Scandinavian Journal of Information Systems

Volume 34 | Issue 2 Article 2

12-31-2022

Designing Local Energy Market Applications

Bent Richter
Karlsruhe Institute of Technology, bent.richter@kit.edu

Philipp Staudt
Karlsruhe Institute of Technology, Germany, philipp.staudt@kit.edu

Christof Weinhardt
Karlsruhe Institute of Technology, christof.weinhardt@kit.edu

Designing Local Energy Market Applications

Cover Page Footnote

The research of Bent Richter is supported by the German Research Foundation (DFG) as part of the Research Training Group GRK 2153: Energy Status Data - Informatics Methods for its Collection, Analysis and Exploitation.

Designing Local Energy Market Applications

Bent Richter, Philipp Staudt, Christof Weinhardt
Karlsruhe Institute for Technology
bent.richter@kit.edu
philipp.staudt@kit.edu
christof.weinhardt@kit.edu

Abstract. Local energy markets and corresponding information systems are a way to integrate and involve residential customers in the energy transition, which can increase acceptance and drive private investment. This study is focused on the generation of design knowledge for these local energy market user applications in general and specifically to ensure long-term user engagement, which is a crucial success factor to maintain long-term effects. To this end, we derive, instantiate and evaluate seven design principles based on a field implementation with user interaction over 13 months using a design science research approach. The design principles and their instantiations are evaluated based on semi-structured interviews with the participants and a consecutive online experiment. The design principles provide fundamental knowledge for the setup of local energy market user applications and are therefore of value for researchers and practitioners alike.

Key words: local energy markets, design science research, application design, design principles.

1 Introduction

Local opposition and social resistance are slowing down the energy system's transformation that is needed for a decarbonized economy (Batel et al., 2013) Energy communities have been discussed in academia for several years as a promising approach to involve citizens in the energy transition and thereby, to increase the local acceptance and support of renewable energy capacity expansion (Brummer, 2018; Caramizaru & Uihlein, 2020; Koirala et al., 2016; Walker & Devine-Wright, 2008). The core idea is that citizens form a community to invest in renewable energy hardware and share lo-

Accepting editor: Henri Pirkkalainen

cally generated environmentally sustainable energy to mutually profit from its returns. In addition to offering financial advantages for the participants and an increase in the environmental sustainability of their energy consumption, the concept contributes to the societal goal of expanding renewable energy generation. Currently, private households often cannot obtain real-time information on their consumption behavior and its environmental consequences or their individual costs (for instance, the current costs and electrical load of turning on the dishwasher). Their overall energy literacy is low, which broadly describes an understanding of energy consumption and the impact of individual behavior on said consumption (Brounen et al., 2013). However, there is an increasing interest in more environmentally sustainable consumption among private households (Sangroya & Nayak, 2017; Wüstenhagen & Bilharz, 2006). For example, the adoption of green electricity tariffs has been increasing steadily over the last years (Kaenzig et al., 2013; Navrud & Bråten, 2007; Sundt & Rehdanz, 2015). Furthermore, an active participation in the energy transition addresses further sustainability goals beyond environmental sustainability, not necessarily in the focus of the Information System community at the moment (Schoormann et al., 2021). Given the desire to behave more sustainably, nergy communities can become a digital platform where the participants monitor their individual consumption behavior and its impacts with the help of digital technology (smart meters, metering software, etc.). Similar existing solutions include, for example, smart home dashboards (Castelli et al., 2017; Meeuw et al., 2018). In addition, such a platform might allow users to share or trade locally generated renewable energy directly among the community. The literature mostly refers to the specific type of energy community that allows trading as a Local Energy Market (LEM) (Mengelkamp, Diesing, et al., 2019).

Interacting with such a digital platform also allows participants to develop a higher energy literacy and to consume energy more sustainably through purposeful behavioral changes. First, high-resolution load data from smart meters enables participants to analyze their consumption behavior more precisely and to identify devices with high energy consumption. Intentionally adjusting the usage of these devices in periods where such a reduction is not or only slightly reducing the participants' utility, decreases the overall energy consumption, while only minimally affecting comfort levels. These are low-hanging fruits to reduce the individual energy costs and emissions (Kuo et al., 2018). Second, the trading platform records individual transactions (such as consuming or sharing electrical energy), which allows to trace the origin of local electricity and provides participants with information on the composition of the sources of their electricity consumption (as well as the costs). This information is helpful for participants to learn how much electricity from renewable sources they have consumed at what time and thus, to evaluate the environmental sustainability of their behavior (Jain et al., 2013). Third, continuing interaction with the platform over an extended period enables the participants to get more familiar with their consumption behavior, the origin of their energy consumption and the ensuing effects and therefore to increase their energy literacy. These new long-term insights and the corresponding feedback help participants to investigate their own consumption behavior and make purposeful behavioral changes (Schwartz et al., 2013).

However, many of the described benefits require participants to interact with the platform over a long time period. A commitment to this long-term engagement is linked to perceived individual benefits that can be derived from the platform. This requires first and foremost that participants are able to understand and use the provided functionality of the platform. If the perceived benefits seem small or the perceived hurdles to realize them are high, participants become inactive and may leave the community. Inactive participants, who do not utilize the provided behavioral information will not make purposeful consumption changes. Therefore, the platform's design plays a central role, which particularly concerns the user interface. An inadequate design may inhibit participants from finding functionalities or might make it difficult for participants to use them as intended. The provided information from the platform can also be misunderstood and thus lead to unintended behavior. Designing a system that fits all relevant community needs is particularly challenging because most of the participants have different levels of knowledge and are non-experts. Their motivation to participate and the time they are willing to dedicate to the system differ widely. In most cases, the interaction with the LEM is not a priority but rather an additional source of information that they might consult irregularly. For this reason, it is particularly important that the platform design supports the participants in easily accessing and understanding the available functionalities and information.

With this study, we acknowledge this importance and therefore report on novel design knowledge for LEM platforms based on a design science research (DSR) project that features a long-term field experiment. In this field experiment, participants interacted with an LEM application in an active phase over 13 months, which followed a preparatory phase of 6 months during which part of the functionality was already available. We report how participants interacted with the implemented information system and which functionalities motivated them over the long-term. The results help to ensure a long-lasting effect for more sustainable behavior based on LEM platforms. We use the term 'long-term engagement' to refer to participants who continually interact with the system over a long-term period and engage with the information provided. This should not be confused with constant or regular engagement. In other words, the objective is that participants integrate the system into their routines rather than engaging with them as much as possible (as is for instance the objective of social media platforms). We elaborate on design principles (DPs) that a) provide practical experiences for new LEM projects and b) contribute design knowledge in the emerging field of energy communities where long-term engagement supports sustainable behavioral change of non-expert users. We investigate the following research question that embodies three parts:

How should a platform and user interface for a local energy market be designed so that participants (i) can understand and use the provided functions, (ii) are enabled to behave according to their preferences and (iii) generally exhibit a long-term user engagement?

To answer this research question, we conduct or DSR project based on the approach by Kuechler and Vaishnavi with three design cycles (Hevner et al., 2004; Kuechler & Vaishnavi, 2008), on which we report in this study. We design a first prototype based on identified requirements (Cycle 1) and derive six DPs based on this design. We then instantiate them in a full application and evaluate the proposed design after a 13 months field testing phase in an existing LEM project (Cycle 2). We conduct individual expert interviews with the project participants for the evaluation. Based on the interview feedback, we conduct an online experiment (Cycle 3) to evaluate the market mechanism preferences of potential LEM participants and derive the seventh DP.

2 Related work

The LEM concept has been a vigorously discussed topic for several years (Bremdal et al., 2017; Mengelkamp, Schönland, et al., 2019; Wörner, Ableitner, et al., 2019). The LEM is more than a reduced version of the national wholesale energy market. In contrast, no large energy suppliers and power plant operators trade with each other. Instead, small local generators and prosumers trade with local consumers such as private households or local businesses in the immediate geographical vicinity (Mengelkamp, Gärttner, Rock, et al., 2018; Teotia & Bhakar, 2016). The LEM platform facilitates the communities' continuous power distribution and financial flows through an allocation mechanism like an auction or peer-to-peer mechanism (Liu et al., 2019). There are various studies on the basic structure of LEMs, the essential components, and its potential integration into the energy sector (Cramer et al., 2018; Mengelkamp, Diesing, et al., 2019; Teotia & Bhakar, 2016). Besides the empowerment to make purposeful consumption behavior changes toward more sustainability, the LEM concept is further associated with other benefits. For instance, it allows small generators to sell their generated energy directly, to avoid intermediaries such as aggregators and to further integrate consumers and prosumers into the energy system (Hall & Roelich, 2016; Sandoval & Grijalva, 2015). The LEMs' local prices are meant to provide incentives for a local expansion of renewable energy generation (Bremdal et al., 2017; Hall & Roelich, 2016; Sandoval & Grijalva, 2015). Furthermore, these price signals, when well designed, may enable more efficient use of local resources, thereby increasing independence from the overall system and reducing emissions through the local balancing of supply and demand using renewable generation (Ilic et al., 2013; Koirala et al., 2016). The LEM concept has gained momentum beyond academia in industry and the policy space (Gui & MacGill, 2018; Mengelkamp, Gärttner, Rock, et al., 2018). There is a rising number of collaborations between industry and academia implementing LEM pilot projects practically paired with a rapidly growing body of academic contributions (Mengelkamp, Diesing, et al., 2019; Sousa et al., 2019; Weinhardt et al., 2019). On the industry spectrum, the interest ranges from representatives of local utilities to large corporations. This remarkable international attention in academia and practice shows that the LEM concept is no longer only a theoretical idea but has practical relevance. The first pilot projects have implemented different variations of LEM user interfaces. The Brooklyn Microgrid case study (Mengelkamp, Gärttner, Rock, et al., 2018), the 'Pebbles' project (Vasconcelos et al., 2019), the 'Quatierstrom' project (Wörner, Meeuw, et al., 2019) and others develop custom made platforms using mobile or online interfaces. Despite the transfer into real-world applications, none of these projects report on the design process or design features of the LEM platform and the user interface or propose design knowledge (e.g., DPs) to generalize findings for the Information Systems discipline.

However, other studies rooted in design research report on specific components of the LEM interface functionality in other contexts. For example, there are similarities between the LEM user interface and energy feedback systems. These systems provide information (consumption, energy mix and costs) through a user interface. Several studies show that feedback on energy consumption can positively impact sustainable behavior and that it may have a positive impact on private households (Gholami et al., 2020; Karlin et al., 2015). Other studies have focused on the design of such energy feedback systems. Ableitner et al. (2017) implement and test different designs of smart shower meters, which give real-time feedback. The authors investigate the impact of different display designs on energy (and water) conservation. The results underline the importance of a carefully designed interface: The authors came to the surprising conclusion that a display design with visual elements on the environmental impacts of the users' behavior resulted in higher energy consumption. Dalén and Krämer (2017) analyze and improve existing energy feedback solutions focusing on the device level using a DSR approach. The authors propose four DPs focusing on the design of smart meter interfaces to promote efficient energy usage in private households and they evaluate a first prototype. Gnewuch et al. (2018) develop DPs for conversational agents for utility service stations regarding user interactions. The DPs' goal is to promote sustainable energy use through the interaction with conversational agents. However, the proposed DPs focus mainly on data processing to enable energy feedback and less on the consumers' perceived utility and long-term engagement.

Stock trading interfaces are another domain of similar interfaces. Lee and Kim (2002) derive three DPs for stock trading websites. The authors proposed a 'Functional Convenience' DP, which distinguishes between an information-gathering process and an order-making process. The former process needs to include useful and up-to-date information, while the latter focuses on the submission of the order and its effectiveness. In addition, the second DP by Lee and Kim (2002) focuses partly on the user's delight (Delightfulness). They state that users will interact with the interface frequently if the interface experience is entertaining and interesting, which creates utility for the user. This description can be interpreted as a form of long-term engagement and further motivates our analysis. The authors' DPs cannot be directly transferred to the LEM context because they do not address the intention to encourage purposeful behavior changes and more importantly, their system addresses professional expert users.

