Embedding IoT in Large-scale Socio-technical Systems: A Community-Oriented Design in Future Smart Grids

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Abstract In traditional engineering, technologies are viewed as the central piece of the engineering design, where the physical world consists of a large number of diverse technological artifacts. The real world, however, also comprises a huge amount of social components – people, communities, institutions, regulations and everything that exists in the human mind – that have shaped and been shaped by the technical components. Smart urban ecosystems are examples of such large-scale Socio-technical Systems (STS) that rely on technologies, particularly Internet-of-Things (IoT), within a complex social context where the technologies are embedded. Despite that the two aspects are deeply intertwined, designing applications that embed IoT in large-scale STS is slowly transitioning from a traditional engineering approach towards a socio-technical approach. The latter has not yet entered the mainstream of design practice. In this chapter, we present our experience of adopting a socio-technical approach in designing a community-oriented smart grid user application. The challenges, implications and lessons learned are discussed. The chapter is concluded by offering a set of good design principles derived from this experience, which are also relevant to the design of other smart urban ecosystems.

1 Introduction

The traditional science and engineering philosophy is dominated by technological determinism, the idea that technology determines societal development [47, 59, 67]. Within this reductionist view, technologies are the central piece of the engineering design, where the physical world consists of a large number of diverse technological artefacts. The plausibility of this view is challenged by the socio-technical systems

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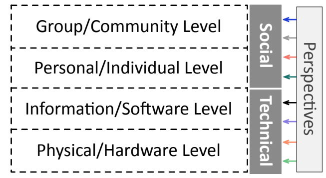

Fig. 1 Levels of STS viewing from different perspectives: the levels are not different systems but overlapping views of the same system [78, 80]

(STS) view [72] which argues that technological and social development form a "seamless web" where there is no room for technological determinism or the autonomy of technological systems [24]. The latter view is premised on the interdependent and deeply linked relationships among the features of technological artefacts or systems and social systems (i.e. the mutual constitution) [59], since the man-made world also comprises a huge amount of social components – people, communities, institutions, regulations, policies and everything that exists in the human mind – that have shaped and been shaped by the technological components [32, 72]. In this view, engineering design is identified as a process through which technologies materialize into products, a process that substantively shapes and reshapes our lives and societies and vice versa [43]. This focus on socio-technical (ST) interconnectedness becomes even more visible in designing new emerging technologies [43].

Smart cities, for example, use technologies such as Internet-of-Things (IoT) within a large complex social context where they are embedded. The goal is to facilitate the coordination of fragmented urban sub-systems and to improve urban life experience [26]. The rise of IoT has important ST implications for people, organizations and society. It is obvious that connecting devices is technically possible, we yet know little about its implications [62]. An ST perspective can be insightful when looking at dynamic technological development and when considering sustainable development [62]. Although STS have been studied for decades, ST approaches are relative new to the design and systems engineering communities [4, 50, 59]. Such approaches are not widely practised despite growing interests [4].

Through this chapter, we review the literature and present our experience of adopting an ST approach in designing a community-oriented smart grid user application. We discuss the challenges, implications and lessons learned from this design experience, and conclude the chapter by offering a set of good design principles which are also relevant to the design of other smart urban ecosystems.

2 Designing in Large-scale Socio-Technical Systems

STS are systems arising through encompassing people communicating with people whose interactions are mediated (at least partially) by technology rather than the natural world [78]. The term "socio-technical" embodies both a research perspective and a subject matter [44]. Facing a complex system, researchers from different disciplines often examine the system from their own perspectives. Engineers, for example, see hardware systems, computer scientists see information systems, psychologists see cognitive systems, sociologist see social systems – in fact, no discipline has a monopoly on science and all those views are valid [80]. Figure 1 uses the notion of system levels to illustrate this perspective difference in STS [78, 80]. Notably, the levels in Figure 1 are not different systems nor partitions of systems, but overlapping views of the same system corresponding to the engineering, computing, psychological and sociological perspectives [78]. The top and bottom of the levels are open-ended, as social groups can coalesce into larger entities such as organizations, cities, nations and beyond [81], while physics and hardware can be studied in micro, nano and smaller scales. The system boundary and the boundaries of those views are not necessarily clear-cut (hence dawn as dashed lines). An STS view is one that incorporates and meaningfully interconnects all levels of considerations: the upper two levels (Group/Community and Personal/Individual) together being social and the lower two (Information/Software and Physical/Hardware) technical. Each upper level can be seen as "arising" or "emerging" from the lower levels. For example, personal cognitions "emerge" from information exchanges supported by software, which "arises" from hardware [78]. The higher a level of view, the higher its degree of abstraction, and the less deterministic and predictive it becomes. With the levels of difference perspectives in mind, the STS view can be articulated as the recognition of three fundamental properties as follows [59].

