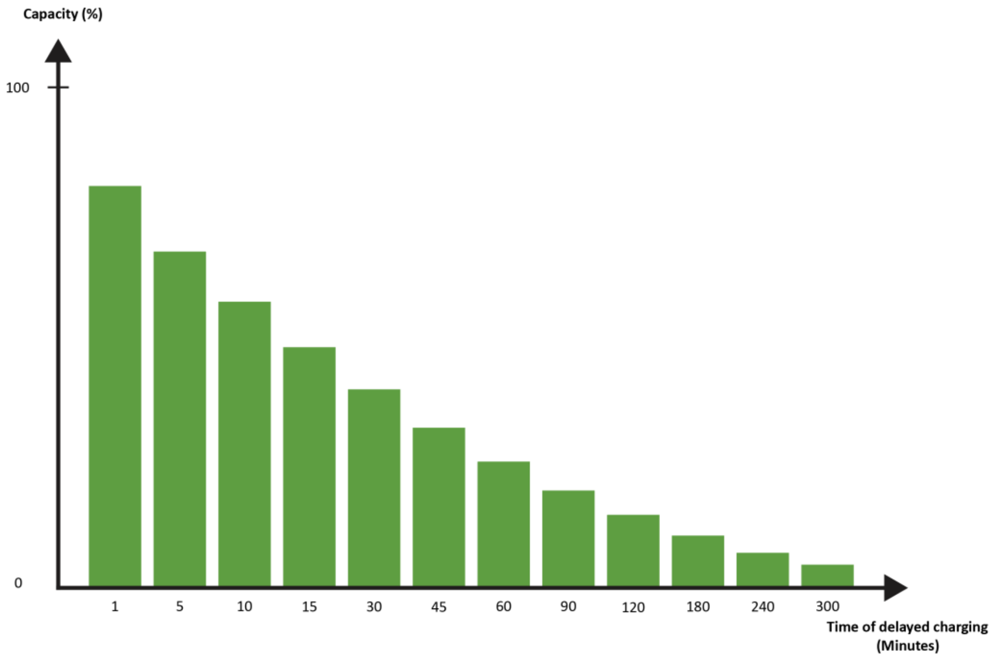

Figure 4 - Flexibility capacity as a function of delayed charging
Source: Energinet

The above figure 4 shows an expected distribution of how much of the fleet of EVs flexibility can be utilized for ancillary services, when delaying charging by a varying amount of time. Again, this is a momentary, hypothetical snapshot, with the purpose of showing that not all of the capacity to deliver ancillary services from EVs is available. If the time of the snapshot changes so will the amount of available flexibility. As a general rule, it can be assumed with reason, that the amount of available flexibility will be greater at nights than during daytime, since most driving happens during the day, which means that the EV will have a high probability of being connected to a charger during the night[5].

Specifically, the figure shows that if Energinet had the need to activate a lot of flexibility, for an event that only takes 1 minute, a lot of the potential capacity would be available. However, as the event increases in duration, the amount of available capacity to accommodate the event decreases. Hence, depending on the duration of an event and the amount of available capacity, different types of ancillary services will be accessible[6].

This trend is assumed due to an EV driver's sensitivities towards always having some range available at any time to e.g., drive to the hospital, go for shopping or other matters.

The obtainable pricing the EV owners can get from selling their flexibility will also be quite a significant factor in the real-world application. For EV owners, selling flexibility can be simplified as a matter of inconvenience that the charging can be delayed, and the EV will still be charged to a specified minimum level at a specified time. The exact financial value EV owners can obtain from selling their flexibility depends on different factors and is not further assessed but is worth noting that the value EV owners can obtain from selling their flexibility comes in many forms, not just financially, but also societal as EV owners could potentially contribute greatly to the green transition.

[5] ENTEC – Digitalization of Energy Flexibility

[6] https://energinet.dk/el/systemydelser/introduktion-til-systemydelser/oversigt-over-systemydelser/

A showcase in the data space for the utility sector

Electricity is not the only form of energy or focus point relevant to the green transition. The potential beneficial overlaps are between several sectors that historically have few to no common interests. The green transition drives these new overlaps and adds to the interest in digitalizing these energy sectors.

This overlap is called sector coupling, an integrated approach to planning energy and other utility systems in the intersection. The idea is that by having the proper data sources from what, how, when and where utilities are being used – structured in interoperable models and protocols coupled with regulatory governance – individual actors and organizations can discover and create new value streams, do better planning, and avoid negative influences between systems. This creates technical and corporative opportunities for a more efficient, faster, and smooth green transition while improving efficiency, flexibility, reliability, and adequacy.

Through the national Digitalization Strategy, the Danish Energy Agency (Energistyrelsen) has been tasked by the government to pursue a so-called Data Space that is the technical collaborative manifestation of sector interoperability in practice, facilitating sector coupling and several other benefits. This will be organized through the Utility Digitalization Program (Forsyningsdigitaliseringsprogram)[7], which aims to define and launch the initial foundation for an ecosystem of utility data and operations in Denmark.

This white paper's contribution to this ecosystem showcases how the electricity sector and transportation sector can be combined in value streams by having the potential to optimize both sectors. The specific values can be many, but without pointing to any one value, it is relevant to focus on how data can be shared, which regulatory concerns must be met, and how regulation can be a barrier to collaboration between transportation and electricity.

Another contribution is the generalization of the access to data and functions of a sectors IoT devices, further enabling an improved coupling to the Data Space initiative. The importance of utilizing smart IoT devices and digital technologies is also highlighted in EU's action plan as an essential part in facilitating a clean energy transition[2]. Furthermore, EU's action plan towards a digitalized and green energy system mentions the key enabler to be the availability of energy-related data among different parties, as access to data enables innovative services to be developed from which consumers, public authorities and the private sector will benefit. This paper supports the strategic visions presented in the EU's action plan and will address why these visions are essential for an efficient and smart market using EVs as a showcase.

Scope

For the project behind this paper, the following are the limitations that define the direction and scope.

1. **Enabling explicit EV flexibility by focusing on the charge point rather than the EV**
   This focus is chosen based on the added opportunities of creating value for Danish society, since by focusing on the charge points, which is and can be a shared infrastructure, it is possible to foster more innovation across different sectors. In the market dialogue held during the research for this paper it was found, with minor exceptions, that focusing on and communicating with the charge point rather than the EV itself is how the market actors are

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[7] Forsyningsdigitaliseringsprogrammet – (Under revision)

already providing ancillary services.