Regarding behavioral changes towards more sustainability, the study by Seidel et al. (2013) develops DPs meant to support organizational sensemaking in sustainable transformations, which is further refined in (Seidel et al., 2017). Sensemaking of information is crucial for individuals to understand the environmental impact of their behavior and to derive corresponding actions and it plays a major role in this study. However, the corresponding DPs do not focus on long-term engagement and are rather aimed at organizational aspects and the communication between different users in this context.

There are several studies that investigate long-term engagement in other domains. Wallis et al. (2013) analyze the motives of amateur musicians to use their instruments over a longer period. The authors identified seven properties and transferred them into the field of human-computer interaction, where they can be used in interface design processes. However, the authors do not derive DPs and design knowledge. Kazhamiakin et al. (2016) present a gamification framework to foster long-term engagement of smart city citizens regarding sustainable behavior. According to the authors, the framework allows the design and execution of gamification solutions, which promote sustainable behavioral changes in regards to urban mobility. Although the authors show concrete instantiations of the presented solutions, they do not propose specific DPs for the interface design. Jain et al. (2012) investigate the connection between interface engagement and reductions in energy consumption. The authors use login data to assess the performance of different interface components. They conduct a six-week study with 43 participants and a prototype interface. The authors confirm that user engagement (logins) is linked to a decrease in energy consumption. While the authors examine different design components, they do not derive DPs from their study results. Furthermore, the duration of their experiment does not necessarily allow deductions on long-term engagement.

Summarizing, design knowledge already exists in other similar contexts such as the user interface for stock trading and energy feedback systems. DPs for energy feedback systems are derived such that their instantiations influence consumption behavior towards more environmental sustainability. Yet, the existing design knowledge does not focus on the participants' long-term engagement. In conclusion, there is a need for design knowledge regarding LEM interface design that motivates the long-term engagement of participants. Table 1 summarizes the research gap identified in this section. In addition, there is a lack of empirically tested LEM implementations over a long interaction period. We close this research gap by proposing new design knowledge with the help of a DSR project based in part on the above-mentioned existing design knowledge. Therefore, we follow the call of Seidel et al. (2017) and promote environmental sustainability through the practical application of Green IS research and thus contribute to the Green IS research agenda.

Research field	*LEM literature*	*Related design research*	*User Interface Engagement*
Research gap	Broad body of literature on LEMs; no generalizable design knowledge for LEM platform and interface	Various studies focused on design intended for more sustainable behavior; not focused on long-term engagement	Mostly no design knowledge; if any, then targeting expert users; analyzed interaction periods relatively short
Related work (excerpt)	(Mengelkamp, Gärttner, Rock, et al., 2018; Vasconcelos et al., 2019; Wörner, Ableitner, et al., 2019)	(Ableitner et al., 2017; Dalén & Krämer, 2017; Gnewuch et al., 2018)	(Jain et al., 2012; Lee & Kim, 2002; Wallis et al., 2013)

Table 1. Summary of research gap

3 Research method

This study is based on a DSR project that develops and instantiates DPs for LEM platforms including the user interface, to enable participants to use the LEM's functions and to motivate long-term participation. We follow the DSR approach by Kuechler and Vaishnavi (2008) to develop the targeted DPs. This approach is suitable due to its iterative structure of the DSR methodology and the corresponding continuous evaluation and improvement of the artifact that features the involvement of real users and experts. DSR in general is particularly suitable for our objective as it allows to identify unknown challenges of the LEM platform and interface design throughout the development process and to address them in later cycles. The initial objective of our DSR project is to develop and provide a solution for an LEM implementation at a neighborhood served by the project's utility partner. Based on this project, we perform an evaluation and deduct generalizable design knowledge throughout the process. With this approach that starts with an implementation objective, we follow strategy 2 as defined by Iivari (2015). In this section, we further describe the DSR project starting with the three cycles and followed by an overview of the field study and the experimental evaluation of Cycle 3.

Our DSR project consists of three cycles as shown in Figure 1. It begins with the initial development and testing of a prototype (Cycle 1). Further, we elaborate on the refinement of the prototype to a complete usable mobile and web application and the implementation as well as the evaluation in the field study phase (Cycle 2). Based on the evaluation results of Cycle 2, which indicated dissatisfaction regarding the market mechanism's complexity, we decided to conduct a third cycle. In this third cycle, we conduct and evaluate an online experiment, in which participants test and evaluate different perceivable LEM market mechanisms (Cycle 3). Since the most significant uncertainty for the design of the LEM platform lies in the participants' perception, we choose to follow the human risk & effectiveness strategy for the evaluation process (Venable et al., 2016). In this strategy, the evaluation of artifacts is quickly moved from formative, artificial evaluation to more formative, naturalistic evaluations in real settings and real organizational situations. We briefly outline the DSR project and provide further background information in the following.

Cycle 1: In this cycle, a prototype interface for the LEM project is developed in collaboration with the project stakeholders. The goal is to design a functional interface, which provides the necessary functional capabilities of the LEM application that allow the users to obtain detailed information from the LEM and to actively participate on the LEM by placing bids. In the first cycle's problem awareness phase, we derive stakeholder requirements utilizing insights from our literature review and from interviews with

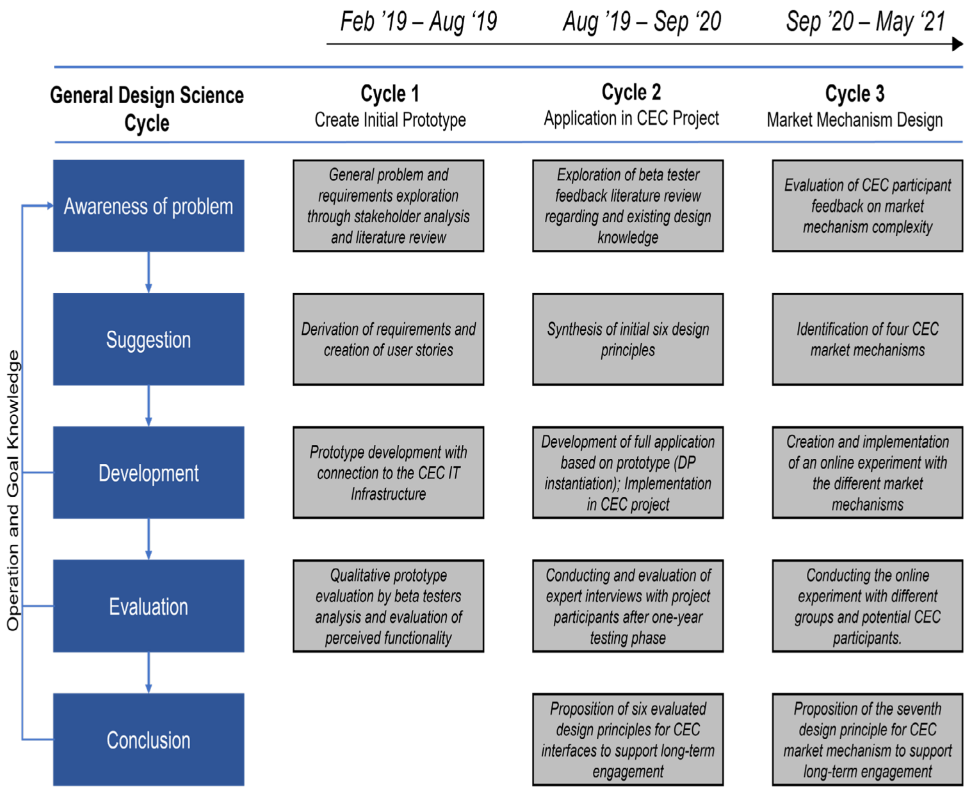


Figure 1: DSR project outline based on Kuechler and Vaishnavi (2008)

project stakeholders. Next, we develop several user stories based on the literature and stakeholder input in the suggestion phase. We leverage the user stories from this step to design a first prototype (interface mock-up). Subsequently, we present this prototype to three selected beta testers and two project managers. All testers evaluate the prototype's design before the field phase in Cycle 2. The three beta testers were also participants of the project during the field phase of Cycle 2.

Cycle 2: The second cycle's objectives are the design evaluation of the LEM platform and its user interface over a more extended period and to derive generalizable design knowledge regarding long-term engagement of the users on LEM platforms. In the problem awareness step, the feedback from the beta testers is evaluated and considered in terms of perceived usability and corresponding suggestions for improvements. In addition, a literature review is conducted regarding existing design knowledge for comparable use cases (trading, smart meter data visualization) as well as long-term engagement. Based on this, we propose six initial DPs in the suggestion phase of Cycle 2. The prototype is then improved and an application with full functionality is created. We recruit participants for the LEM project by conducting a recruitment event in the selected neighborhood. Next, we install smart meters in each participant's home and connect them to the information system. All participants receive an individual tablet computer with the pre-installed mobile application. The duration of the Cycle 2 phase is 13 months and participants use the provided application during the entire period. Following this period, we collect feedback from all ten participants employing semi-structured interviews and evaluate the six suggested DPs which support long-term engagement and meet the stakeholders' requirements. The negative effect of the market mechanism's complexity is noticeable feedback from the participants regarding long-term engagement.

Cycle 3: In the third and last cycle, we aim to investigate the perception, understanding and effect of different market mechanisms and identify an additional necessary DP. This cycle is based on the second cycle's findings and is essential to ensure that the developed DPs from the previous cycles can fulfill their potential benefits and increase the users' engagement with the LEM platform. Due to the difficulty of evaluating different market mechanisms within a field test given the uncontrollable external factors that influence engagement, an online experiment is conducted in this cycle. Each participant of the experiment tests four different market mechanisms. These correspond to different approaches, such as an auction or time-of-use rate mechanism. Within the experiment, the participants go through various scenarios with the respective market mechanisms. The goal is to determine which form of market mechanism the participants prefer in terms of interaction and complexity.

3.1 Field study setup

As mentioned earlier, we select the human risk & effectiveness strategy (Venable et al., 2016). We choose this strategy for the evaluation because the DSR project is user-oriented and the artifact should be evaluated by testing it with real users in a real-world setting to ensure the necessary external validity for claims regarding the project's objective of long-term engagement. The evaluation is conducted through semi-structured interviews. The online experiment only concerns a component of the overall system and can therefore still be placed within this strategy.

We conduct three separate evaluations according to the DSR process proposed by Kuechler and Vaishnavi (2008). We provide necessary background information for the evaluation steps of the three performed cycles in the following. The first cycle evaluates the design of an initial prototype based on the first identified requirements R1-3 with three beta testers and two employees of the project's utility partner. The second cycle evaluates the derived and instantiated DPs after a testing phase over 13 months. The testing phase group consists of ten project participants including seven consumers and three prosumers (households with their own solar generation capacity). Additionally, the utility partner provides solar panels (23kWp) and a combined heat and power (CHP) plant (50kW) that are integrated in the LEM and its platform. The implemented market mechanism clears every 15 minutes and distinguishes between local solar and CHP generation. A detailed description of the mechanism is given in (Richter et al., 2019). Participants submit bid prices for the power generation sources that remain constant until actively changed, which is not mandatory or necessary to do at any point. This makes a constant monitoring of or interaction with the system by the participants unnecessary. All interviewed participants are from the neighborhood, where the project is implemented and have lived there for several years. Half of the participants reside in single-family houses, the others in multi-family houses. The average number of household residents is two and the average age is 49. At the beginning of the project's field phase, the participants receive their own tablet computers on which the application is installed and set up. In addition, the participants are able to install the application on their own mobile devices or access it via a web interface. The login data is provided by the project team and communicated individually to the participants.

