Lessons Learned from Demonstrating Smart and Green Charging in an Urban Living Lab

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Abstract. Smart and green electric vehicle charging needs digital support which integrates systems from the energy, transport and building sectors. The GreenCharge project has proposed, demonstrated, and evaluated such support in an urban living lab setting. The proposed solutions are documented in a Reference Architecture meant to act as a blueprint both facilitating the extension and integration of the involved systems in the prototype implementation and supporting replication. However, successful uptake also depends heavily on motivating and engaging relevant stakeholders. In this paper, we share our experience and lessons learned from the design, implementation, and deployment of the proposed solutions in an urban housing cooperative. Barriers and drivers regarding this innovation process are identified and recommendations to overcome the barriers are suggested. The findings are intended to help stakeholders and policy makers to develop successful strategies for sustainable electric mobility and electric energy supply.

1 Introduction

Electric mobility (eMobility) partially powered by local renewable energy sources (RES) is a powerful measure to decarbonise the transport sector and offer demand flexibility to the electric energy supply system [1]. However, several barriers need to be overcome to reach massive electric vehicles (EV) adoption. Prospective EV owners are concerned about the availability of the charging infrastructure where they can charge their EVs when needed. Charging of many EVs at the same time produces peak loads and pressure on existing electricity infrastructure for electricity providers and building owners. The charging demands need to be coordinated with other energy activities in the neighbourhood. It is also challenging to use local RES optimally due to a mismatch between the availability of locally produced renewable energy and the energy consumption patterns.

The GreenCharge project (https://www.greencharge2020.eu/) aims to address the above challenges and demonstrate how technological solutions and associated business models can be integrated and deployed to overcome barriers to wide scale adoption of EVs. The GreenCharge concept for *green and smart charging* is built upon cross sectorial collaboration involving business actors and supporting technical systems from the transport, electric energy supply and building sectors [2]. The idea is based on energy smart neighbourhoods (ESN), where EV charging is managed together with other local energy demand and local RES in the neighbourhood, exploiting demand flexibility and local storage capacity to adapt local demand to local production in order to facilitate smart EV charging with renewable energy. The digital support for such an ESN is a system of systems (SoS) with complex functionality and interactions. To facilitate the integration into such SoS in a well-defined manner, GreenCharge has defined a Reference Architecture (RA) for a full-fledged specification of the ecosystem [3]. Different systems can be implemented or extended based on a subset of the specifications in the RA and collaborate to facilitate smart and green charging.

Urban living labs (ULL) in Oslo, Bremen and Barcelona have been selected to evaluate the solutions and facilitate learning and future replication. The implementation and demonstration of smart and green charging in an urban living lab can be seen as a realisation of the RA with selected functionality adapted to local context and needs. The adoption of the GreenCharge solutions in ULLs has to address a number of technical, social, and organisational challenges. In this paper, we present the design, implementation and deployment of the proposed solutions for smart charging with optimal energy management in a housing cooperative in Oslo, and lessons learned from this process. The focus is to learn from this process. The related research questions are:

- RQ1: Which enablers and barriers affected the work?
- RQ2: What are the lessons learned that can support re-implementations of smart and green charging?

In the following, Section 2 discusses related work and Section 3 describes the approach for the overall innovation process and the evaluation and learning. Section 4 presents the context of the Oslo ULL. Section 5 describes the RA and the prototype deployed in the ULL. Lessons learned from the process evaluation are presented in Section 6, before we conclude the paper in Section 7.

2 Background and Related Work

ENTSO-E has provided a deep analysis of eMobility and its impact on the power system [1], focusing on interfaces between transport and energy sectors. The GreenCharge concept and the Reference Architecture are consistent with the framework and recommendations proposed in [1]. In addition, the interfaces with the building sector are considered, and all types of energy use in neighbourhoods are included, charging included.

Smart charging refers to charging supervised by an exterior control system, as opposed to the state-of-the-art (SotA) charging [1]. The current SotA technology and services that facilitate charging of a fleet of EVs involve a *reactive* management system, which ensures that the aggregated electricity load for charging several EVs does not surpass the available capacity in the parking place. In this case, all EVs immediately start charging after plugging in. If the capacity limit is reached, all EVs will have their charging power reduced, either by reducing the charging speed or charging the cars randomly in sequence. Hence, the system provides a safe solution for charging of multiple EVs, but the EV users might become dissatisfied if the desired charging demand is not met.