2. **Capabilities and principles rather than specific technologies, standards, and protocols**
Defining which capabilities and principles a solution must adhere to rather than focusing on what should be implemented and how, creates a technology agnostic approach. This approach creates the foundation for market actors, regulators, and other stakeholders to discuss why and how a general solution should be designed rather than focusing on the individual solutions to the problem.

3. **A national Danish focus towards a EU-centric view**
Denmark is not the only European country trying to combat climate change by integrating renewables and undergoing significant changes in how the security of supply is kept. However, by focusing on the Danish market, regulation, and the inherently Danish problems, there is a better chance of pinpointing the problem(s), due to a narrower scope and hence less complexity to consider at this present early stage. That said, the exact solution(s) can very well be an undertaking for both the national government and the EU, together with the respective member states' market actors. Denmark is a natural location to implement an initial national solution due to the high degree of digitalization throughout society and the Danish energy system being at the forefront of the green transition.

Objectives

The primary objective of this paper is to share thoughts and insights achieved during our work with understanding the ecosystem surrounding EVs and their integration in the future sector coupled energy system.

Energinet is continuously working on improving the elements of the green transition that we are responsible for, and this work presents a corner of the work related to EVs and data ecosystems.

Second, this paper aims to show the need for stability in a market environment in rapid development due to economics, climate change, consumer behavior, regulation, and technological advances.

By proposing a capability- and principle-based software architecture, this paper proposes an approach that will deliver a common framework for collaboration between private consumers, businesses, market actors, regulators, and other stakeholders. The hope is that from this common framework, the engaging parties will be able to create new value from the already established and ongoing expansion of EV infrastructure and put it to its best possible use.

Method

The purpose of this paper is to spark a dialogue revolving around EVs and the charging infrastructure with a dedicated focus on delivering an innovative proposal for a technical solution to a market.

The notable primary sources of information are semi-structured dialogues with relevant parties, to be able to adapt the solution to the current market by knowing the current markets limitations and historical knowledge obtained by participating in relevant projects in Denmark and EU.

The exploration and investigation of the current market is not completely exhaustive as the dialogues only includes a few market actors and the focus was to gain an understanding of the current charging market and relevant technical barriers. The overall challenges identified in later sections are challenges identified by the authors and not necessarily expressed in the dialogues.

The final technical solution has been sought validated by an internal workshop, with relevant Energinet experts. However, while the objectives of the workshop were fulfilled, this validation will not be elaborated upon further.

Market review: The current state

Intending to propose a new standard software architecture framework for the EV charging market environment, it is essential to have insights into how the current market actors operate and whether there are any barriers in the current charging market relevant both for service providers and consumers.

But first, it is important to establish the market actors' roles, responsibilities, interests, and ways of operating. In the following section, the existing market is first presented, followed by an overview of the current maturity level of the charging market both from a technical and consumer point of view and finally, the challenges identified in the current market are described from this papers point of view.

Overview of the current charge point market environment

The existing market actors and their responsibilities

The EV market contains several different actors and parties with different responsibilities and functionalities to establish a charging ecosystem. In this section, existing actors and their responsibilities are presented as well as their interest areas in the market[8].

Charge point operator (CPO)

- Depending on the CPO, CPOs install, own, operate, maintain, and manage charge points, including private and public charging stations. To ensure charging operations, CPOs must manage hardware and software aspects. This includes maintenance of hardware as well as the software backend technology required to establish communication between their assets and data management.
- CPOs have an interest in supporting their customers' EV charging experience and have an interest in expanding their charging infrastructure. Several CPOs are also showing interest in participating in ancillary services as part of their business model.
- CPOs can also offer EV owners a full charging subscription where consumers can charge at home with their own box, charge at public stations, and get electricity tax reimbursement, all managed by the CPO. In that case, a CPO takes on different stakeholder roles, as described in the following sections.

E-mobility service provider (eMSP)

- An eMSP offers services related to charging for EV owners by connecting different charging infrastructure owners with the EV owners. Examples of such services include providing roaming opportunities, smart charging solutions, services to enable reimbursement for charging for Danish EV drivers, and apps to locate public charging stations.
- The term eMSP covers several service providers with different interests. Generally, eMSP is interested in developing new, innovative business models and software solutions for EV owners. Still, for this to happen, easy integrations toward charge points are required. eMSPs are also interested in charge points being 'smart' and able to provide third-party access – otherwise, their products, such as smart charging, cannot be used by the charge point.

[8] Electric Vehicle Charging - Definitions and Explanation - january 2019_0.pdf (rvo.nl)

Aggregator

- An aggregator is a company that operates sources of flexibility to deliver energy services to, for example, participate in balancing the transmission electric grid. In the case of EV charging, an aggregator will have control over a fleet of charging stations or EVs and pool their capacities together to participate in the balancing market.
- Aggregators are interested in the charge points' communications and control capabilities to use the charge point as an ancillary service. Aggregators depend on the availability of integration possibilities to charge points – otherwise, they cannot communicate with a charge points station.

Transmission system operator (TSO)

- A TSO owns, maintains and manages the transmission grid, which includes assets with a voltage above 100 kV for the electricity transmission grid. Energinet, the Danish TSO, is responsible for the security of supply, which means they are responsible for maintaining the balance between production and consumption.
- For further information related to the interest of a TSO, the reader is referred to the introduction section or see the definition by Entso-E[9].

Distribution system operator (DSO)

- A DSO owns, maintains, and manages the distribution grid, which includes assets with a voltage under 100 kV and is directly connected to the end consumers and electricity producers with limited production capacity. The Danish DSOs are responsible for the development of infrastructure on the distribution level in their respective area so that their electricity grid can continue to handle the increasing electrification.
- The DSOs, like the TSO, have an interest in keeping the electricity grid stable which, in terms of EVs, requires the DSOs to have some degree of knowledge about the charging patterns and location of the charging stations to avoid bottlenecks and disruption of the stability of the distribution grid. The DSOs also have an interest in the charge points as a flexibility asset, to potentially be controlled if, for example, the electricity consumption in a localized area is too great for the distribution grid to handle then it would benefit the DSO if the consumption from EVs were lowered for a duration. Alternatively, instead of it being the DSO that collects the relevant information and expose the desired behavior to the EVs, the problem is solved without direct involvement from the DSO, and energy communities[10] are set up, to optimize the common use of the available net capacity – without having to build extra capacity.

Roaming Hub

- A roaming hub is a company that operates and maintains a roaming network of publicly available EV chargers. With EV roaming, EV drivers could charge at any charge point integrated into the roaming hub if they, for example, are traveling in another country.
- Roaming hubs are interested in CPOs and eMSPs using their roaming network and making the EV charging experience as easy as possible.