3.2 Market mechanism experiment

Based on the feedback in Cycle 2, a third cycle was necessary, to explicitly address the complexity of the market mechanism for LEMs. For this purpose, an online experiment was conducted, in which participants tested four different market mechanisms. The participants were asked to buy energy as cheaply as possible in each scenario. For bought renewable energy, a donation was made to a charity engaged in environmental sustainability to simulate the additional effects of buying sustainably generated energy. We opted to evaluate this cycle in a laboratory experiment because it allowed for more participants, a controlled environment (internal validity) and broader immediate feedback. The experiment was conducted online with 115 participants. Of these, 41 were female (36%) and 74 were male (64%).

Within the experiment, the goal for the participants was to develop a feel for how the market mechanisms work and to evaluate, which of these mechanisms appeals to them the most. Based on the experiment, we gain better insights into why participants prefer specific market mechanisms over others. This preference is essential information for LEM operators when developing and implementing LEMs. In the experiment, four market mechanisms were tested: a time-of-use mechanism (TOU), a real-time pricing mechanism (RTP), a periodic tariff based on individual bids (PET) and an auction mechanism (AUC) as implemented in Cycle 2. Therefore, the tested market mechanisms can be classified along the amount of interaction (TOU and RTP require no interaction, AUC and PET require user bids) and the frequency of price changes (with TOU and PET prices change infrequently, while with RTP and AUC prices may change in every period). The experimental setup consisted of five rounds. In the first four rounds, users tested each of the different market mechanisms in a randomized order to avoid an impact of the sequence. In the fifth round, the users were able to choose their preferred mechanism out of the four tested.

Each round is structured similarly and consists of three days with a corresponding morning, afternoon and evening period. Within each day, there is a fixed amount of renewable and conventional energy available to the LEM unknown to the participants in advance. The participants compete with two other virtual participants (that simulate the neighbors), which follow fixed bidding strategies. The participants' task in each round is to consume a given amount of energy over the three days. To procure this energy, they have a fixed amount of money at their disposal. The payout for the experiment participation is determined by how much money the participants have saved at the end of each round. It provides an incentive for the participants to purchase the necessary supplies as cheaply as possible. The required power quantity that the participants must buy is divided into a fixed and a variable share. The participants must cover the fixed share at the respective time of the day, while the variable portion can be shifted within the day. Shifting demand leads to a small cost for the participants, representing the inconvenience of shifting demand. The experiment is thus incentive aligned.

The possible amount of RES generation in the respective day segments varies as in real life. The available amount is highest in the afternoon, which is the daytime with the highest solar radiation. Likewise, the participants receive information about the maximum and minimum deviation over the day. Based on this information and a general description of the market mechanism at the beginning of each round, the participants can choose their actions, consisting of shifting demand and choosing market bids in the PET and AUC mechanisms. Participants are asked various questions regarding their perception of the mechanisms after each round. The experiment is implemented using the open-source framework oTree (Chen et al., 2016).

4 Artifact description

In the following, we describe the design process for the artifact, the derived requirements and DPs and their instantiations. We begin by describing the problem space and the resulting requirements, user stories and the prototype of Cycle 1. Based on this, we describe the derived DPs, their instantiation in the field in Cycle 2 and the structure of the market mechanisms and the corresponding online experiment evaluated in Cycle 3 in the solution knowledge section.

4.1 Problem space

For a structured description of the problem space and the identification of essential requirements, we adopt the conceptual model of Maedche et al. (2019). First, we investigate the underlying needs and problems of the project's stakeholders (LEM operator and participants) by exploring the existing literature and by conducting interviews. On the one side, the need of LEM operators is that participants engage with the platform in the long-term and use it continually because without interaction, the platform does not generate any environmental benefit or financial profits. This is inevitably related to the design of the LEM platform and its interface, as it connects the users to the platform. On the other side, participants have no explicit formal needs because they participate on the platform voluntarily. However, they will decide to interact with the user interface and thereby with the LEM platform if first, the provided functionality of the platform is valuable for them and second, if the interface design allows participants to understand and thus access the functionality. These needs lead to the design goal for an LEM platform and its interface: The LEM platform should be designed such that participants derive a personal benefit from using the platform and consequently, interact with the platform continually, forming a long-term engagement.

To achieve the goal, we formulate the following five requirements. While requirements R1 and R2 are partly based on the literature (as described in the following), R3-5 are based on feedback from the project's utility partner and project participants. First, it is necessary to grant the users access to relevant data from the information system via the platform interface (Mengelkamp, Gärttner, Rock, et al., 2018; Wörner, Ableitner, et al., 2019). This functionality is equivalent to the feedback systems described in the literature review (Dalén & Krämer, 2017; Loock et al., 2013; Tiefenbeck et al., 2019). Besides the individual load data, the system should provide information on the available electricity generation from different sources, the market results and the individual costs. Several existing projects support the requirement of reporting on the energy origin implicitly by distinguishing between transactions with local resources and those sourced externally (Ableitner et al., 2020; Mengelkamp, Gärttner, Rock, et al., 2018; Vasconcelos et al., 2019). Notably, the utility project partner emphasized the importance of such feedback for local generation sources in the stakeholder interview. Based on this information, users can evaluate their behavior and derive actions or desirable behavioral changes. This constitutes the first requirement (R1): Users need to be able to access the relevant market and load data in order to be able to evaluate their behavior promptly and to react correspondingly. Second, the possibility to express individual preferences through bidding is another central feature of the LEM concept (Mengelkamp, Gärttner, Rock, et al., 2018; Teotia & Bhakar, 2016; Wörner, Ableitner, et al., 2019). In addition to monitoring their personal behavior, users must be able to respond to changing market situations, such as changing weather conditions or market prices by communicating a representation of their preferences (Mengelkamp et al., 2017; Mengelkamp, Gärttner, Rock, et al., 2018; Wörner, Meeuw, et al., 2019). This functionality is equally important for local generators. Therefore, the second requirement (R2) is that users must be able to formulate and communicate individual preferences to purchase or sell electricity on the local market. Third, the utility partner pointed out that data security and privacy need to be considered very explicitly as load values constitute sensitive information. Furthermore, existing data protection policies specify that individual load information needs to be protected. In addition, data leakage (for instance, the possibility to see other users' bid values) creates an unintended market advantage and decreases trust in the platform. Therefore, the system must prevent users from accessing other participants' load data or bids. Consequently, the third requirement (R3) is that users must not be able to access other users' data or place unauthorized bids in their names.

In the evaluation phase of Cycle 1's prototype design, a beta tester recommended to introduce regular notifications and updates. Participants should receive some form of a regular reminder with summarizing information, which allows them to get a quick overview of the current situation and their performance on the LEM platform (specifically if time is a constraining factor). We transform this suggestion into the fourth requirement (R4) that users should regularly receive information from the system that allows them to evaluate their behavior over the latest period with low effort. In the second cycle, we evaluate the beta tester's prototype feedback based on the field experiment with the fully developed application. Important feedback from the evaluation of Cycle 2 is that the complexity of the implemented market mechanism meant that participants did not always understand the consequences of their actions and that this led to inactivity. In the interviews, we could exclude the possibility of design errors in the information representation and understanding (see Section 5). We conclude that the market mechanism's complexity has a strong effect on the participants' long-term engagement. Therefore, we derive the fifth requirement (R5) that users should be able to understand the market mechanism and the consequences of their bidding actions with a reasonable effort. Table 2 summarizes all five requirements.

Requirement	*Description*
R1	Users need to be able to access the relevant market and load data in order to be able to evaluate their behavior promptly and to react correspondingly.
R2	Users must be able to formulate and communicate individual preferences to purchase or sell electricity on the local market.
R3	Users must not be able to access other users' data or place unauthorized bids in their names.
R4	Users should regularly receive information from the system that allows them to evaluate their behavior over the latest period with low effort.
R5	Users should be able to understand the market mechanism and the consequences of their bidding actions with a reasonable effort.

Table 2. Overview of requirements

4.2 Solution space

Prototype development and design

Since there is little previous design research on LEM platforms and interfaces, an initial prototype is developed and evaluated in the first cycle. The prototype design contains all the necessary functions derived from the literature and stakeholder input but had limited functionality since the underlying IT infrastructure is not yet implemented. We presented the prototype to beta testers for evaluation. Three of them were households that later participated in the project and already had smart electricity meters installed.

The two project partner employees had access to load data from an electricity meter installed in the project partner's office building. Each of them received a tablet computer with the pre-installed application prototype. The participants had one hour to familiarize themselves with the application. Before the interviews, all agreed to participate in the evaluation and provided their demographic data. The survey was conducted on-site with two researchers, one conducting the interviews and the second taking notes.

Design principles and artefact instantiations

The user feedback on the prototype design and the derived literature insights from related design domains are the basis for the first six initial DPs. Each DP is connected to a subset of the derived requirements (problem space). The first three DPs address R1. We divided R1 into three DPs because the intended effect of the feedback that is provided by the system to the users differs depending on the provided data. For example, information on the consumption behavior might have limited meaning regarding an adjustment of the bidding behavior. DP4, DP5, DP6 and DP7 address R2, R3, R4 and R5, respectively. We formulate the DPs loosely based on the framework of Gregor et al. (2020). As the implementer is always the LEM operator and the objective is always to ensure long-term engagement, we do not mention this explicitly in every DP. An overview of the relationships between requirements and DPs is provided in Appendix A.

In the field phase of Cycle 2, each DP is instantiated within the field project. The prototype mock-up from Cycle 1 is transformed to a full-scale usable application. This application is developed with the cross-platform development framework 'Ionic' for mobile applications. The framework combines different front-end programming languages (HTML, CSS, JavaScript), allowing simultaneous development for the two largest mobile platforms, the Android and the iOS operating systems. Additionally, the users can access the platform via a web browser. Each of these access forms has the same structure. We improve and adapt the initial prototype in the second cycle using the information gained in the evaluation step. Figure 2 shows the improved instantiations of DPs 1-4 after the feedback in Cycle 1. In the following, we present all seven DPs and their instantiations for the field phase of the project in Cycle 2.

Design principle 1

As discussed in relation to R1, the user feedback system is a central building block of the overall functionality. The academic community extensively discusses and investigates the effects of 'Energy Feedback Systems' (Karlin et al., 2015). Instead of consumption

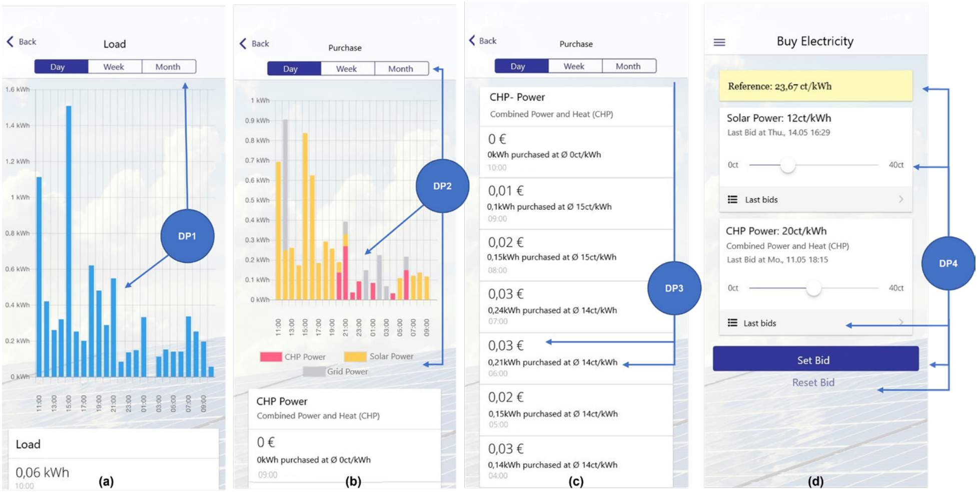


Figure 2: Visualization of DP 1-4 instantiations

feedback for single devices, we focus on aggregated information as it addresses the overall behavior. Feedback should focus on individual behavior and enable the users to identify their general, recurring behavioral patterns and the corresponding implications for cost and environmental sustainability. However, consumption values alone are difficult to understand as most users are non-experts and do not have energy-specific expertise (Brounen et al., 2013; Dalén & Krämer, 2017). Therefore, it is crucial to put consumption data it into a sensemaking context (Seidel et al., 2013). The users need a relative reference to judge their power consumption and to compare different periods. It is a known fact that consumption information should be visualized to the users (Froehlich, 2009). It allows them to investigate and assess their consumption behavior more quickly. Regarding individual consumption data, this leads to the following DP1.