Another solution is a *predictive* smart energy management system with optimal scheduling, which provides an optimal plan for scheduling the charging of individual EVs. The optimal plan is calculated based on the departure time of each EV, and its charging need (the difference between the actual State-of-Charge (SoC) at plug in, and the desired SoC when plugging out). In such a system, the charging of EVs that will be unplugged the next day can be postponed (temporarily stopped), and EVs that plan to leave within the next few hours can be prioritised. GreenCharge follows this approach.

In the literature, optimisation models are used in a simulation environment to investigate predictive smart energy management [4][5]. However, only a few demos have been tested in real life, and the experiences are not always successful. For instance, in the INVADE project (https://h2020invade.eu/the-project/), the aim was to design and develop a flexibility management system based on optimisation. However, the demos in the project experienced large challenges in the transfer of real-time data between the different stakeholders, and the implementation of the optimal scheduler [6].

3 Approach

Urban living labs (ULL) have been a popular approach to address the challenges related to sustainable urban interventions. According to Steen and van Bueren [7], the characteristics of urban living labs include four dimensions: a) *aimed* at innovation, formal learning for replication and increasing urban sustainability; b) covering *activities* of development (all phases of the product and service development process), co-creation and iteration (feedback, evaluation and improvement); c) *participants* from public and private sectors, users and knowledge institutes, all with decision-making power; d) innovations taking place in the *real-life use context*. They further identified five overarching phases in the innovation process: research, development, testing, implementation and commercialisation. The GreenCharge innovation process adopts the urban living labs approach and covers the first four phases (except commercialisation), where demonstration and evaluation are performed in real-life settings with collaboration of a multidisciplinary development team and the active involvement of users in the whole process.

The design science method [8] is used and adapted to support the overall iterative research and innovation process. The activities are considered an integral part of the ULL concept, as illustrated in Fig. 1. The main principles of the approach are:

1. **Environment – context:** The current environment provides input on stakeholders, needs, requirements, barriers, existing models, etc.
2. **Design and Build:** The artefacts are established.
3. **Demonstrate and Evaluate:** The artefacts are tested and evaluated.
4. **Knowledge base:** The validated results and the knowledge gained enhance the knowledge base and are shared for further exploration and exploitation.

The artefacts designed and built are a Reference Architecture, business models and prototypes integrating hardware and software. The artefacts are developed through iterative and interlinked processes illustrated by the **relevance, design, and evaluate**

cycles in the figure. The three cycles have been enriched with characteristics of ULL described above (indicated as a, b, c, d). The relevance is verified and validated through the environment to ensure that the requirements are met and that the artefacts are relevant/correct. A multidisciplinary project team, residents, and the housing cooperative administration have been actively participated in the co-creation of the innovative solutions. The business models and prototypes realise selected parts of the architecture, and they are designed, built, and tested in ULLs to demonstrate their feasibility and to facilitate evaluations. Evaluations are done based on data collected from the demonstrations and by means of simulations to investigate the possible impacts and to learn about the innovation process. This paper focuses on the latter, and covers the design, implementation and deployment stages for the prototype artefacts and the associated parts of the Reference Architecture.