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[9] Transmission System Operator (entsoe-event.eu)

[10] https://energy.ec.europa.eu/topics/markets-and-consumers/energy-communities_en

Overview of current charging market landscape

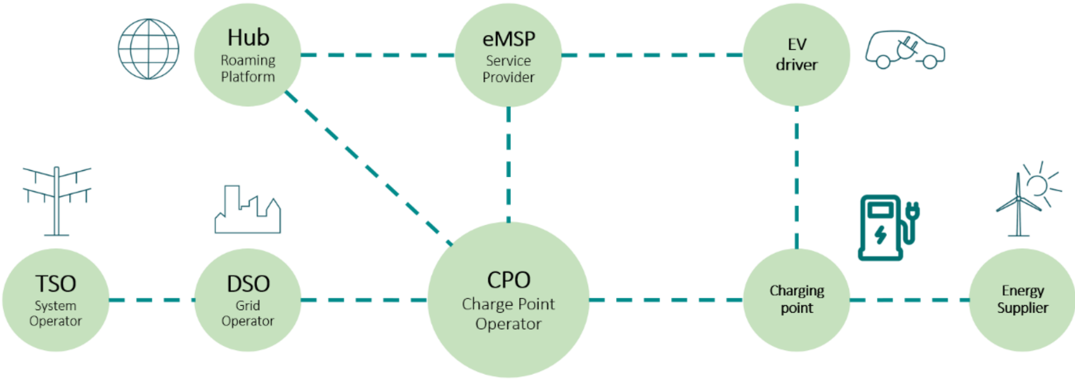

Figure 5 – Simplified overview of actors in the charging market and how they are connected by data exchange (dotted lines). Figure is made with inspiration from the publication 'Electric Vehicle Charging' [11]

A simplified overview of the charging landscape with the different actors can be seen in Figure 5 above. The CPO is the center of the landscape because the CPO enables all data exchange and communication required to connect with the charge point in the current landscape. EV drivers interact with a charging session by plugging their car into their home charge point, or, in most cases, they interact using a service provided by an eMSP. An eMSP can take on multiple actor roles, such as CPO and energy supplier, to avoid developing multiple integrations with different CPOs. The roaming platform connects both to the CPO and eMSP to establish a connection between different market players to enable charging on different public charge points. The CPO also has a connection with the DSO, especially in public charging stations, because the DSO maintains the public distribution grid and needs to ensure the security of supply, which can be disrupted when a large amount of charging stations is placed. The DSO connects with the TSO in different areas, but around flexibility and balancing the grid, the DSOs and TSO communicate using a balancing responsible party (BRP).

An actor also not shown in the landscape but becoming more important is the aggregator, which manages the operation of different sources of flexibility to enter the ancillary service market[12]. For more information about the current system design and stakeholder overview, the reader is encouraged to read another report by Energinet[12].

Open protocols and standards are readily available to ensure a standardized charging infrastructure for data exchange and communication between the different actors. Some of the leading communications protocols includes the Open Charge Point Protocol (OCPP), which is considered the de-factor standard for communication between charge points and the management system of CPOs, the Open Charge Point Interface (OCPI), which is a protocol for communication between CPOs and eMSPs, and the ISO 15118 standard, which enables plug & charge and bi-directional charging[13,11].

Still, the EV charging industry is developing rapidly, and new protocols and standards could continue to be developed. OCPP 1.6 is the communication protocol implemented for most charge points, but there is no regulation about which capabilities or protocols on charge points CPOs must use.

For this paper, an agnostic approach has been chosen concerning the communication between different entities and actors. This paper focuses on technical capabilities and principles that will solve the identified challenges. Therefore, the architectural principles described in the solution will

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[11] Electric Vehicle Charging - Definitions and Explanation - january 2019_0.pdf (rvo.nl)

[12] https://energinet.dk/media/im1dlj5u/vehicle-grid-integration-research-rethinking-energy-international-alignment.pdf

[13] https://www.greenflux.com/spotlights/open-protocols/

be independent of a specific protocol. Protocols and standards are essential to ensure market interoperability and enable actors' communication. Still, it will be up to the market to determine which protocols to use.

The maturity level of the current market and limitations

As the number of EVs is rising, the charging market is also developing rapidly in recent years. This section aims to discuss some of the limitations in the current charging ecosystem, both regarding technical limitations and limitations from a consumer point of view.

As described previously, a developing field for communication protocols in the charging market aims to standardize integrations between charging stations, service providers, EVs, and other stakeholders. However, the protocols can be interpreted differently by hardware producers, as discovered by market actor dialogues. This means service providers must develop specific integrations for each charging box to establish communication and provide an intelligent charging service. This barrier slows down the ability of service providers to offer smart charging/flexibility services on differing hardware, despite the OCPP version 1.6 compliance. Another technical limitation for service providers is that valuable data from an EV or specifically an EVs BMS is generally not available. Without information about an EVs 'State of Charge' (SoC), service providers rely on their users to manually enter current battery levels each time they plug in for service providers to determine an intelligent charging plan. Lack of communication with EVs can potentially limit the possibilities of services providers to provide flexible products that can assist with the green transition.

In recent articles from Danish media, points from an unpublished report by the Danish Competition and Consumer Authority are presented that raises concerns with the current charging market[14,15]. One of the concerns revolves around the need for more transparency in the bundling of products offered by CPOs where EV owners can charge at public stations, home charging using a charging box, and the opportunity for tax reimbursement. The bundling of products is an issue for several reasons: First, it creates a vendor lock in for EV owners because switching to another CPO is not easy or cheap as the charging box is owned by the CPO. Second, the bundling of products can be exploited by large providers since they can use their market power in public charging to gain an advantage in the home charging market[16].The unpublished report suggests a list of recommendations to improve the conditions of competition for the charging market which includes increasing the transparency for pricing, better opportunities for consumers to keep a charging station when changing service providers and temporary banning the bundling of services to name a few[16]. These recommendations clearly states that the Danish Competition and Consumer Authority have identified serious issues in the current charging market and appropriate steps and regulations are required to ensure a fair functioning market in the future. Currently the report is in hearing, but several market actors have commented on the report such as Clever, stating that the report does not reflect reality as it is built on outdated data[17] and the market have since developed rapidly, and FDM, stating that banning the bundling of products is not the right decision but agrees that the current charging market is opaque and there are several issues with the current market that requires attention[16].