DP1: *In order to allow users to draw conclusions on how their individual consumption is affected by their behavior and to interpret the outcome, the LEM user interface should provide visualizations of consumption data as well as a form of reference to enable users to put the visualized data into context.*

Instantiation and testable proposition. Figure 2a displays the visualization of consumption values through a graph. The users can switch between the displayed periods of a day, week or month. Below the graphic representation, a table shows the load value for every period. Users can compare their load values to historical values, which allows them to compare consumption values and deduce implications based on their consumption behavior. This can then be used to derive strategies to reduce consumption and costs. We expect that after the field phase, users report to have used the visualization to track their consumption and to link their consumption values to their behavior.

Design principle 2

Access to individual consumption data alone is not sufficient to judge individual environmental sustainability. Participants cannot retrieve how environmentally friendly their actions are by evaluating the consumption data alone. However, as discussed, environmental awareness and the need to reduce the environmental footprint are increasingly important for individual households. The possibility of local renewable energy consumption is a key feature of all implemented LEM pilot projects. Besides, studies indicate a higher willingness to pay for local and renewable electricity in certain population segments (Mengelkamp, Schönland, et al., 2019; Tabi et al., 2014). This sustainability trend cannot only be observed in the field of electricity. There is also a need for more sustainability in other areas of society like food or transportation. In this sense, the local utility partner pointed out that the representation of local energy generation resources is critical to embrace sustainable local consumption. The target is to incentivize participants to consume locally generated renewable energy. Comparable to the first DP, the consumption mix information requires an understandable visualization, which allows a distinction between different sources and needs to provide a reference. Therefore, the application must process the origin of the energy generation, making it easier for the participants to identify their consumption mix and to compare it with their individual preferences. The second DP addresses this as follows.

DP2: *In order to allow users to assess the sustainability of their consumption, the LEM user interface should provide visualizations of the composition of individual consumption from different generation sources as well as a reference to put the shown data into context.*

Instantiation and testable proposition. Figure 2b shows the instantiation of DP2. Here, comparable to the Figure 2a, load values are shown divided along three different colors, each of which represents a different generation type. We make a distinction between local electricity generation from solar generation (Solar Power), from a CHP plant (CHP Power) and from the power distribution grid (Grid Power). Again, we display historical values to allow consumers to compare against the composition in previous periods. Consumers also had access to the total generation of individual resources in order to better understand the market results and the influence they might have through their bid prices. We expect that after the field phase, users would report to have consulted this visualization and to have changed their bids if they felt that their share of locally generated renewable energy did not correspond to their preferences.

Design principle 3

Apart from different energy generation sources and the sustainability of the individual consumption mix, energy costs are essential for households (Mengelkamp, Schönland, et al., 2019). Today, due to the lack of smart metering infrastructure, households often only have estimations of their own consumption and related costs. The supplier then invoices the respective deviation at the end of the year. In the worst case, this can lead to high additional, unanticipated payments. Furthermore, it inhibits households to react to high consumption and corresponding high costs quickly through behavioral adjustments. Households thus only receive limited and above all, no direct cost feedback on their consumption behavior (Vine et al., 2013). In regard to LEMs, researchers assume cost-minimizing consumers and profit-maximizing local generators in almost all contributions (Mengelkamp, Gärttner, Rock, et al., 2018; Ströhle & Flath, 2016; Wörner, Ableitner, et al., 2019). Additionally, the stakeholder interviews underline that displaying costs is necessary to avoid surprisingly high bills for the participants and to establish an economic and perceivable connection between behavior and costs that allows for sensemaking (Seidel et al., 2013). Furthermore, it strengthens trust in the platform. The feedback is necessary for participants to assess their actions from a sustainability and a financial point of view. Therefore, we formulate the third DP as follows.

DP3: *In order to allow users to adjust their consumption behavior to reduce costs and to better understand the financial implications of their behavior, the LEM user interface should provide consumption costs transparently and instantly and allow users to compare it to a reference to enable them to put the data into context.*

Instantiation and testable proposition. Figure 2c displays the instantiation of DP3. The instantiation presents the transaction data table and distinguishes the costs along each energy source. The presented figure shows the costs for energy from the CHP plant. Each entry represents an hour of a day and shows the total costs, the consumed amount and the average price (in cent per kWh) of that hour for that source. This representation can also be aggregated for different periods, as described above. We expect that this instantiation is frequently consulted by consumers during the field phase to ensure cost control and that users would report that they changed their behavior based on the displayed data.

Design principle 4

The submission and adjustment of bids as a representation of individual preferences is a unique characteristic of markets and a particular argument for LEMs. In reference to the two preceding DPs, the participants cannot only influence their consumption mix and energy costs by behavioral adjustments but also by changing their bid price for specific energy generation sources. In the case of surprising feedback, e.g., a low share of local consumption, the participants can increase their bids and signal a higher willingness to pay for local sources. In the LEM literature, nearly every concept relies on some form of consumer involvement and includes a bid submission process (Bremdal et al., 2017; Mengelkamp, Gärttner, & Weinhardt, 2018; Wörner, Ableitner, et al., 2019). This functionality allows the active integration of consumers and prosumers and promotes allocation efficiency for the local resources. However, a remark from the stakeholder interviews is that consumers are non-experts and have only limited experience with auction mechanisms, which can lead to hesitation and it introduces additional complexity. A risk exists concerning false user inputs and a lack of understanding of how to submit a bid successfully. Since different market mechanisms accept different bid inputs, the user interface's input mask must prevent wrong or illogical inputs. Therefore, a simple interface is required, supporting the participants by only allowing bids in a reasonable price range and by not requiring constant bid updates. The evaluation of Cycle 1 resulted in the integration of a reference value to create an orientation point for the consumers and prosumers. DP4 addresses this as follows.

DP4: *In order to facilitate the bidding process for users, the LEM user interface should feature an assistance system that ensures valid bid entry and it should provide reference values to provide orientation for users when choosing their bids.*

Instantiation and testable proposition. Figure 2d shows the bidding interface as the instantiation of DP4. A controller interface prevents erroneous inputs and users can bid for electricity from local solar generation and the CHP in a range from 0 to 40 Euro cents using a slider element. A reference value shows the grid tariff. Participants can submit a bid by clicking the 'Set Bid' button or reset their bid if it has not yet been submitted. Additionally, they can see their past bids to evaluate past actions, which provides further reference. We expect users to report that they had adjusted their bids if the market results communicated based on the instantiations of DPs 2 and 3 were not corresponding to their preferences and that the bid prices would vary around the reference value.

Design principle 5

The LEM literature does not explicitly discuss security functionalities concerning sensitive data. Consumption data of individual households is among the most sensitive personal data as it provides direct insight into household behavior. For example, energy data allows drawing conclusions about the current occupancy (Beckel et al., 2014). For this reason, the utility project partner specified in the interviews that the operator must protect all participants' privacy and it has to be impossible for uninvolved third parties or other participants to gain access to individual consumption data. If this cannot be guaranteed, participants may decide not to participate and additionally, this approach may violate the applicable law. Furthermore, the operator must prevent other participants from placing bids on behalf of other participants. Otherwise, the trust in the system and its functionality is at risk. A DP that describes a comparable functionality can be found in vom Brocke et al. (2017). We define the fifth DP as follows.

DP5: *In order protect sensitive data of users, to establish trust and to ensure compliance with legal data protection requirements, authentication mechanisms need to be established on the LEM platform*.

Instantiation and testable proposition. To ensure privacy and to protect sensitive data, DP5 is instantiated by providing each participant with a user account, comprised of an e-mail address as user name and a self-set password. The user interface contains a login display and after starting the application the user must enter the account credentials to access individual data. Given that the DP is based on R3 that was mainly introduced based on feedback from the utility partner, we expect users to pay little attention to this DP but that they would welcome it once we would direct their attention to it in the interviews.

Design principle 6

As stated above, the typical target group of LEMs is not engaging professionally in (energy) markets and has no comprehensive domain knowledge. This begs the question to what extent and at what frequency the participants can be expected to actively engage with the LEM system. Attention and time are often limiting factors and participants can often only irregularly deal with their performance on the LEM. In the evaluation phase of Cycle 1, beta testers suggested a recurring reminder that features summarizing data over a set time period (see DPs 1-3), which helps the participants to monitor information from the system with low effort. A simple overview of all relevant information allows participants to evaluate whether an active action on the market is necessary. Regular intervals allow to compare the aggregated values. For example, participants who are currently otherwise involved could be informed via a weekly e-mail with the latest information on their behavior and directly identify a week with increased consumption. For this reason, DP6 is defined as follows.

DP6: *In order to activate users regularly and to enable low-effort monitoring, the LEM user interface should send regular reports summarizing past activity and events on the LEM in a structured form because it facilitates interaction with the system without requiring users to dedicate substantial time and attention to the system.*

Instantiation and testable proposition. DP6 is instantiated through a weekly report sent via e-mail. This report includes the amount of energy consumed, the power source composition of the participant, the overall costs and the individual average electricity price for the last seven days. Additionally, the average price of all participants is communicated for reference and to provide context (i.e., to enable a better sensemaking (Seidel et al., 2013)). Given that this DP is based on R4, which is introduced by a beta tester in the first cycle, we expect that users would welcome this feature and report to have regularly reacted to these reports.

Design principle 7

The interview feedback after Cycle 2 made it clear that the complexity of the market mechanism is an important challenge in LEM design and might hamper participant engagement. The high complexity of the market mechanism in Cycle 2 had a reported impact on the participants' behavior. According to the participants' statements, they could not clearly link their actions (DP4) to the market results (DP 1-3). Therefore, we find that a complex market mechanism inhibits the effectiveness of the other DPs as it inhibits sensemaking of participants. Similarly, the high complexity requires participants to study the market mechanism somewhat intensively in order to understand it clearly. This necessity is an additional hurdle for active participation due to limited time and attention. However, understanding the market mechanism is essential for active participation and a good performance on the LEM and vice versa the understanding is paramount for efficient market outcomes. According to the interview statements, none or little understanding leads to a decrease in activity and participants consequently interact less often with the LEM. The market mechanism's complexity seems to strongly influence the perception and perceived utility of the users. Therefore, we define a seventh DP in order to deal with this issue. However, this DP was not instantiated in Cycle 2 as it was only created after the corresponding evaluation. The corresponding testable proposition is that we expect a higher satisfaction of users with a market mechanism that is perceived to be less complex. The proposition is tested using the online experiment outlined in Section 3.2.

DP7: *In order to ensure that participants feel comfortable in interacting with the LEM platform's market mechanism, the mechanism should be easy to understand because this facilitates interactions with the LEM and prevents frustration and inactivity of users.*

5 Evaluation

5.1 Evaluation methodology

Every DP is based on a functional requirement of the stakeholders. If this requirement is met, a participant should be able to derive a benefit from it. This benefit is the basis for participants using the application and thus for a long-term engagement. In the following, each DP and its instantiation is first examined regarding the participants' ability to use the provided functionality and therefore, whether the instantiation fulfills the underlying requirement. We then particularly evaluate whether the implementation motivated participants to engage with the platform over the long-term.