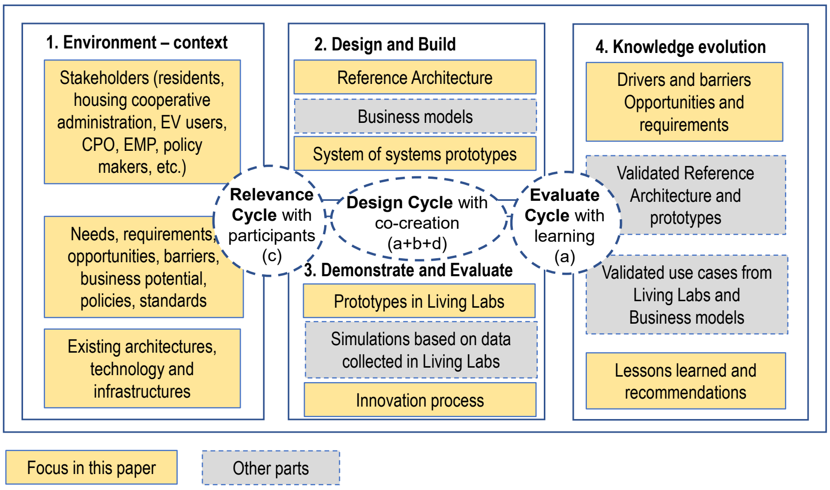

Fig. 1. Design science framework adapted to smart and green charging.

The process evaluation builds on the CIVITAS evaluation framework [9] and is based on qualitative analysis through collation and analysis of activities throughout the whole process to understand more clearly why new solutions succeed or fail. The evaluation focuses on identifying drivers, barriers and risks, as well as the required supporting activities. The analysis is based on the following input: 1) *pre-analysis* of stakeholders with a significant role in the process and their specific roles, risks, possible barriers and drivers; 2) *monitoring and assessment* of relevant actions and events to understand what has happened and why. The monitoring identifies supporting activities that have a significant influence, such as communication, introduction of a new design method, planning or decision-making methods, stakeholder involvement and engagement activities. The "noise" from irrelevant activities must be taken into consideration. The implementation of the automatic research data collection needed in the impact evaluation was for example a complex and comprehensive task that caused many discussions and actions that were not relevant to the process evaluation. 3) *Involvement of the stakeholders* to collect input on what they have experienced and learned. The input is collected through minutes from meetings and logs documenting challenges, events and decisions during this process. 4) *Focus groups*. A focus group was arranged with all actors involved in the ULL to investigate the barriers and drivers encountered and the effect of supporting activities. A neutral facilitator asked open questions, and the participants discussed. The input was analysed. The results are summarised in section 6.

4 Relevance Cycle – the Context

The Oslo ULL addresses a housing cooperative, Røverkollen, where each apartment has its own, private parking space in a common garage. Røverkollen housing cooperative is located in a suburb in the eastern part of Oslo and has 246 apartments divided on 5 housing blocks. To provide convenient green charging to the residents, 60 new charge points (CP) were installed in the garage, 70 kWp of photovoltaic solar panels on the garage roof, and a stationary battery on the ground floor.

The stakeholders involved in the ULL are residents (users and owners of the private CPs), Røverkollen housing cooperative administration (facilitating that the residents can charge at their own parking place), the utility company/ DSO and electricity provider (representing the public grid and the grid infrastructure), and the multidisciplinary project team - Fortum (technology provider acting the role of Charge Point Operator (CPO)), ZET (technology provider acting for eMobility provider (EMP) and part of the Local Energy Manager (LEM) roles), eSmart (technology provider acting the role of LEM), Oslo municipality (urban planning authority and policy maker) and SINTEF (research institute).

Before GreenCharge, the few EV owners in Røverkollen used 4 CPs outside the garage for charging. As more residents have bought or plan to buy EVs, the housing cooperative decided to allow EV owners to install their own private CPs in their parking garage. Røverkollen wants solutions for smart energy management to facilitate the charging of all EVs without high investment for upgrading the existing electricity infrastructure, and at the same time, ensure that the total charging demand is within the electricity capacity limits. Further, as there is a high peak load tariff for large consumers in Norway, Røverkollen wants to reduce the energy peaks by utilising local RES which at the same time increases the greenness of the charged energy.

The initially installed load management system (LMS) from the CP providers had a *reactive* control feature as described in Section 2. There were no incentives for “green” charging behaviour, i.e., no economic benefit and no technical support to shift charging to periods with high production from local solar panels and/or low demand on the grid.

The GreenCharge innovations offer a *predictive*, optimal and coordinated energy management with flexible and priority charging that can satisfy the above needs. Predictive smart energy management is supported, i.e., optimal distribution of the EV charging over time (accounting for other use of energy in the garage), adapted to PV availability, and to individual charging demand both regarding the amount of and timing of the energy requested. The residents and the Røverkollen administration were motivated and actively involved in the process of co-creation and testing the innovative solutions.