Similar points, as presented in recent articles, were discovered in the process of this paper. From an EV driver perspective, the need for more transparency in the charging market is an issue and

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[14] Uigennemskueligt lademarked kan koste elbilsejere dyrt | Penge | DR

[15] Konkurrence på lademarkedet: Styrelse lægger op til et forbud mod kernen i Clever-forretningen (finans.dk)

[16] https://pro.ing.dk/mobilitytech/artikel/rapport-faelder-haard-dom-over-lademarkedet-elbiler-ladeoperatoerers-all

[17] https://finans.dk/debat/ECE16044960/clever-laekket-rapport-rammer-helt-ved-siden-af-skiven/

potentially a barrier for people considering investing in an EV. For the green transition we are dependent on consumers making the transition from fossil fueled vehicles to EVs therefore it is important to ensure a fair and transparent charging market to enable this transition. Another significant limitation of the current charging market is that the hardware and infrastructure are not separate from the software and services. Therefore, the EV owner cannot freely choose between service providers or electricity companies for their charging box. This disrupts the development of new, innovative market solutions and products because an EV owner with a charging box can potentially be locked to a specific CPO that controls integrations to the charging box. In case this is not addressed in the future, with for example regulations, it could result in further disruption of the free competition in the charging market.

Another relevant limitation in the current charging ecosystem, which is a limitation in many areas, is the absence of data sharing. As data is becoming an essential resource and a core component in the digital age, it is becoming increasingly critical to ensure access to and use of data among different actors and sectors to unlock the full potential of data-driven innovation, as established in EU's Data Act[18]. For the Danish charging market, increased insight in data for several different market actors could support the green ambitions. However, there are several barriers to overcome, both regulatory, technical, financial, and organizational as described in the following report by Energinet[19]. As digital technologies in the energy sector can be a key enabler for reaching the green transition, corporation between sectors to overcome the barriers is required both for ensuring data-driven innovation and to empower consumers[2]. Of course, this is not just relevant for the charging ecosystem, but as it is a rapidly developing market close to consumers, it is eminent to ensure a healthy and fair market fit for the future.

Overall challenges and guiding principles

In the previous sections, the maturity level and limitations of the current charging market were described, and several identified challenges are related to different areas. The following listed points are the challenges that needs to be addressed to help reach the green transition and will act as guiding principles for the following architecture.

1. Liberalization of the data communication to and from private charge points
2. Data sharing to and from the charging infrastructure across sectors
3. Lowering the barrier for EVs to participate in balancing the electricity grid
4. Lack of a technical foundation for defining laws and regulation
5. Structure of ownership

The first challenge mentioned in the previous section is a current topic in the Danish media. It specifies the need to unbundle private charge points so EV owners can avoid vendor lock-in to specific products, services, and CPOs. It is essential to ensure a free market for EV owners and critical for developing innovative services to support the green transition so that the market is competitive. An unbundling of hardware and software could advance competition and enable the adaptation of EVs to happen smart from the beginning.

As more people invest in EVs more charge points are required nationwide. The electrification of the transport sector can be a challenge and expensive for the society and consumers if the charging stations are not built smart from the start[20]. Opening for data sharing to and from the charging

[18] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0068

[19] https://energinet.dk/media/pe3fphvg/rapport-analyse-af-ladestanderdata.pdf

[20] https://danskemobilitet.dk/files/media/dokumenter/2020-11/Smart-fra-start-anbefalinger-til-fremtidens-ladestandere.pdf

infrastructure would enable the energy sector to develop smart infrastructure from the beginning, and real-time data can provide a revised picture of electricity consumption which will help ensure that production meets consumption demands. It is a challenge that dynamic and static data about charging stations is not released by the CPOs because there are several benefits in having a free data flow between sectors, which is further discussed in another report by Energinet[21].

The third challenge is that the barriers for EVs and charging stations to assist in balancing the electricity grid are high, and the potential for EV batteries will only be utilized if this issue is addressed. These issues, such as vendor lock-in and bundling of services, are relevant because potential EV owners wishing to participate in balancing the grid are excluded if they are locked to a service provider that does not offer the service. If the market is not competitive, new flexibility services will not be developed since there is a very limited market.

The fourth challenge concerns the overall need for more regulation and standards in the charging ecosystem. EVs are rolling out across Europe to an increasing degree because the electrification of the transport sector is a critical part of reaching the green transition. Electrification is happening in more than just the transport sector with EVs. Still, the overall digitalization in the energy sector with heat pumps and many other IoT devices will grow, making it a priority for Denmark and the EU to act. But will the necessary legislation follow? There is a need for technical descriptions to define how the charging ecosystem and general IoT ecosystem should look in the future to best support the green transition and the free market. An action plan that enables data sharing across sectors from a digitalized energy system is a big step forward, as initiated by the European Commission[2]. A report by the Centre on Regulation in Europe about energy data sharing and EV smart charging also mentions regulatory challenges for smart charging to be related to interoperability and standardization to be a prominent issue that needs to be addressed to optimize data sharing that enables smart charging[22]. But legislation to support the rollout of EVs and ensure an optimal charging infrastructure with open standards to communicate with charging stations is also required.

The fifth challenge is that there needs to be a standardized process for integrating with charge points in the current charging market because the data control ownership of charge points lies with the CPOs. This means that the CPOs ultimately decide which actors, such as eMSPs, are allowed third-party access to their charge points even though an EV driver owns the charging box. To ensure an open and competitive market, service providers should be able to integrate with an EV owner's charging box without going through the CPO because service providers would potentially have to develop integrations for each different CPO. Building integrations for different charging boxes and CPOs is an enormous task that especially small start-ups will struggle with, and the market should not limit the possibilities of small start-ups to develop innovative products and services and hence hinder access to new entrants.

The identified challenges will all be addressed to different extents in the suggested solution, which either entirely or partly solves the issues mentioned. The suggested solution consists of a technical architecture that most importantly enables the democratization of charging stations, ensuring the unbundling of hardware and software in the charging infrastructure and potentially for all IoT devices.

[21] rapport-analyse-af-ladestanderdata.pdf (energinet.dk)

[22] 221019_EVData_FinalReport.pdf (cerre.eu)

Democratizing Charge Points

The exploration of this paper and dialogues with market actors and regulators exposed a need for a specific architectural direction. This section explores and explains the architectural direction of this paper and its benefits and tradeoffs.

This given architecture aims to democratize the charge point ecosystem, allowing owners complete control over their hardware and enabling service providers to compete on equal terms. Enabling existing and new service providers will also allow Energinet to improve latency which improves the responsiveness, to the charge points so they can be better utilized for participating in grid balancing required in the green transition.