We evaluate the instantiations with the ten project participants following Kaiser's approach (Kaiser, 2014), referring to them as experts (EXP). All ten participants were able to use the application over the entire field phase. Given the participants' extended exposure to the LEM platform, all interviewed participants are suitable for expert interviews. The long interaction period under real-world conditions is ideal for evaluating the instantiations as well as the external validity of the DPs. Even if an interviewed participant only used the LEM platform infrequently, the feedback explaining this behavior can provide insights on how future systems can be improved. Besides their general impression of the system, participants were asked explicitly about the instantiations of the DPs. The expert interviews followed a semi-structured approach that allows interviewers to ask questions on different topics and based on the answers, allows switching between topics in the guideline. All ten interviews were conducted via telephone due to the COVID-19 pandemic restrictions, were recorded and subsequently transcribed and evaluated. Before each interview, the interviewer explained the interview's objective and gave some context information regarding the guideline. The interviewees were informed about their data protection rights and asked for consent to record the interview. A high-level overview of the interview guideline is provided in Appendix B.

DP1

The first DP is based on R1, which expresses that users need to be provided access to relevant market and load data in order to be able to evaluate their behavior promptly and to be enabled to react correspondingly. DP1 focuses on the provision of individual load data and should support participants in the understanding of their own consumption behavior. All participants stated that they accessed their individual load data and investigated their consumption behavior. Therefore, the instantiation of DP1 and thus, the fulfillment of R1 was successful. Regarding the perceived utility, participants stated that the visualization of the consumption values is valuable for them. In addition, the possibility to study the consumption behavior in a substantially higher resolution than what was provided (e.g., in minutes or seconds rather than in the 15-minutes resolution) would have had a high value for most participants. EXP5 noted that at the beginning of the project, he was surprised about high consumption in the morning and found out that boiling water causes this peak

> [...] it was also interesting and revealed some interesting findings. I was surprised by how much the kettle consumes. So, we have already gained insights from that, which we have then tried to incorporate into our everyday life..

Similarly, EXP10 expressed a great surprise that seemingly small devices cause such high consumption. She also stated that she exchanged information with her neighbor on findings regarding the consumption of household appliances

> We just looked at it [consumption visualization (DP1)] and his wife said that the dishwasher as on.

EXP5 even tried to determine the exact power consumption of individual devices with the help of the visualization. EXP2 used the application to identify the high base load of a dehumidifier in the basement. He remarked that the high consumption surprised him and that the device is now only turned on when necessary.

> The thing needs an insane amount of electricity, although it is not that big. For me, one realization is that when the humidity is at 40-50 percent, that's when you turn it off. That was really helpful.

EXP9 stated that he used the visualization to evaluate the effect of shifting the washing machine's consumption or dishwasher to the daytime hours. EXP1 and EXP6 highlighted the report (DP6) with the aggregated consumption values as the primary source of information on consumption behavior and only used the mobile app's visualization in case of substantial deviation from their expectation. EXP2, EXP7, EXP9 and EXP10 mentioned that over the project duration, they used both forms, the visualization and the report, to different degrees depending on the available time and motivation. EXP8 and EXP3 stated that individual consumption values are interesting, but they did not change their behavior. The both stated that the perceived value of the time invested for a more active engagement with the topic exceeds the perceived potential savings. EXP6 would have liked to be able to set the aggregation periods of the data visualization herself beyond the offered resolutions. EXP2 emphasized that there is nothing to improve in terms of structure and presentation and that it helped him a lot in understanding his consumption behavior. It is clear that participants have a high interest in the given instantiation of DP1 and in some cases, use it to adjust their behavior. According to their statements, after the high initial interest, the participants have increasingly resorted to the regularly aggregated consumption values provided in the weekly reports in order to continually observe their consumption behavior. DP1 and its instantiation is connected to a high perceived utility by the participants and supports long-term engagement with the system in terms of a continuing checks of the individual consumption behavior and occasional behavioral adjustments. The instantiation of DP1 also helped to improve the energy literacy of some participants and led to surprising realizations, which also seemed to improve their engagement with the system.

DP2

Like DP1, DP2 is also based on R1. It focuses on the consumption mix and energy generation source, which should help participants to understand the impact of their consumption in terms of environmental sustainability and allow them to adjust it correspondingly. Again, all participants state that they understood the instantiation of DP2, which suggests a proper design. However, the perceived utility from DP2 is different than for DP1. Although the participants generally welcomed the visualization of the electricity mix and market transactions, they used the provided instantiation much less than that related to DP1. In contrast to DP1, the participants reported that they mostly consulted the weekly reports to assess their generation mix. EXP5 and EXP7 stated that they had dealt with the visualization in detail and had tried to influence their local electricity share by changing the bids. Since the composition of the mix also depends on other external factors such as the weather and since the system did not provide explanatory features, the users experienced a lack of clear, immediate feedback from the system. This indicates that more explanatory features might be necessary. EXP6 confirmed that as the project progressed, behavioral changes were rather instigated by the reports.

> There were peaks and I thought about what it could be and then actually changed certain behavior.

EXP10 explained that the share of local energy in electricity consumption has a high personal value for her. EXP9 examined whether a behavioral change affected the proportion of locally purchased energy.

> We do pay attention to move the consumption into the sunshine hours.

Overall, we conclude based on the interview statements that for DP2 an aggregated form of information over some period of time is preferred and that the time series data is not studied more closely. Likewise, participants do not consider the tabular presentation of individual transactions as valuable. Furthermore, immediate feedback is necessary. However, it was confirmed that DP2 is valid as the corresponding information was accessed through different means (i.e., the reports). Therefore, DP2 helps to foster long-term engagement. Instantiations of DP2 could be more effective if participants received additional recommendations on how to behave more sustainably and if market outcomes were enriched with causal information features, e.g.,

> Your renewable share was 30% because your bid was 2 Cents too low to access more renewable energy.

DP3

DP3 also corresponds to R1. The presentation of cost information should enable participants to assess the financial implications of their behavior. Participants stated that they had used the provided cost information and that this information is generally important to them. The former confirms the importance of DP3. However, regarding the perceived utility of the DP3 instantiation, the participants stated that the tabular presentation of costs in the application was not useful and that they informed themselves regarding costs using the data in the weekly reports, which is comparable to the results of DP2. EXP2, EXP3 and EXP6 declared that electricity costs play an essential role for them and that a higher resolution than the annual billing has a high added value. However, all state that they are not interested in a cost resolution on a 15-minute basis. They all prefer aggregated values that are easier to compare. EXP6 emphasized that learning her average price and all other participants' average price from the reports helped to derive a better bid adjustment. EXP5 and EXP8 indicated that the costs' high resolution does not significantly impact their view and hence, does not result in a bid adjustment. In detail, EXP8 stated that he had been paying electricity costs for years and only wants to deal with them when there are higher deviations.

> I mean, I have relatively fixed energy costs, which I have paid in the same way for years and I don't give myself any more trouble here at the end. If the data had possibly been a bit more drastic, you could say, well, now we have to think about whether we do something. But it just wasn't like that.

Similarly, EXP5 noted that expected financial savings are small and that he does not have the time to look into it in detail. Overall, access to individual cost data is important for participants and supports their long-term engagement. However, the instantiation should focus on aggregated data visualization. An additional incentive for participants to engage with the platform more closely would be high individual saving possibilities. Given that energy prices are currently on the rise worldwide, this might further accelerate the expansion of LEMs.

DP4

The fourth DP is related to R2, which states that users must be enabled to formulate active preferences in terms of bids to purchase or sell electricity on the LEM and to communicate these preferences to the LEM platform. All participants consistently evaluated the bidding interface positively. EXP2 and EXP3 stated that the slider bidding interface is easy to understand and intuitive. The indication of the reference price in the bidding menu, an improvement from the first cycle's feedback, is positively highlighted by EXP10.

> Yes, that (reference value) helps me. [...] And I have stayed under it, also because neighbors have said that they have stayed under there, too.

Therefore, the underlying functionality of the DP4 instantiation is understood and used by the participants. However, regarding the perceived utility and connected long-term engagement, EXP2, EXP5, EXP7 asked for more transparency and information about the consequences of bid changes. According to their statements, there is a high degree of felt uncertainty regarding the consequences of a bid change. All participants stated that the complexity of the market mechanism was too high, which led to uncertainty about the optimal bidding behavior (for more details, see (Richter et al., 2019)). None of the participants understood the functioning of the mechanism in detail. They stated that the mechanism is too complex and that a proper understanding would have required too much time. This is a considerable statement as the market mechanism was repeatedly explained at project gatherings. It shows that complexity should be carefully managed for LEM platforms. EXP2 suggested that while adjusting the bids, information should be provided regarding the changed bid's expected effects. The application should notify the user when specific key values (e.g., share of green energy) are exceeded. EXP2 also noted that navigating to the bidding menu was too complicated. It should be noted that the instantiation of DP4 generally achieves the intention of the DP and seemingly supports a long-term engagement with the system as participants did continually experiment on the market. However, the platform's structure, the complexity of the market mechanism and the transparency of the actions' consequences play an important role in whether the participants feel confident using the feature. Based on the participants' feedback, we conclude that more information should be provided regarding the consequences of user input, the complexity of the mechanism should be reduced and well balanced with user interaction and decision support systems should be employed to support users in the bidding process. We address this further in Cycle 3, when we evaluate the perceived complexity of different market mechanisms.

DP5

DP5 is based on R3, which requires that users must not be able to access other users' data or place unauthorized bids in their names. This DP is intended to foster long-term engagement by establishing trust through the protection of sensitive data. If participants do not feel their individual data is safe, they will likely not use the system. In its implementation, DP5 requires users to frequently log in manually into the system on their devices. None of the participants stated that they felt their data was insufficiently protected. Instead, the manual login that did not provide an option to store username and password was criticized and inhibited some users from frequent use of the application. EXP3 and EXP6 confirmed this. EXP6 often wanted to check the exact data after a report review but could not remember the login data and did not have the motivation to look it up. All participants mentioned in their interviews that this is a disabling factor.

> In the beginning, yes, we looked into it, but then we always had to log in and this was such a hassle. The easier, the better.

It became clear that frequent manual login is a high hurdle for using the application and use of the LEM platform. In respect to long-term engagement, future instantiations should consider the tradeoff between data security and ease of use. On the one hand, high protection measures reduce the perceived utility and therefore reduce long-term engagement. On the other hand, low protection can lead to data leakage and violation of privacy or data protection laws, which results in lower trust in the system. Nevertheless, no participant voiced privacy concerns, which confirms that the DP instantiation achieved its intended goal even though the implementation caused discomfort and should be improved.

DP6

The sixth DP is based on the prototype input from Cycle 1 and the resulting R4, which states that users should receive regular notifications summarizing data from the previous period. The selected DP instantiation were weekly e-mail reports for each participant. All participants acknowledged these reports. Therefore, the intended functionality was accessible. The feedback from all participants was very positive and they agree that a regular reminder in the form of a weekly e-mail report containing all information from DP 1-3 in aggregated form is a valuable addition. As noted in the evaluation of the previous DPs, some users used the instantiation of DP6 to reap the benefits of DPs 1-3. EXP4 stated that the report enabled him to keep track of the project and his power consumption with a low entry barrier. Similarly, EXP3 and EPX10 both emphasized that even without understanding the underlying market mechanism, the recurring values from the report can give a good intuition for one's performance after a short time. As mentioned above, EXP6 used the weekly report to monitor consumption patterns with minimal effort.

> I have to be honest, I always take a quick look at the report and then just check the amount. And only if it is remarkably low or high, then I look at what could have caused it. If it's okay, then I don't look too closely.

EXP1 also commented positively on the reports and the personal value but noted that the mailing should remain limited to a weekly cycle and there should be no overlap of the aggregated periods. There are different opinions regarding the periodicity of the communication. The majority feels that a weekly cycle is sufficient. EXP5 prefers more frequent messages, while EXP8 and EXP9 favor longer periods in between the reports. The priority of the information (DPs 1-3) within the report is also assessed differently. EXP3, EXP5, EXP7, EXP9 and EXP10 indicated a preference for the electricity mix. EXP 1, EXP2 and EXP6 on the other hand showed interest in the data on cost and market price development. EXP2 and EXP6 also indicated that they additionally have a strong interest in the weekly consumption number.