5 Design Cycle Activities

5.1 Reference Architecture (RA)

The GreenCharge innovations require cross sectorial collaboration involving business actors and supporting technical systems of the energy supply, transport and building sectors. The electric energy supply and the building sectors are mature and highly regulated sectors with well-established business structures and supporting technical systems. In the younger eMobility sector, a business structure with business actor roles, supporting appliances as well as technical and business systems has already emerged as well. Therefore, our approach to realising the GreenCharge concept is to extend the functionality of and the collaboration between these already existing systems.

In line with this approach, the RA aims to specify the participation of relevant existing systems in the realisation of the GreenCharge solution in terms of modified and/or added responsibilities and collaboration patterns necessary to support the GreenCharge concept. This is described in terms of UML stakeholder-, use case-, decomposition-, and collaboration models in the RA document [3]. An initial version was developed in the beginning of the project in co-design between the research and commercial partners to facilitate a common understanding of the GreenCharge concept and serve as a blueprint for the implementation of the digital support for prototypes used in ULLs. Then it has been refined towards the end of the project to reflect lessons learned during the implementation and use of the prototypes in ULLs.

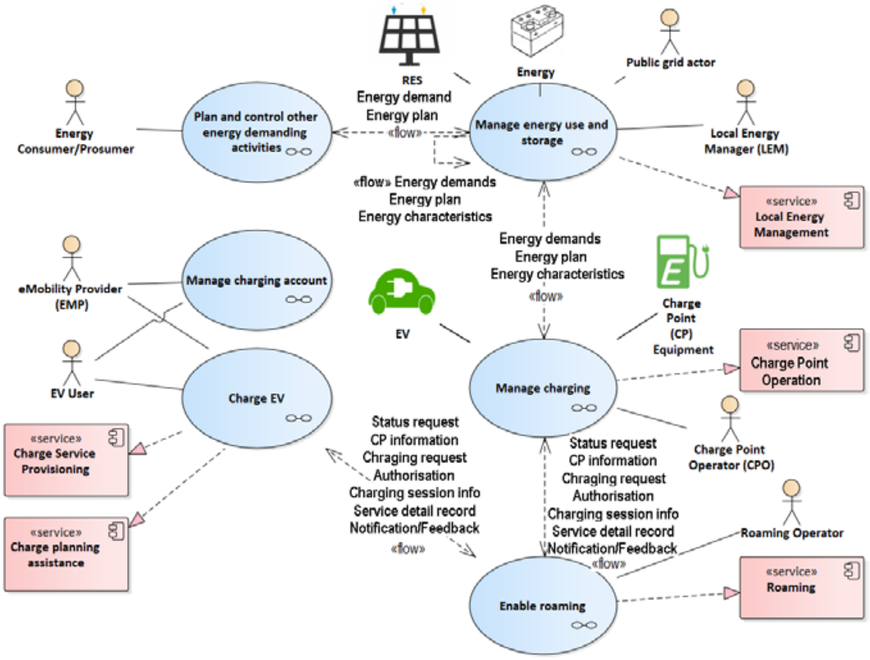

Fig. 2. Stakeholders, use cases and services for smart and green charging.

Fig. 2. gives a high-level view of the RA with stakeholder roles (stickmen) and important technical equipment (pictograms), main use cases (ovals) and software *services* supporting them (rectangles). The key elements and the extension needed to support the GreenCharge innovative features include: *Charge Service Provisioning* supports EMPs in the selling of charging services to EV drivers. This involves authorising the use of selected CPs and taking care of billing and payment. In addition, it provides the user interface to the *Charge Planning Assistance* service assisting EV drivers in planning the charging of their EVs and booking charging at suitable CPs. This is an innovative service not commonly provided in SotA charging stations. It is to be provided by EMPs as an extension of their offer to their customers (EV drivers) and provides important information about the flexibility of the planned charging session, such as planned arrival and departure times, required amount of energy and whether they allow Vehicle-to-Grid (V2G). *Charge Point Operation* supports CPOs to operate their CPs to fulfil charging requests relayed through EMPs. It needs extensions to support advance booking of CPs. *Roaming* enables seamless access to CPs by connecting EMPs and CPOs. It needs to be extended with support for advance booking and for relaying the flexibility information. *Local Energy Management* automates shifting and shaping of flexible loads and use of local storage resources in a neighbourhood with the aim to optimise utilisation of local RES and reduction of peak power. Demand flexibility information is solicited from the building inhabitants. Establishing such ESNs is a shared responsibility of the building owners in the neighbourhood.