The current ecosystem and control flow is described in Figure 6. As can be seen, dependencies between vendors need to be created, and each subset of the charge point operator might have its interfaces for interconnection. Additionally, this creates increased natural latency between actors, which is highly dependent on implementation details. At the same time, several of these might not value latency as it is not a central component of their business model, which hinders adoption and implementation to support the purpose of enabling EVs to balance the electrical grid.

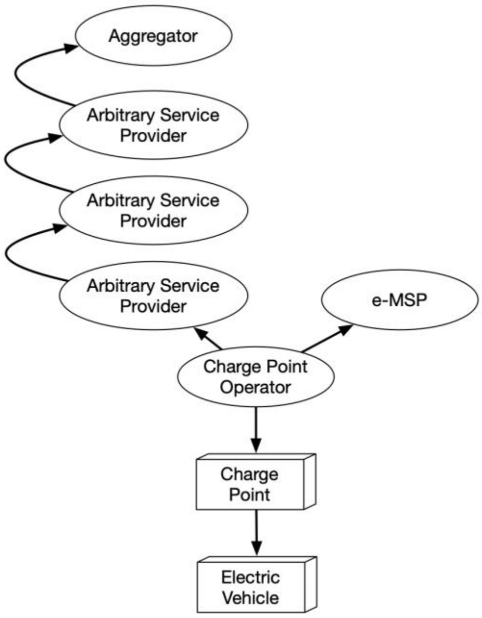

Figure 6 - Current state of the ecosystem.

We wish to introduce several capabilities into this ecosystem:

1. Capable of letting Charge Point Owners[23] have complete control of what is happening on the Charge Point, and who is doing it, and let them be able to give detailed control of what access is given.
2. Capability to have multiple Service Providers on a single Charge Point with equal rights and opportunities.
3. Capability to interact with the Charge Point with low latency befitting the fastest types of ancillary services for grid balancing.

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[23] A Charge Point Owner can be a company, public authority or private citizen holding the legal rights to exert control of a charge point.

4. Capability to regulate specific actors based on their function within the ecosystem and create a foundation for ownership structure.
5. Capability to let users effortlessly participate in ancillary service markets with as few actors as possible (Simplify the control chain).
6. Create a capability for new markets of services to be created on top of charge points to support the future EV fleet.

The current state of the ecosystem has many drawbacks that can be mitigated by introducing a few simple abstractions as well as fulfilling all the capabilities described above. Figure 7 explains that by introducing an abstraction layer that handles authentication and nuanced delegation of trust, service providers can interact directly with the charge point without intermediaries.

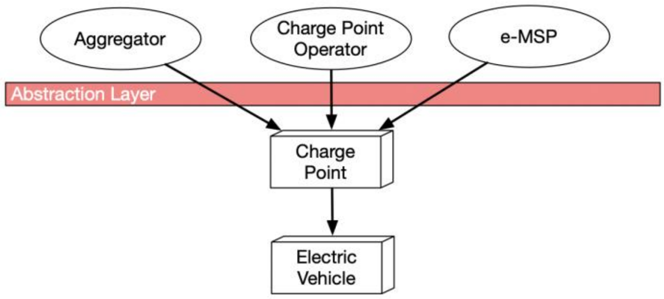

Figure 7 - Proposed future state of the ecosystem.

The benefits of assuming such an abstraction are manyfold and would enable several desired changes in the ecosystem:

1. The charge point would effectively be democratized, and the control power would be turned over to the system's owner.
2. Multiple actors can simultaneously have direct access (control of charging, read metering data, set/update charge plans, and more), hereunder an aggregator acting on behalf of Energinet. This would allow Energinet to activate balancing resources with lower latency.
3. The lower latency, in general, would allow services to deliver as several types of current and future balancing products.
4. It could be used as an abstraction to split hardware owners and service providers from each other, which creates the potential for a market opportunity for new types of service providers on top of the physical infrastructure.
5. Another benefit is that established roles would help regulators create laws governing these commercial actors, which, with sufficient mass, becomes an owner of critical infrastructure in Denmark.

These changes in the ecosystem also correspond to the principles and values described in the previous section.

Architectural Presentation

Several desired architectural quality attributes were identified in the process of this paper:

1. The Authentication and Delegation Service (ADS) must be highly available with nearly zero percent downtime.
2. The ADS should be a facilitator, not a bottleneck. Create as little interaction as possible with the ADS.
3. There should be direct access to the charge point and no middlemen.

4. Charge points should need as few changes as possible, as these require hardware manufacturers to change their implementations. Hardware is always challenging to upgrade or change once deployed, as it is exceedingly expensive.

Based on the above restrictions, the following principles and flows were designed, as shown in Figure 8. Three flows were described to support the interactions needed—first, the ownership flow; concentrates on how ownership of a charge point is established. Second, the delegation flow focuses on how a charge point owner can delegate part of the charge points functionality to a service provider. Finally, the third flow, the actuation flow, shows how a service provider is supposed to act within the system and how simple it should be at this point.

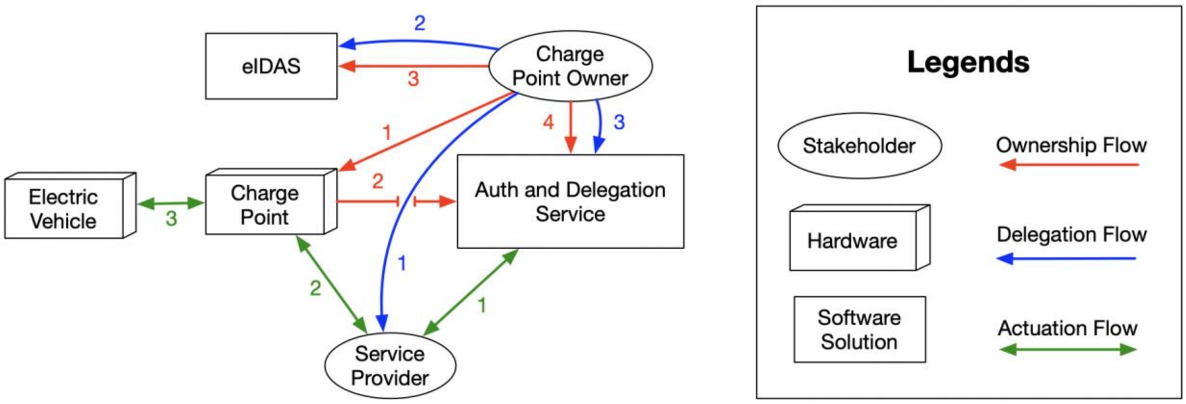

Figure 8 - High-level architecture to enable proposed architectural quality attributes.