> The bottom line was that I could do more with the report. You could look back and say: ok, I paid more this week, let's take a look at the costs and the individual transactions, what's the reason for that?

EXP4 stated that he had not used the app at all except for the initial period and then only used the reports' information. Overall, the instantiation of this DP is a success and represents a major assistance for the participants. The DP supports participants' long-term engagement as it reminds them of the project on a regular basis and provides comparable consumption information over time that is perceived as useful for the participants. After the field project's end, several participants asked whether they could still receive the reports showing the high value for long-term engagement of the DP.

Additional interview feedback from cycle 2

In addition to the explicit feedback on the DPs, the interview responses include other interesting insights. The provision of their own tablet computer and the possibility to access the app via their own devices was rated very positively. For example, EXP2 mentioned that he installed the application on his cell phone to track load values even during working hours. He criticized the navigation within the app, namely the navigation from the consumption interface to the bidding interface. Similarly, EXP2 favors the possibility of directly initiating a bidding process within the visualization of consumption values or the report. Furthermore, all participants mentioned a decreasing activity. The interview partners gave different reasons for this, which can be divided into two categories. First, all participants agreed on the market mechanism's uncertainty and complexity, which resulted in less interest in the market performance and bidding activity. EXP1 and EXP5, for example, explicitly requested more transparency. In principle, the market mechanism's functioning was perceived to be understandable, but there is no clear recommendation for action and the participants expressed the desire for decision support systems. EXP2 expressed the idea of an automated agent that would continuously adapt the bids to the market conditions corresponding to his objectives. Second, it became clear that many participants are interested in the topic but do not want to attribute extensive time resources to it. Therefore, it is essential to provide an easy-to-use design and to reduce complexity, which allows participants to understand the provided information or possible consequences of bidding actions quickly.

DP7

The feedback from Cycle 2 clearly shows that the application was perceived positively in general, but with necessary revisions regarding the market mechanism. In order to address this issue, we evaluated possible market designs in a laboratory experiment to better understand how market mechanism alternatives for LEMs are perceived. The experiment is described in more detail in Section 3. It took the participants of the online experiment about 35 minutes to complete. A total of 575 rounds were played by 115 participants. Participants were able to opt out of playing if they felt that the round's complexity was too high and received a fixed payout. They did so in 202 cases (35%). Of the remaining 373 rounds, participants shifted their variable demand in 340 rounds (92%). It shows that participants understood the mechanics of the mechanisms and acted correspondingly. On average, people earned the most when playing with RTP. When choosing the mechanism for the fifth round, 58% of the participants opted for the TOU (29%) or RTP (29%) mechanisms. These are the easiest mechanisms where prices are externally communicated. These are followed by the AUC (23%) and the PET (19%) mechanisms, which require explicit bids. This result shows that while there is not one popular mechanism, less complex mechanisms are generally preferred. Within the experiment, participants were also asked to specifically state the perceived satisfaction with and perceived complexity of each mechanism on a 7-point Likert scale. Here, the

AUC received the lowest satisfaction scores (4.0) and participants perceived the highest complexity (5.2). RTP pricing got the highest satisfaction score (5.1), followed by TOU (4.8), which are also perceived as the least complex mechanisms (4.5 and 4.8, respectively). When asked which market mechanism participants would prefer in real-life for themselves, 41% indicated TOU, 39% chose RTP and only 12% and 7% chose PET and AUC, respectively. Overall, 67 of the participants indicated a different mechanism in that question than what they had selected in the fifth round. This information may explain the 23% of the AUC in the selection of the fifth round. Participants seem to have tried again to improve themselves, expected a higher probability for high financial gains or tried to understand the mechanism better through practical experience. Of all 26 participants who chose the AUC again, only 3 participants indicated that they preferred it in real life. A clear result of this experiment is that simpler and less complex mechanisms are favored. These mechanisms should support the participants' long-term engagement as they can better understand the consequences of their interactions with the market mechanism.

5.2 Evaluation summary

The derived DPs and the corresponding evaluated instantiations allow LEM operators to design an LEM platform and its corresponding user interface in a way that participants i) understand and are enabled to use the provided functionality, (ii) can behave according to their preferences in the local market and (iii) generally exhibit a long-term user engagement due to the perceived benefits from the platform. The instantiations of DPs 1-4 achieve a high approval among the interviewed participants. The interviewees made use of the associated features, if not directly through the provided instantiation then at least through the weekly reports. None of the participants reported difficulties finding information or submitting bid prices beyond some discomfort caused by the repeated need to manually log in. Regarding the ability to behave according to individual preferences, the instantiations of DP2 and DP3 provided little to no benefit to the participants and are therefore not used after an initial testing phase. The feedback shows that LEM participants are interested in the actual power consumption, energy origin and cost but on different aggregation levels than what was provided in the project field phase. In the case of energy consumption (DP1), the users are interested in temporally granular data, while in the case of energy origin and cost, the aggregated information over a defined period is more interesting and helpful. It seems that most participants have learned to intuitively evaluate the data from the report based on past reports. Focusing on DP4 that incorporates the bidding process, the feedback shows that market

DP	*Key findings*	*Testable proposition*
1	Helps participants to monitor their own behavior and devices Supports long-term involvement and motivation Helps participants in evaluating their consumption behavior	Instantiation was used as expected, users reported to have linked their consumption to their behavior.
2	The energy mix is a relevant information for some participants Aggregated information has a higher value to participants than granular information	Instantiation did not fulfill requirement; users resorted to reports to acquire information; data did not trigger bid changes due to complex market mechanism
3	Costs are an important information for the participants Aggregated information has a higher value to participants than granular information	Instantiation did not fulfill requirement; users resorted to reports to acquire information; reported costs did lead to behavioral adjustments
4	Complexity and lack of a decision support system prevent bidding activity Effects of bid changes must be directly perceivable	High complexity of instantiation strongly criticized; reduced activity; reference value and slider were positively evaluated and used
5	Login is a high hurdle for participation Tradeoff between security and usability necessary	Mostly perceived as a deterrent; no data protection concerns; shows trust in LEM operator
6	Allows to monitor individual metrics and performance easily Helps participants to quickly develop an intuitive evaluation of the data Supports long-term acceptance and engagement with the LEM platform	Highly appreciated; served as alternative data source concerning DPs 1-3; important value proposition to increase long-term engagement
7	Mechanism that requires frequent interaction might not be functional in the long run Preference for simpler mechanism with lower involvement and predictable outcome	Results show that lower perceived complexity is related to higher satisfaction with market mechanism

Table 3. Summary of key findings regarding the DP instantiations

design and complexity play a significant role regarding long-term engagement. Participants are unwilling to engage in bidding if the market mechanism is too complex. In the given implementation, the mechanism's complexity induced a high degree of uncertainty about the new bid's impact and the perceived monetary incentive to invest considerable time resources is not large enough. Thus, many participants shy away from the effort to deal with the market dynamics in more detail and therefore either use a trial-and-error approach or only monitor the values after reaching a satisfactory level without further interaction. All of this shows that if the users are given the possibility to place a bid, it needs to be doable with very little effort and the effects need to be predictable. This makes a case for less complex market mechanisms, which we confirmed using an online experiment. On this basis we formulate DP7. In contrast, the results regarding the instantiation of DP6 show the vital benefit of automatic, regular notifications. A regular reminder combined with aggregated information allows participants to track the individual metrics easily. It also shows that regardless of the market design, these reports are valuable to participants to monitor and adjust their behavior.

In terms of long-term engagement, fulfilling the first two components of the research question is essential: If participants cannot use the functions of the LEM platform or do not derive any added value from the functionality provided to them and accordingly do not adjust their behavior, they become inactive and do not contribute to the system's objective. DPs 5, 6 and 7 specifically target and influence long-term engagement. The feedback regarding the instantiation of DP5 shows that even small hurdles, such as searching for login data, can lead to participants becoming inactive. This result is in alignment with the result of DP6, as it ensures access to valuable information without the necessity of initiating a complicated process by the participants. The study reveals that participants prefer a less complex market mechanism, which is reflected in DP7. High complexity leads to uncertainty, which results in inactivity. In general, market operators have to design an LEM platform with great caution. Due to the limited time each participant is willing and able to invest, simple mechanisms and easily accessible information seem to ensure a higher satisfaction, which ensures continuing activity. All findings are presented in Table 3.

6 Discussion

The contribution of our study is situated within the 'exaptation' area of the DSR knowledge contribution framework (Gregor & Hevner, 2013). Table 4 provides an overview of the components of our DPs. Note that we have not explicitly named implementer and user according to Gregor et al. (2020) in Table 4 because they are the same for all

DP	*Aim*	*Context*	*Mechanism*	*Rationale*
1	Allow users to understand relationship between behavior and energy consumption	Household energy consumption	Visualizations of individual historical consumption data	Supports the participants in the understanding the connection between behavior and consumption
2	Allow users to evaluate the share of local renewable energy generation in their consumption	Household energy consumption and energy generation provided to LEM platform	Visualizations of the different individual generation sources	Supports the participants in assessment of the environmental sustainability of their behavior
3	Allow users to oversee the costs of their consumption and understand the impact of their behavior on costs	Household budget and energy consumption	Visualization of consumption costs transparently and instantly	Users react to financial incentives and transparent data provision can cause behavioral adjustment
4	Allow users to change the share of consumption covered by local renewable generation according to their preferences	Household values and budget as well as LEM platform interaction of the community	Bid submission interface ensuring input validity, reference bid value	Helps participants in the bidding process and provides orientation, fosters interaction
5	Protect user data and prevent access to other users' market account	LEM platform	Authentication mechanisms	Establishes trust towards the system and compliance with data protection requirements
6	Engage users through regular feedback on market results by aggregating and sending data over fixed periods of time	Household values, tech affinity of household, available time resources of household	Option to activate a notification service with customizable periodicity	Facilitates the participants' engagement with the platform and enables tracking of individual metrics
7	Ensure market participation by holding the market mechanism's complexity to a minimum	Tech affinity of household, available time resources of household	Market mechanism with low complexity	Facilitates interaction with the LEM

Table 4. DP components following Gregor et al. (2020).

DPs: The implementer is the LEM operator, which would often be the role of a local utility and the user is the participant (i.e., the private household) in an LEM.

LEMs are a new concept and there are not many implementations apart from pilot projects. In the domain of Green IS, researchers call for more experience from practical implementations, real-world projects and prototypes with the help of DSR approaches (Gholami et al., 2016; vom Brocke et al., 2013). Therefore, our study follows the call of Seidel et al. (2017) and promotes sustainability as well as the practical application of Green IS research. We contribute to the proposed research agenda on the design of green information systems with our newly derived and evaluated DPs. The derived DPs align themselves with and build upon the previous contributions to GreenIS. The LEM platform's functionality is partly composed of other, well-known fields (e.g., energy feedback system) and there are certain similarities to individual DPs from other studies. The DPs presented in this study differ from the existing DPs in their focus on ensuring the long-term engagement of participants. For example, the DPs from Dalén and Krämer (2017) focus primarily on the process of smart meter data recording and processing in order to provide users with meaningful information. Only the last DP of their study focuses on providing cost information, without evaluating whether participants use the provided information in the long-term. In addition, their DPs do not mention behavioral changes towards more sustainability. In contrast, the derived DPs from our study can be seen as a subsequent design step. Here, the focus lies on utilizing the data to provide additional utility to the participants and therefore, to foster long-term engagement. Furthermore, it enables participants to learn from this data and adjust their consumption behavior according to their preferences in regards to costs and environmental sustainability.