Each ULL implements a subset of services defined in the RA according to the local context and business needs. Altogether they cover all the features in RA.

5.2 System of System Prototype in the Oslo Living Lab

The garage is managed by a prototype of system of systems (SoS) implementing a selected subset of services defined in the RA adapted to the local context as illustrated in Fig. 3. Since the Fortum Charge & Drive management system and the eSmart Connected Prosumer system are commercial systems, special design and workaround has been done for the integration of this SoS prototype in order to reduce the changes of the operational systems. This prototype manages the CPs in the garage and offers flexible charging (default option) and priority charging (has priority when there is not enough energy to fulfil all demand). In addition, it supports *predictive, optimal and coordinated use of energy***.** Information on energy demand from charging requests and heating cables, energy availability from the public grid, local RES and stationary battery, as well as historical data are used to dynamically calculate optimal energy distribution among energy demanding activities in the garage. The charging of individual EVs, use or storage of energy from local RES, and the use of energy from stationary batteries are then scheduled for optimal load balancing and optimal use of energy from RES.

As shown in Fig. 3, the prototype consists of four system components implementing four services defined in the RA. The *Fortum Charge & Drive management* implements *Charge Point Operation* service for the steering of the CPs. The *ZET App & Charge Management backend* is a new development and implements *Charge Planning*

Assistance and *Charge Service Provisioning* services. It is used by the EV users to start the charging and to provide input on user profile information (such as information about the EV and default values to simplify the charging requests) and charging requests with charging constraints. The EV user can monitor the charging process and check the estimated SoC in the App. The *Local Service Management* service is provided by *eSmart Connected Prosumer* platform and the *ZET individual charge planning*: The *eSmart Connected Prosumer* monitors issues that may affect the energy availability and use (weather, RES production, stationary battery, heating cables, charging demands with varying flexibility), and calculates a dynamic *overall capacity plan* for optimal energy use at an aggregated level (i.e., predicted total capacity in the garage that can be used for the next 48 hours with 15 minutes interval). When receiving the capacity plan, the *ZET Individual Charge Planning* generates *individual charge plan* for each CP, upon which the *Fortum system* controls the start/stop and the energy transferred at individual CPs. The eSmart system also controls the charging/discharging of the stationary battery.

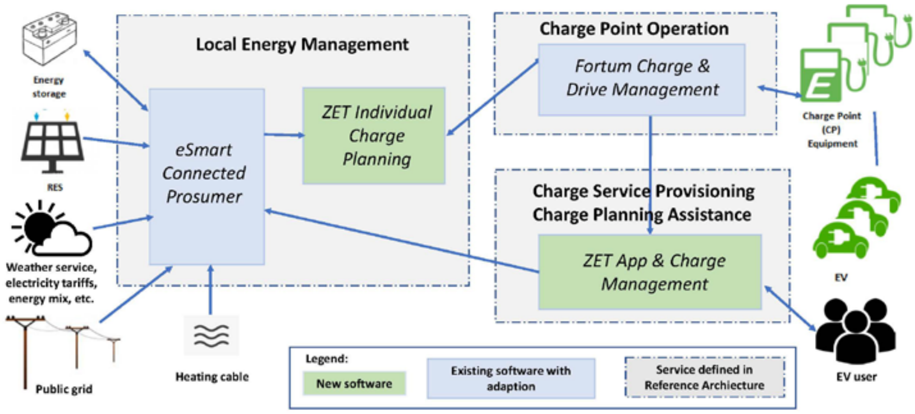

Fig. 3. The system components in the prototype and their interactions.