The Ownership Flow

The purpose of the ownership flow is to onboard a device and assign ownership. Figure 9 shows a detailed depiction of the underlying interactions needed for this flow to exist. Numbers in the list below correspond to the interactions in the diagram.

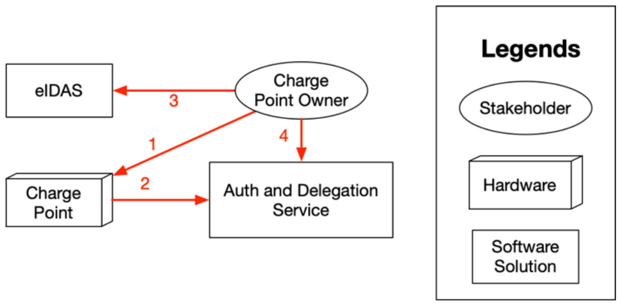

Figure 9 - Ownership Flow

1. The Charge Point Owner app notes the Public Key of the Charge Point and asks for it to register the Charge Point Owner in the ADS.
2. Charge Point registers in the ADS that the Charge Point Owners Public Key owns it.
    a. Note that an alternative flow is to collect the signed message from the charge point and then let it flow with the rest of the process to point 4.
3. Charge Point Owner uses eIDAS (an EU initiative that closely resembles MitID in Denmark, see more in the terms explanation below) or an equivalent service to sign with the identity that they have.
4. The Charge Point Owner registers the signed ownership with the ADS.

The steps above create a signed proof of ownership where the charge point states that the charge point owner should own it, and the charge point owner acknowledges this is true by signing the proof. Now a two-way handshake has been created, which ensures the integrity of the ownership.

The Delegation Flow

The function of the delegation flow is to assign rights to a service provider on behalf of the charge point owner. Figure 10 shows this simple interaction. Numbers in the list below correspond to the interactions in the diagram.

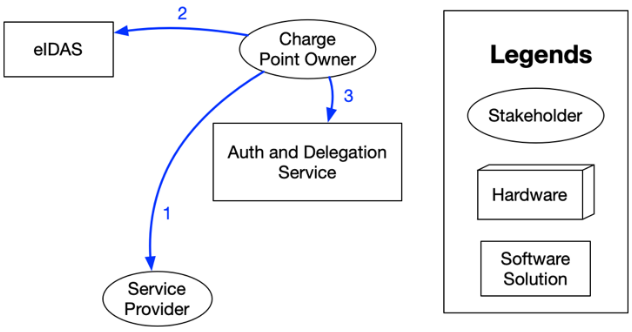

Figure 10 - Delegation Flow

1. The charge point owner collects the public key of the service provider they wish to allow a level of access.
2. The charge point owner uses eIDAS or an equivalent service to sign the rights it wishes to grant, combined with the service provider's public key.
3. The charge point owner registers the signed delegation with the ADS.

This simple interaction allows any service provider to look up its rights to a particular system and the charge point to pull a list of public keys that are allowed into the system and their access rights.

The Actuation Flow

The function of the actuation flow is to show the simple interaction needed from service providers. That future interaction with the Charge Points can be done directly without further interaction with other parties; Figure 11 details how the actuation flow works. Numbers in the list below correspond to the interactions in the diagram.

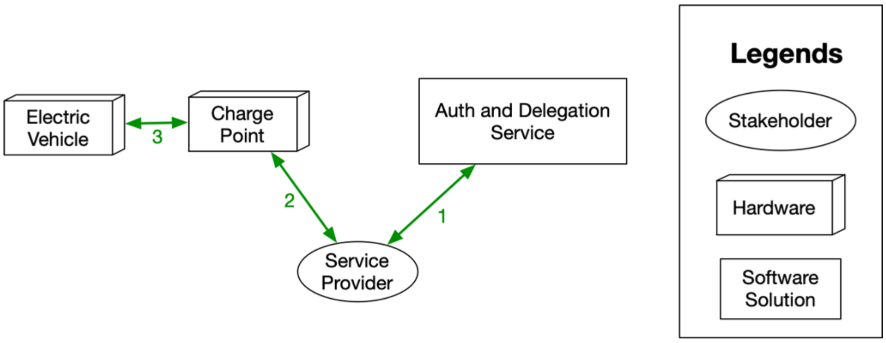

Figure 11 - Actuation Flow

1. Once, and only once, until an error occurs, the Service Provider verifies it has the rights it needs to function.
2. The service provider authenticates with its private key and has control rights defined in the ADS. A command sent could, for example, be a charging plan that would allow a charge

point to charge according to the plan. Note, authentication is performed decentralized on individual charge points.
3. The charge point performs the action that it was instructed to do in point 2.

Note that all future interactions will bypass the ADS and directly coordinate with the charge point itself.

Notes on technology choices of the ADS

While specific technologies are not the primary concern of this paper, some of the thoughts of the authors of this paper, on this matter, could still be beneficial for future implementers. The ADS should be distributed, highly available, and resilient to manipulation. During our exploration, we found that a permissioned distributed ledger in the form of a blockchain could potentially be a viable solution for these aspects. A permissioned blockchain would still bring all nodes under the control of a governing body, while the ledgers are still immutable and cryptographically verifiable. Also, blockchaiskns utilize public-private keys as the underlying mechanism, a preferred and recommended method for signing, encrypting, and ensuring the authenticity of any interaction in any distributed system. Also, the distributed nature of a blockchain would ensure that the network would always be available and thus minimize downtime. Other solutions exist that can bring similar architectural benefits, but few with such coherence between architectural drivers and outcomes.

Terms, Components, and Stakeholder Explanation

Several technical terms have been used in the above text. This section attempts to explain these and what they mean.

- Public Key: The public part of a public-private key set. This key allows a user to encrypt a message that the private key holder can only read. Alternatively, it can be used to verify that a message signed by a private key is authentic.
- Private Key: This is the private part of the public-private key set. This key allows a user to read an encrypted message encrypted by the public key. It also allows this key holder to sign messages that can later be verified using the public key.
- Ledger / Block Chain: A highly distributed public or private ledger that is immutable (unchanging) and resilient to tampering. It is cryptographically verifiable, and even if several nodes are lost in the Danish geography, it will still keep serving the infrastructure and allow for delayed recovery of nodes without downtime to the system users.
- eIDAS: An EU initiative for a standard identification protocol for authentication, signing, and encryption. The Danish equivalent is MitID.
- Charge Point Owner: A specific charge point's legal and functional owner.
- Charge Point: A piece of hardware that connects to the electricity grid and distributes electrons to an electric vehicle.
- Electric Vehicle: An electric car, such as a Tesla or a VW ID4.
- Service Provider: A provider of an arbitrary service related to the charge points. The currently common use cases for this actor are a charge scheduling provider, a meter collector, and electricity tax refund services.
- Authentication and Delegation Service (ADS): A service for storing rights to a system, which allows other services to see what they are allowed to interface with on other systems, as well as those systems to know what others should be able to access. Please see more in the section “The Authentication and Delegation Service.”