The first three DPs are in part based on Gnewuch et al. (2018), who aim to provide consumers with information so that they can behave more sustainably. The first DP of their study is particularly similar to DPs 1 and 6 of our study as we built on this existing design knowledge. However, in addition to the effect on consumption behavior, the presented DPs have been evaluated for whether they support long-term engagement. This analysis as well as a fully functional instantiation and field test is missing in the study of Gnewuch et al. (2018). In comparison to the presented DPs by Seidel et al. (2013), there are several differences. Again, the first DP of their paper shows similarities to DP1 of our study but with a focus on providing information that creates disruptive ambiguity to surprise the user and induce personal reflection. In contrast, DPs 1-3 of our study focus on providing information to specifically change the users' behavior. The resulting benefits for participants result in long-term use.

6.1 Limitations and outlook

Even though we have followed the established guidelines for the implementation of a DSR project, some limitations need to be discussed. First, we tested the DPs in only one field study. It is unclear how the participant structure or the market design influence the results and whether these effects occur in other LEM setups. A common shortcoming of this and similar studies is a self-selection bias because project participation is voluntary. During the interviews, the experts were asked to provide their answers for each DP independently of their feelings towards the project or its objectives, but this can of course not be ruled out. However, even if certain biases cannot be eliminated, the provided answers hold interesting guidance for the design of LEM platforms and corresponding user interfaces. Furthermore, our derived results regarding the market mechanism have not been evaluated in the field longitudinally. Additional research is needed to derive externally valid results. LEMs can be expected to gain popularity given the increasing gap between the costs of locally generated renewable energy and energy procured from wholesale markets. This makes the concept not only interesting for private households, but it is an increasingly valuable tool for local utilities. They can use a diversified portfolio of local energy generation resources to serve local customers at a price well below wholesale levels. Furthermore, the concept adds further incentives to invest in renewable residential energy technology. The presented design knowledge is thus an important contribution from the information systems domain to an increasingly important energy transition. Furthermore, the results provide some generalizable design knowledge for communities that potentially want to integrate several other consumer commodities such as water, gas or heat. The evaluation of the presented DPs in different settings with, e.g., other demographics or commodities can supplement the presented findings.

7 Conclusion

This paper presents the results of a DSR study that focuses on design principles for a local energy market platform and its user interface. It consists of three cycles. In the first cycle, we identify four requirements through stakeholder interviews and literature research and evaluate a prototype design. In the second cycle, we propose and evaluate six initial design principles that are based on a literature review and feedback from Cycle 1. The prototype from Cycle 1 is improved resulting in a mobile and web application that instantiates the formulated design principles and is tested in a field study with ten participants over 13 months. At the end of this phase, the application is evaluated with a focus on the instantiated design principles using semi-structured interviews.

The design principles are positively evaluated as they allow the participants to improve the understanding of how their behavior is linked to their energy consumption, their energy mix and their energy costs. The design principles are further evaluated in terms of their effects on long-term engagement with the local energy market. Based on the evaluation, the instantiations of most of the design principles within the application require only slight adjustments but the complexity of the market mechanism is specifically criticized and seems to deter participants from the use of the local energy market platform. Regarding the market mechanism's complexity, we state a fifth requirement and derive a seventh design principle in the third cycle. In this third design cycle, we show that simple market mechanisms with less interaction are preferred and increase the users' satisfaction with the market mechanism. The perception of these mechanisms after long-term interaction requires further research. In conclusion, the derived design principles and the feedback on the instantiations can help researchers and practitioners in designing local energy market platforms and corresponding user interfaces. We contribute with valuable design knowledge to future research, provide practical experience for local energy market implementations and extend the research on energy feedback solutions as proposed previously in Dalén and Krämer (2017), Gnewuch et al. (2018) and Seidel et al. (2013) among others. Furthermore, the presented design knowledge can be generalized for similar platforms for other consumer commodities (e.g., water, gas, heat). We thus contribute to a more environmentally sustainable resource use facilitated by the use of information systems.

References

Ableitner, L., Tiefenbeck, V., Hosseini, S., Schöb, S., Fridgen, G., & Staake, T. (2017). Real-world impact of information systems: The effect of seemingly small design choices. *WITS 2017 Proceedings*, 387-402.

Ableitner, L., Tiefenbeck, V., Meeuw, A., Wörner, A., Fleisch, E., & Wortmann, F. (2020). User behavior in a real-world peer-to-peer electricity market. *Applied Energy*, *270*, 115061. https://doi.org/10.1016/j.apenergy.2020.115061

Batel, S., Devine-Wright, P., & Tangeland, T. (2013). Social acceptance of low carbon energy and associated infrastructures: A critical discussion. *Energy Policy*, *58*, 1-5. https://doi.org/10.1016/j.enpol.2013.03.018

Beckel, C., Sadamori, L., Staake, T., & Santini, S. (2014). Revealing household characteristics from smart meter data. *Energy*, *78*, 397-410. https://doi.org/10.1016/j.energy.2014.10.025

Bremdal, B. A., Olivella-Rosell, P., Rajasekharan, J., & Ilieva, I. (2017). Creating a local energy market. *CIRED—Open Access Proceedings Journal*, *2017*(1), 2649-2652. https://doi.org/10.1049/oap-cired.2017.0730

Brounen, D., Kok, N., & Quigley, J. M. (2013). Energy literacy, awareness, and conservation behavior of residential households. *Energy Economics*, *38*, 42-50. https://doi.org/10.1016/j.eneco.2013.02.008

Brummer, V. (2018). Community energy—benefits and barriers: A comparative literature review of Community Energy in the UK, Germany and the USA, the benefits it provides for society and the barriers it faces. *Renewable and Sustainable Energy Reviews*, *94*, 187-196. https://doi.org/10.1016/j.rser.2018.06.013

Caramizaru, A., & Uihlein, A. (2020). *Energy communities: An overview of energy and social innovation*. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC119433

Castelli, N., Ogonowski, C., Jakobi, T., Stein, M., Stevens, G., & Wulf, V. (2017). What Happened in my Home?: An End-User Development Approach for Smart Home Data Visualization. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 853-866. https://doi.org/10.1145/3025453.3025485

Chen, D. L., Schonger, M., & Wickens, C. (2016). oTree—An open-source platform for laboratory, online, and field experiments. *Journal of Behavioral and Experimental Finance*, *9*, 88-97. https://doi.org/10.1016/j.jbef.2015.12.001

Cramer, W., Schmitt, C., & Nobis, M. (2018). Design Premises for Local Energy Markets. *Proceedings of the Ninth International Conference on Future Energy Systems*, 471-473. https://doi.org/10.1145/3208903.3212066

Dalén, A., & Krämer, J. (2017). Towards a User-Centered Feedback Design for Smart Meter Interfaces to Support Efficient Energy-Use Choices: A Design Science

Approach. *Business & Information Systems Engineering*, *59*(5), 361-373. https://doi.org/10.1007/s12599-017-0489-x

Froehlich, J. (2009). Promoting energy efficient behaviors in the home through feedback: The role of human-computer interaction. *Proc. HCIC Workshop*, *9*, 1-11.

Gholami, R., Emrouznejad, A., Alnsour, Y., Kartal, H. B., & Veselova, J. (2020). The Impact of Smart Meter Installation on Attitude Change Towards Energy Consumption Behavior Among Northern Ireland Households: *Journal of Global Information Management*, *28*(4), 21-37. https://doi.org/10.4018/JGIM.2020100102

Gholami, R., Watson, R., Hasan, H., & Bjorn-Andersen, N. (2016). Information Systems Solutions for Environmental Sustainability: How Can We Do More? *Journal of the Association for Information Systems*, *17*(8), 521-536. https://doi.org/10.17705/1jais.00435

Gnewuch, U., Morana, S., Heckmann, C., & Maedche, A. (2018). Designing conversational agents for energy feedback. *International Conference on Design Science Research in Information Systems and Technology*, 18-33. https://doi.org/10.1007/978-3-319-91800-6_2

Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly*, 337-355.

Gregor, S., Kruse, L., University of Liechtentsein, Liechtentsein, Seidel, S., & University of Liechtentsein, Liechtentsein. (2020). Research Perspectives: The Anatomy of a Design Principle. *Journal of the Association for Information Systems*, *21*, 1622-1652. https://doi.org/10.17705/1jais.00649

Gui, E. M., & MacGill, I. (2018). Typology of future clean energy communities: An exploratory structure, opportunities, and challenges. *Energy Research & Social Science*, *35*, 94-107. https://doi.org/10.1016/j.erss.2017.10.019

Hall, S., & Roelich, K. (2016). Business model innovation in electricity supply markets: The role of complex value in the United Kingdom. *Energy Policy*, *92*, 286-298. https://doi.org/10.1016/j.enpol.2016.02.019

Hevner, March, Park, & Ram. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 75. https://doi.org/10.2307/25148625

Iivari, J. (2015). Distinguishing and contrasting two strategies for design science research. *European Journal of Information Systems*, *24*(1), 107-115. https://doi.org/10.1057/ejis.2013.35

Ilic, M., Galiana, F., & Fink, L. (2013). *Power systems restructuring: Engineering and economics*. Springer Science & Business Media.

Jain, R. K., Taylor, J. E., & Culligan, P. J. (2013). Investigating the impact eco-feedback information representation has on building occupant energy consumption behavior and savings. *Energy and Buildings*, *64*, 408-414. https://doi.org/10.1016/j.enbuild.2013.05.011

Jain, R. K., Taylor, J. E., & Peschiera, G. (2012). Assessing eco-feedback interface usage and design to drive energy efficiency in buildings. *Energy and Buildings*, *48*, 8-17. https://doi.org/10.1016/j.enbuild.2011.12.033

Kaenzig, J., Heinzle, S. L., & Wüstenhagen, R. (2013). Whatever the customer wants, the customer gets? Exploring the gap between consumer preferences and default electricity products in Germany. *Energy Policy*, *53*, 311-322. https://doi.org/10.1016/j.enpol.2012.10.061

Kaiser, R. (2014). *Qualitative Experteninterviews: Konzeptionelle Grundlagen und praktische Durchführung*. Springer-Verlag.

Karlin, B., Zinger, J. F., & Ford, R. (2015). The effects of feedback on energy conservation: A meta-analysis. *Psychological Bulletin*, *141*(6), 1205-1227. https://doi.org/10.1037/a0039650

Kazhamiakin, R., Marconi, A., Martinelli, A., Pistore, M., & Valetto, G. (2016). A gamification framework for the long-term engagement of smart citizens. *2016*

IEEE International Smart Cities Conference (ISC2), 1-7. https://doi.org/10.1109/ISC2.2016.7580746

Koirala, B. P., Koliou, E., Friege, J., Hakvoort, R. A., & Herder, P. M. (2016). Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. *Renewable and Sustainable Energy Reviews*, *56*, 722-744. https://doi.org/10.1016/j.rser.2015.11.080

Kuechler, B., & Vaishnavi, V. (2008). On theory development in design science research: Anatomy of a research project. *European Journal of Information Systems*, *17*(5), 489-504. https://doi.org/10.1057/ejis.2008.40

Kuo, T. C., Tseng, M.-L., Lin, C. H., Wang, R.-W., & Lee, C.-H. (2018). Identifying sustainable behavior of energy consumers as a driver of design solutions: The missing link in eco-design. *Journal of Cleaner Production*, *192*, 486-495. https://doi.org/10.1016/j.jclepro.2018.04.250

Lee, Y., & Kim, J. (2002). From Design Features to Financial Performance: A Comprehensive Model of Design Principles for Online Stock Trading Sites. *J. Electron. Commer. Res.*, *3*(3), 128-143.

Liu, Y., Wu, L., & Li, J. (2019). Peer-to-peer (P2P) electricity trading in distribution systems of the future. *The Electricity Journal*, *32*(4), 2-6. https://doi.org/10.1016/j.tej.2019.03.002

Loock, C.-M., Staake, T., & Thiesse, F. (2013). Motivating Energy-Efficient Behavior With Green Is: An Investigation of Goal Setting and the Role of Defaults. *MIS Quarterly*, *37*(4), 1313-1332.