Initially the ambition was to include also a number of apartments in the ESN, but this was dropped due to regulatory constraints. Since each apartment and the garage has separate grid contracts and meters, the coordinated smart energy management of the apartment and the garage in such case would lead to unfair distribution of energy cost.

6 Evaluation Cycle with Lessons Learned

This section presents the findings from the process evaluation. Key drivers and barriers identified in the process are discussed here. A complete and detailed description of the drivers and barriers can be found in [10].

6.1 Key Drivers and Barriers

Table 1 provides an overview of the key drivers identified and their effects and Table 2 provides an overview of the key barriers identified and how they were handled.

Table 1. Key drivers and effects.

Driver type	Key drivers	Effects
Behavioural	**Positive attitude** from the housing cooperative administration to the new solutions.	Input on needs and possibilities.
	Subsidises of CP investments	Participants recruited
	Promotion activities like launch event, explanatory videos, information meetings and letters to residents.	Increased awareness and knowledge among residents.
	Stakeholder engagement through meetings and workshops on business models.	Roles, focus and user needs clarified.
Economic	**eMobility incentives** in Norway, such as tax reductions, toll road fee reductions.	eMobility acceptance and positiveness.
	Subsidises from municipality and housing cooperative association.	Investments in CPs, stationary battery, and PV panels.
Implement-ation capacity	**Multidisciplinary team** with technology providers (CPO, EMP, LEM), business model experts, municipality, researchers, housing cooperative administration, and residents.	Cross-sectoral solutions, in line with the ULL characteristics.
	Flexibility of partner with respect to additional tasks and responsibilities.	Problems could be solved.
Technical /economic	**Business models and technology alignments** in workshops with business model designers and technology providers.	Technology support for the implementation of business models.

Table 2. Barriers and how they were handled.

Barrier types	Barriers	How handled
Complexity	**Complex and novel solution.** Lack of off-the-shelf components and integration of systems from several partners.	Requirement updated to match new insight. Unforeseen problems addressed when they occurred.
Technical	**Integration with CP equipment**. Interface did not work as expected and blocked the smart energy management.	Testing, investigations, and delays. Software workaround solved problem and safety risk, but reduced the quality.
	Integration of outdoor heating cables. Difficult to control correctly. Cannot predict the consumption pattern due to unknown dependencies on temperature, delay, humidity, etc.	Direct control not implemented for safety reasons – cannot risk icing. The load integrated as a non-flexible residual load instead.
	Integration between management systems. No standardised interfaces for integration of charge management and local energy management.	Custom interfaces to the systems and their capabilities (as planned).

	Access to SoC is a problem since current protocols do not support access to current SoC from the EV's on-board systems.	Collection of SoC via user interface in App. The user provides SoC values manually.
Regulatory	**Regulatory barrier in local grid infrastructure** blocked the creation of a virtual smart meter and blocked billing of the planned ESN as one customer.	Data from the garage and from some apartments are used as input to simulation of more comprehensive ESNs in order to investigate the possible effects on key performance indicators.
Collaboration	**Coordination and communication problems** due to the multidisciplinary work and the many actors involved.	Weekly telcos to follow up blockers and coordination between activities.

The biggest barriers we experienced are associated with the lack of support in commonly used protocols for the novel features of GreenCharge solutions and the difficulties with making experimental modifications and extensions to 24/7 systems. For example, regarding the integration with CP equipment, the built-in CP load management system (LMS - with simple load balancing) blocked the scheduling done by the smart energy management. At the end, the built-in LMS had to be disabled. However, this leads to a safety risk in case of technical problems (e.g., software errors, loss of Internet connection) where fuses may blow, equipment may be damaged, and charging may be blocked. To mitigate this, a software workaround was designed regarding smart energy management: a low speed redefault charging ensured some charging in any case, and capacity was reserved for low-speed charging, to prohibit overloading. The disadvantage of this approach is that the reservation leaves less capacity for use in optimisations, and the value of the solution is reduced.