Solved problems of the architecture

If implemented and adopted, the architecture has the potential to solve or technically enable the following.

- Unbundles the physical charging infrastructure and the services a Charge Point Owner would be able to freely choose from in an open market
- Facilitates the integration of EVs and charge point data into an EU Data Space
- Lowers the technical barriers that EVs and charge point face to be able to provide ancillary services that help balance the electrical grid
- Provides a technical foundation for a unified charging ecosystem when charging in any EU country
- Acts as a trusted metering ID giving consumers the option of choosing an electricity agreement specific for the charging of their EV, while charging at any given charge point
- Provides a basis on which legal and commercial roles and responsibilities can be defined and legislated upon
- Standardizes any communication and interaction, which changes the EV charging market into a democratized ecosystem

Open Questions, Challenges and Opportunities

It is our understanding that Energinet cannot fully utilize the complete flexibility from EVs as it is today. As our market review shows, this is mainly due to a lack of awareness from users, an EV charging market that is characterized by unhealthy market tendencies enforced by regulation and the market being in its early days. The proposed architecture of this paper is Energinets best bet on a viable solution, where the current and future problems, needs and opportunities of not only Energinet, but also consumers, market actors and other stakeholder was sought accommodated by the architecture.

Since this proposal, coming from purely Energinet, has the scope of addressing some of the fundamental issues from a certain technical and socioeconomic perspective, the architecture itself cannot achieve its potential without national and international changes with regards to market development and innovation, together with laws and regulations, mixed into a coordinated and collaborative effort. Multiple stakeholders in different societal areas should be involved in finalizing the thoughts and ideas presented here.

Challenges associated with implementing the proposed architecture

From a technical and systemic perspective, there are still important, unanswered questions concerning how such an architecture should be implemented. This non-exhaustive list contains the most obvious questions that could arise for the reader.

1. **Centralized vs. decentralized ADS**
   The ADS is a very important component of the architecture. Instead of building it in the classic sense, where it essentially acts as a centralized database, there is a need for a system with more resiliency, high availability, and based on a zero-trust architecture. There are generally two directions: a centralized or a decentralized ADS. The pros, cons, and similarities between the two options won't be fully discussed here. Still, the implications of choosing one over the other are highly impactful for the resulting availability of the platform. However, the ownership and governing body of the ADS can each have requirements concerning which of the centralized or decentralized approaches is the best fit. A decentralized approach is recommended based on the resilience needed for a system

like this.

2. **Ownership of an ADS**
The striking question of who should own, maintain, develop, and govern the ADS is vital to realize its potential. While this paper will not try to point to a specific ownership model, it can be noted that Energinet won't necessarily have to hold ownership to benefit from the existence of the ADS in the proposed architecture. Also, as a system like the ADS can be generalized to solve closely related issues, such as IoT ownership and control, as well as move between areas like heat pumps and more, there should be a certain amount of deliberation before choosing such a governing and operational party. Furthermore, the question of ownership has a dependency on the geographical scope of an ADS (See point 3.). It should also be noted that developing the ADS as Open-Source software is a priority to uphold the democratic principle, enable collaborative potential, and foster innovation.

3. **Unified user charging experiences**
The architecture is described as Energinets most informed bid on enabling EV's flexibility potential, but it is also designed to be a digital infrastructure for charging without energy flexibility. The advantage of utilizing the architecture for all charging needs is that users will not be forced to have multiple user interfaces for charging in different locations and scenarios and multiple vendors to provide services. So, to accommodate user experience across all the different ways a user can charge a car, the architecture should ideally be implemented as the gateway for all charging needs, both for charging on public and private charge points.

4. **Considerations of the system**
The system will only be as robust as its weakest component. Since the architecture will have some elements of IT (Information Technology) and some of OT (Operational Technology), several security concerns need to be addressed. The need for a heavy focus on security cannot happen only during implementation – it should be a key area of concern if a decision to implement is taken. In contrast to IT-only projects, this architecture contains elements of both IT and OT, which means that in a worst-case scenario, physical damage to people and equipment is at risk if a malicious actor gains access to control and command structures of the system. Furthermore, there is a significant dependency on eIDAS and/or MitID. This does not mean it can't technically be done without one of these systems, but adopting the system used needs to be considered for the intended purpose. If roaming across borders is among the intended goals, then that should be factored in when deciding which solution to move forward with.

5. **Federated ADS': Communication between multiple ADS' when roaming across borders**
It should be considered if a single ADS can serve any number of countries or if there is a need to have separate ADS's per EU member state. That consideration depends on a multitude of factors. Still, the decision also has an architectural component since if the ADS is also sought to be a part of the solution for roaming, especially when roaming across EU borders, there needs to be some minimum level of compatibility between multiple ADS'. Otherwise, there is the risk of users not being able to charge their EVs when visiting other countries. There is a definite overlap with current federated data space initiatives in the EU and member states.

6. **Multiple control entities**
   If the architecture is implemented, the EV charge point has the potential by design to be controlled by multiple entities. However, it also poses an operational risk that two or more entities with some form of control of the charge point can have conflicting interests in what to do about a charger. The consequence is that the user might not get the intended service because the entities have opposite interests in how to operate the charge point at the same period. This can be mitigated by implementing operational rules by either increasing the awareness of the entities about other entities, by allowing the user to set specific rules to prevent, or by limiting the number of entities that control the charge point at a given time. Alternatively, this can be solved by limiting the number of specific types of control that can be given within specific areas at a time. Modeling this, however, would run the potential to hamper the innovation that could happen on top of this market, as strict control limits potential use cases.

7. **Critical infrastructure**
   As EVs continue to increase in popularity, more emphasis should be placed on the criticality of EVs, and charge points controlled by private companies. An added risk is aggregated control of large enough electrical capacities that can be activated and deactivated on command. This constitutes critical infrastructure that could potentially significantly impact the electricity grid's stability. Unfortunately, currently, market actors are not covered by critical infrastructure governance. A system like the ADS could help with levers regulators could utilize to control the mass accumulation of capacity regulated as critical infrastructure.