Maedche, A., Gregor, S., Morana, S., & Feine, J. (2019). Conceptualization of the problem space in design science research. *International Conference on Design Science Research in Information Systems and Technology*, 18-31.

Meeuw, A., Schopfer, S., Ryder, B., & Wortmann, F. (2018). LokalPower: Enabling Local Energy Markets with User-Driven Engagement. *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, 1-6. https://doi.org/10.1145/3170427.3188610

Mengelkamp, E., Diesing, J., & Weinhardt, C. (2019). Tracing Local Energy Markets: A Literature Review. *It—Information Technology*, *61*(2-3), 101-110. https://doi.org/10.1515/itit-2019-0016

Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., & Weinhardt, C. (2018). Designing microgrid energy markets. *Applied Energy*, *210*, 870-880. https://doi.org/10.1016/j.apenergy.2017.06.054

Mengelkamp, E., Gärttner, J., & Weinhardt, C. (2018). Intelligent Agent Strategies for Residential Customers in Local Electricity Markets. *Proceedings of the Ninth International Conference on Future Energy Systems*, 97-107. https://doi.org/10.1145/3208903.32089071

Mengelkamp, E., Schönland, T., Huber, J., & Weinhardt, C. (2019). The value of local electricity—A choice experiment among German residential customers. *Energy Policy*, *130*, 294-303. https://doi.org/10.1016/j.enpol.2019.04.008

Mengelkamp, E., Staudt, P., Garttner, J., & Weinhardt, C. (2017). Trading on local energy markets: A comparison of market designs and bidding strategies. *2017 14th International Conference on the European Energy Market (EEM)*, 1-6. https://doi.org/10.1109/EEM.2017.7981938

Navrud, S., & Bråten, K. G. (2007). Consumers' Preferences for Green and Brown Electricity: A Choice Modelling Approach. *Revue d'economie politique*, *Vol. 117*(5), 795-811. https://doi.org/10.3917/redp.175.0795

Richter, B., Mengelkamp, E., & Weinhardt, C. (2019). Vote for your energy: A market mechanism for local energy markets based on the consumers' preferences. *2019 16th International Conference on the European Energy Market (EEM)*, 1-6. https://doi.org/10.1109/EEM.2019.8916544

Sandoval, M., & Grijalva, S. (2015). Future Grid Business Model Innovation: Distributed Energy Resources Services Platform for Renewable Energy Integration. *2015 Asia-Pacific Conference on Computer Aided System Engineering*, 72-77. https://doi.org/10.1109/APCASE.2015.20

Sangroya, D., & Nayak, J. K. (2017). Factors influencing buying behaviour of green energy consumer. *Journal of Cleaner Production*, *151*, 393-405. https://doi.org/10.1016/j.jclepro.2017.03.010

Schoormann, T., Strobel, G., Möller, F., & Petrik, D. (2021). Achieving Sustainability with Artificial Intelligence—A Survey of Information Systems Research. *International Conference on Information Systems*. International Conference on Information Systems (ICIS) 2021 Proceedings, USA. https://aisel.aisnet.org/icis2021/soc_impact/soc_impact/2

Schwartz, T., Denef, S., Stevens, G., Ramirez, L., & Wulf, V. (2013). Cultivating energy literacy: Results from a longitudinal living lab study of a home energy management system. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1193-1202. https://doi.org/10.1145/2470654.2466154

Seidel, S., Bharati, P., Fridgen, G., Watson, R. T., Albizri, A., Boudreau, M.-C. (Maric), Butler, T., Chandra Kruse, L., Guzman, I., Karsten, H., Lee, H., Melville, N., Rush, D., Toland, J., & Watts, S. (2017). The Sustainability Imperative in Information Systems Research. *Communications of the Association for Information Systems*, *40*, 40-52. https://doi.org/10.17705/1CAIS.04003

Seidel, S., Recker, J., & Brocke, J. vom. (2013). Sensemaking and Sustainable Practicing: Functional Affordances of Information Systems in Green Transformations. *MIS Quarterly*, *37*(4), 1275-1299.

Sousa, T., Soares, T., Pinson, P., Moret, F., Baroche, T., & Sorin, E. (2019). Peer-to-peer and community-based markets: A comprehensive review. *Renewable and Sustainable Energy Reviews*, *104*, 367-378. https://doi.org/10.1016/j.rser.2019.01.036

Ströhle, P., & Flath, C. M. (2016). Local matching of flexible load in smart grids. *European Journal of Operational Research*, *253*(3), 811-824. https://doi.org/10.1016/j.ejor.2016.03.004

Sundt, S., & Rehdanz, K. (2015). Consumers' willingness to pay for green electricity: A meta-analysis of the literature. *Energy Economics*, *51*, 1-8. https://doi.org/10.1016/j.eneco.2015.06.005

Tabi, A., Hille, S. L., & Wüstenhagen, R. (2014). What makes people seal the green power deal? — Customer segmentation based on choice experiment in Germany. *Ecological Economics*, *107*, 206-215. https://doi.org/10.1016/j.ecolecon.2014.09.004

Teotia, F., & Bhakar, R. (2016). Local energy markets: Concept, design and operation. *2016 National Power Systems Conference (NPSC)*, 1-6. https://doi.org/10.1109/NPSC.2016.7858975

Tiefenbeck, V., Wörner, A., Schöb, S., Fleisch, E., & Staake, T. (2019). Real-time feedback promotes energy conservation in the absence of volunteer selection bias and monetary incentives. *Nature Energy*, *4*(1), 35-41. https://doi.org/10.1038/s41560-018-0282-1

Vasconcelos, M., Cramer, W., Schmitt, C., Amthor, A., Jessenberger, S., Ziegler, C., Armstorfer, A., & Heringer, F. (2019). The PEBBLES project—enabling blockchain based transactive energy trading of energy & flexibility within a regional market. *CIRED 2019*. https://doi.org/10.34890/591

Venable, J., Pries-Heje, J., & Baskerville, R. (2016). FEDS: A Framework for Evaluation in Design Science Research. *European Journal of Information Systems*, *25*(1), 77-89. https://doi.org/10.1057/ejis.2014.36

Vine, D., Buys, L., & Morris, P. (2013). The effectiveness of energy feedback for conservation and peak demand: A literature review. *Open Journal of Energy Efficiency*, *2*(1), 7-15. https://doi.org/10.4236/ojee.2013.21002

vom Brocke, J., Fettke, P., Gau, M., Houy, C., Maedche, A., Morana, S., & Seidel, S. (2017). Tool-support for design science research: Design principles and instantiation. *Available at SSRN 2972803*.

vom Brocke, J., Watson, R. T., Dwyer, C., Elliot, S., & Melville, N. (2013). Green information systems: Directives for the IS discipline. *Communications of the Association for Information Systems*, *33*(1), 30.

Walker, G., & Devine-Wright, P. (2008). Community renewable energy: What should it mean? *Energy Policy*, *36*(2), 497-500. https://doi.org/10.1016/j.enpol.2007.10.019

Wallis, I., Ingalls, T., Campana, E., & Vuong, C. (2013). Amateur Musicians, Long-Term Engagement, and HCI. In S. Holland, K. Wilkie, P. Mulholland, & A. Seago (Eds.), *Music and Human-Computer Interaction* (pp. 49-66). Springer London. https://doi.org/10.1007/978-1-4471-2990-5_3

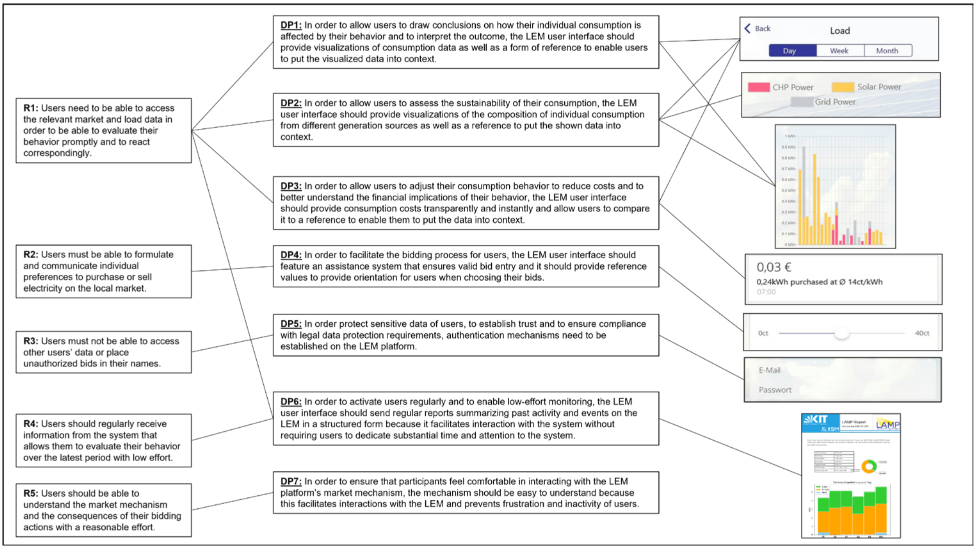
Weinhardt, C., Mengelkamp, E., Cramer, W., Hambridge, S., Hobert, A., Kremers, E., Otter, W., Pinson, P., Tiefenbeck, V., & Zade, M. (2019). How far along are Local Energy Markets in the DACH+ Region?: A Comparative Market Engineering Approach. *Proceedings of the Tenth ACM International Conference on Future Energy Systems*, 544-549. https://doi.org/10.1145/3307772.3335318

Wörner, A., Ableitner, L., Meeuw, A., Wortmann, F., & Tiefenbeck, V. (2019). Peer-to-Peer Energy Trading in the Real World: Market Design and Evaluation of the User Value Proposition. *40th International Conference of Information Systems, ICIS 2019 Proceedings*, 1221. https://aisel.aisnet.org/icis2019/sustainable_is/sustainable_is/2

Wörner, A., Meeuw, A., Ableitner, L., Wortmann, F., Schopfer, S., & Tiefenbeck, V. (2019). Trading solar energy within the neighborhood: Field implementation of a blockchain-based electricity market. *Energy Informatics*, *2*(1), 11. https://doi.org/10.1186/s42162-019-0092-0

Wüstenhagen, R., & Bilharz, M. (2006). Green energy market development in Germany: Effective public policy and emerging customer demand. *Energy Policy*, *34*(13), 1681-1696. https://doi.org/10.1016/j.enpol.2004.07.013

Appendix A. Overview of requirements, design principles and design features



Appendix B. Summary of guideline for semi-structured interviews (translated from original)

1. Introduction
    a. Explain objective of the interview
    b. Communicate duration of approximately 45 minutes
    c. Ask if there are any questions before start
2. Collect general information
    a. Age, household size and type
    b. Motivation to participate
    c. Energy literacy before LAMP
    d. Behavioral change through LAMP
3. Price formation and energy origin
    a. Impression of price formation
    b. Price formation appropriate
    c. Observation of price development
    d. Understanding of price formation
    e. Importance of energy origin
4. Reports
    a. Impression and use of reports
    b. Reaction to reports
    c. Use of provided information to change behavior
    d. Use of provided information to change bidding
    e. Use of provided information to lower costs
5. User Application
    a. Impression of user application
    b .Consumption visualization
        i. Use of visualization of consumption values
        ii. Change of behavior based on consumption visualization
        iii. Deepened understanding due to consumption visualization
    c. Energy mix visualization
        i. Use of visualization of consumption values
        ii. Change of behavior based on consumption visualization
        iii. Deepened understanding due to consumption visualization
    d. Cost visualization
        i. Use of visualization of consumption values
        ii. Change of behavior based on consumption visualization

iii. Deepened understanding due to consumption visualization

e. Bidding interface

i. Ease of use of interface

ii. Value of displayed reference price

f. Security features

i. Concern for privacy issues

ii. Login process