Another serious barrier is that the electric energy sector is a highly regulated one with a regulatory regime lagging behind the rapid growth of decentralised RES and the increasing interest in local energy communities like ESNs. In Røverkollen, although it was technically feasible to create a virtual meter and bill the initially planned ESN as one entity, it was refused by the local DSO because it was against the regulation. We also suspect that DSOs are reluctant to accept such solutions because they would lose payment for the use of the grid to transfer locally produced energy between the members of the local community. Hopefully, this will change in the future as local RES and smart house technology and becomes more widespread.

6.2 Lessons Learned

Key lessons learned important for future sustainable eMobility strategies include:

Flexible charging can be implemented, provided that the charge management system and the charge point equipment can be integrated and controlled in a detailed and flexible way. Charge point equipment control must support individual control of each charge point. It must be possible to start and stop the individual charge points at any time and to charge with different power from different charge points.

The implementation of an ESN is a challenge. Today, this is not done by easy plug and play. Off the shelf components from different providers cannot easily be combined due to the lack of standards and standardised interfaces. It may also be difficult to control the systems and equipment involved (charge points included).

Business models should address more than just the money flows. Price models may for example be used to encourage the desired charging behaviour. Flexibility should be rewarded, which is not common today.

6.3 Recommendations

This section provides recommendations derived from the process evaluation.

Stakeholder involvement: Several types of actions must be considered to get input from and to involve the stakeholders, e.g., workshops and meetings, information letters to EV users, launch events creating publicity, interviews and questionnaires. Affected stakeholders must be involved whenever relevant, e.g., regarding the purchase of hardware, the design of the functionality supported by the technology (e.g., App), business models, and price models. Users must know how they can find information and how they can get support.

Business models and price models: The business and price models must be designed in collaboration with all partners involved. The traditional approach to business models is not sufficient. The value proposition is also about sustainability with respect to environmental and societal aspects, e.g., to reduce energy peaks. The right combination of technical solutions, business models, and price models has the potential to motivate to a desired behaviour and to handle business related problems.

Design and implementation: The implementation must be followed up at a weekly basis. All partners involved must participate. Blockers, problems, and potential problems must be identified at a detailed level, actions must be decided, and responsibilities must be assigned. Blockers and actions must be followed up.

Hardware and equipment for ESNs: *The needs must be specified in detail. Statements from the providers regarding the ability of the devices cannot be trusted* unless they are based on a detailed specification of the needs. *The integration with the energy management system and the ability for equipment control* must be emphasized and verified. Many charge points are today provided with a built-in solution for simple load balancing that may cause problems in an ESN. The local energy management in the ESN may not be able to control the charge points as required. Thus, the details must be discussed with the provider of the software controlling the charge points to facilitate integration with the energy management system. *The involvement of experts is crucial.* Considering the problems described above, most building/property owners should use external expertise on the design and development of the total ESN solution.

Policy, standardisation, and harmonisation issues: Charging protocols must provide the current SoC to facilitate optimal charge planning in ESNs. Navigation systems must facilitate the provision of desired SoCs, e.g., based on planned trips or artificial intelligence using input on the EV user's habits. Providers of charge point equipment must arrange for integration with local energy management in ESNs to facilitate an extended load balancing that takes predictions and the needs of the whole ESNs into account. Providers of devices such as stationary batteries must recognise the needs in ESNs and support the control mechanisms required. The software integration between local energy management and charge management must be standardised.

7 Conclusion

The GreenCharge Reference Architecture provides a full-fledged specification for implementing solutions for smart and green charging. When implementing and demonstrating the solutions in selected urban living labs, adaptions and workaround have to be done due to the constraints of the local context and the available technology. Moreover, a successful adoption of innovative solutions needs not only well-functioning technical systems, but also support in other aspects, such as user engagement and economic and policy incentives. This paper presents the lessons learned from demonstrating smart energy management and smart charging in a housing cooperative in Oslo. We experienced barriers related to technical, regulatory and collaboration issues, in particular, the integration with the energy management system, the ability for equipment control, the lack of support in commonly used protocols for the proposed innovative features and the difficulties with making experimental modifications and extensions to 24/7 systems. Recommendations to overcome such barriers are suggested. For instance, standards are crucial for facilitating the integration of local energy management and charge management.

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