8. **Dual activation**
   Suppose a charge point delivers ancillary services to Energinet through an aggregator. In that case, there is also the possibility that essentially the same flexibility is sold twice since the EV itself might have the capabilities needed to deliver ancillary services. This can be circumvented in several ways. Three examples are (1) by limiting the options for participation in ancillary services to either the EV or the charge point, (2) by creating a 'charging session' each time the EV is connected to a charger, where the combination of the EV and the charge point is placed as a bid, by the aggregator or (3) to let the aggregator solve the problem by requiring that the same aggregator handles the flexible capacity from both the EV and the charge point, that then knows when not to place a bid for both at the same time.

The need and impact regarding national/EU legislation

From the described perspectives, legislation needs to – ideally – compel any entity engaged in EV charging to use the architecture and build its solutions with the ADS and general architecture as a base while following the capabilities and principles.

The interests of market actors that are intended to adopt the legislation must also be considered at an early stage. This should be done on an experimental and voluntary basis before any legislation is written to fully explore and develop the technical and business-related potentials that might not have been a part of this paper.

During conversations with Rolf Riemenschneider at the EU Commission, it became apparent that legislation in the field would follow soon. It is paramount that any solution implemented does not restrict the agenda in the EU, lest more significant changes in the built environment must be changed. The principal legislation will relate to specifically free roaming services for EVs. Whatever solution is chosen should not conflict with this agenda. Their future will look more into balancing the energy grid using EVs. Still, this investigation is immature, and Denmark has rich opportunity to influence decisions. D4E, or Dataspaces for Energy, will be the initiative that will explore this further in the future.

While Danish interests should be highlighted in the ongoing EU agenda regarding this topic, Denmark would be well-suited to act as a prototyping country for the subsequent EU legislation due to the Danish advancement of the green transition in the energy sector, the general use of MitID along with other public digital services and the adoption speed of EVs. This approach should move forward with the objectives of minimizing conflicts with the EU agenda. At the same time, for a given period test the potential value, gather feedback, and refine the solution for a broader EU implementation. It should be noted that the EU is prepared to give EU member states that lead the way advantages and support so that innovation will happen in this field.

A few guidelines can also be given for Danish national legislation that accommodates the above requirements.

- Regulation of how guiding principles can enable EV charging flexibility.
  It can be a requirement for lower TSO/DSO consumer tariffs that the EV charging happens flexibly, it can be a requirement to be eligible for electricity tax reimbursement, or market structures can incentivize the flexibility.

- The job of creating legislation regarding EV charging spans multiple legislative domains but needs a holistic and unified approach; it should be addressed by not advancing legislation in one area of government but as a coordinated effort among the relevant ministries, departments, and agencies.

- To allow the subsequent EU regulation to be implemented, the Danish legislation and regulation should be limited to a specific point in time, after which it is expected for Danish interpretation of the EU legislation to take over.

It should be noted that Energinet cannot currently offer specific technical requirements for the physical consumer-oriented devices (e.g., charge points) and other systems that are critical components of the future charging infrastructure envisioned in this paper. If Energinet were to specify the technical requirements at this point, there is a high probability that requirements would not satisfy future needs, as too many factors are unknown without further exploration. There is also an inherent need for socioeconomic cohesion between the requirements' quality and the value they expect to create. There needs to be a coordinated effort to discuss the requirements and qualities to support the Danish interim legislative implementation. This should focus on testing the societal value creation for consumers, market actors, and Energinet. Energinet will be a natural partner in those discussions but should perform this duty with relevant partners.

Opportunities for collaboration and innovation

Besides legislation, there is a need for a market-driven approach to unleash the potential innovations when democratizing charge points infrastructure. This can be done either before, during or after the legislation implementing the architecture is written, but it is important that subsequent legislation will support the widespread innovation potentials that is possible, by utilizing the capabilities and principles put forth in this paper.

Examples of innovations that require such subsequent legislation is given to the reader.

- While this paper presents the architecture on a backdrop of EV charging, it can also be utilized for other use cases and other types of IoT devices. This could mean heat pumps, having some similarity in properties and features as an EV charge point, but it could also be smart door locks. The use case of door locks could be the need of an owner of an apartment that has been rented out for a short period of time, that needs to delegate access to lock and unlock the apartment.

- Electricity agreement not being bound to one metering ID at one time and place. If implemented and with the right legislation, it would be possible to some degree, for a person with an agreement with an electricity supplier, to use the same agreement for not only the home address but also for a house rented for a period of time, or really any electricity need that is not bound by the home address.

- Local sharing of charging infrastructure where the EV charge point owner can rent out their otherwise private charge point, to for example the neighbors many guests for a birthday, that needs to charge their EV. This could be a relevant use of the opportunity to use an electricity agreement not bound on the metering ID on the home address.

- By changing when an electrical load the use of voltage and the current during a period of an alternating voltage the load can provide reactive power. An EV charger doing so will be able to help secure the DSO net stability by providing local voltage regulation. The importance of this is that when moving to an inverter-dominated energy production, which is a byproduct of integrating solar and wind power in the electricity grid, there will be a bigger need for dynamic reactive power regulation. This is not a standard feature for EV charge points, so seeking this functionality would heighten the electrical requirements for EV charge points.

Conclusion and Recommendations

This paper presents a series of current challenges of the current market surrounding EVs originating from studies of the future energy system and the role of EVs in achieving balance between electricity production and consumption.

It is found that while market actors are currently engaged in enabling demand response and balancing services from electric vehicles, the charging market is characterized by unhealthy trends and consumers being de facto locked to a single provider. By introducing a software architecture, based on simple and democratic capabilities and principles, it is shown how it is possible to define a technical framework for better collaboration, competition, user friendliness, legislation and ultimately, a step in the right direction for the green transition.

By enabling the owner of a charge point to freely delegate granular control and read access to a charge point, the owner of a charge point and EV users will be able to have more options. Both in terms of which charge points are accessible and the freedom of choice of services that can be deployed to increase the utilization and value of each charge point. This is seen as a change from an EV charging ecosystem to a democratized EV charging ecosystem.

Using EV charging as an active part in the transition to green electricity production by adopting the proposed solution presents exciting opportunities. Alarmingly, it is also found that if EVs are not carefully integrated into the electrical grid with due diligence, there are risks of increasing cost of integrating renewables, lower security of supply, and higher CO_2-emissions. If not for the exploitation of the opportunities, actions should be taken for the elimination of the risks.

To realize such an EV charging ecosystem along with its benefits, legislative action is required. This report is Energinets input on which concerns to consider and which steps to take to support the architecture for legislators.