First, the mutual constitution of people and technologies. This mutual constitution (by the social and the technological) generates complex and dynamic interactions among technological capacities, social norms, histories, situated context, human choices, actions and so on. In STS, social interactions are enabled or supported by technological means. The two adapt to one another, which is referred to as the mutual adaptations.

Second, the contextual embeddedness of the mutuality. The context of a sociotechnical system is not taken as static or delineable. There are dynamic situational and temporal conditions that influence the mutual adaptations throughout the course of design, development, deployment, uses and even retirement phases of the systems of interest.

Third, the importance of collective action. Collective action refers to the joint pursuit of one or more shared (potentially conflicting) goals by two or more interested parties such as problem owners, shareholders, users and communities affected (without implying positive or negative outcomes). It shapes and is shaped by both the context and the technological components.

Researchers who hold an STS view investigate more than just the technological (sub-)system or just the social (sub-)system or even the two side by side, but also the phenomena that emerge when the two interact [44]. An ST approach tries to abstain from oversimplifications that seek a single or dominant cause of change, but studies the complexity, dynamic and uncertainty in the networks of institution, people and technological artefacts in the process of technologically involved change [59]. The levels of perspectives and the three fundamental properties of STS aforementioned help researchers organize, categorize and allocate their inquiries and knowledge.

What does na STS view mean to design in particular? The rest of this section discusses the impact of a STS view on (I) the understanding of the design problems, and (II) the design process and design artefacts.

Understanding the Design Problems or Situation Designing in STS is becoming increasingly challenging partly due to the increasing systems complexity and scale. Large-scale STS often are not designed as a whole by one team in one project, but are incrementally "piece by piece" transformed and evolved from many generations of "legacy" systems. Designers and engineers are therefore faced with ill-structured or wicked problems that are not straightforward to determine what systems boundaries to choose, what issues to address and what aspects to consider regarding the design. [BC]

An STS view by definition advocates a systemic approach towards understanding including but not limited to information acquisition, diagnosis and analysis. Developing an understanding of the design problems or situation entails firstly looking into the roles, responsibilities, powers, interests and requirements of the stakeholders involved [14]. As will be discussed later in the section, iterations in a design process deepens this understanding. Pragmatically, a designer can start with upper level (more abstract) views and dive into the lower level (less abstract) ones. At each level, the designer investigates questions such as what are the corresponding goals to achieve (or problems to tackle) [14, 75] and associated requirements to fulfil [81], which social/technical elements (or components) are important to each level of views, how do the elements operate/behave individually, how do they interact within and across the levels, and what are the possible outcomes of the interactions and in what context [4]. Table 1 provides a set of such questions categorized by the three STS properties and associated to the levels of systems views. The questions are by no means exhaustive but serve as examples to orient ways of thinking during design. Given the nature of STS, the answers to many of such questions are context specific, influenced by situational and temporal conditions [4, 50]. This means the contextual information associated with the answers also need to be well studied and documented.

In an ST approach, social requirements must become part of technical design [79]. Figure 2 illustrates the relation of requirements at different levels [81]. Each level of view unveils requirements which cumulate level by level. The requirements at a level affect not only that level but all those below it [81]. For example, a communal requirement may add new requirements at personal level which in term affects software and hardware requirements. When a technical design fails to fulfil requirements derived from the personal or social level, there is a deficit between what society needs and what technology does – this is when the "social-technical gap" emerges [79].

As mentioned earlier, large-scale STS are often"systems of evolution" rather than "systems of revolution" [4, 50]. Significant changes in a system should be accom-

Table 1 Examples of questions to investigate categorized by STS properties and associated to levels of systems views

Properties	Levels of Focus	Examples of Questions to Investigate
Mutual constitution	All	Which elements (or components) are important at each level? [a] How do the elements behave and interact? What are the possible outcomes of the interactios? What are the goals, constrains and requirements, if any, of the elements?
Contextual embeddedness	Group/ community Personal/ individual	What are the situational and temporal conditions where the behaviours and interactions take place? What are the influences of the situational and temporal conditions on the outcomes of the behaviours and interactions? How those situational conditions may change over time?
Collective action	Group/ community Personal/ individual	What are the community (or institutional) goals, constrains and requirements? How are the community (or institutional) goals, constrains and requirements aligned with the individual goals, constrains and requirements? What is the group and individual attitude towards the community (or institutional) goals or collective action?
General [b]	All	What is the level of resolution to use when describing and analysing the system? What is the set of values that underpin the design thinking about the system? What are the criteria and metric of evaluating whether and to what extent the desired goals are achieved and maintained?

[a] Elements can also be weighted in scale, e.g. from *important* (must be included in the study), to *can be relevant* (can be included in the study), to *not relevant* (can be excluded from the study).
[b] It concerns all three properties above.

panied by a well designed and managed change process where feedback is returned for analysis and adaptation [4]. For this, a good understanding of the existing system and work/operation processes is necessary to design and plan the change process. Many core difficulties in complex projects stem from implementation of the design in the real world [50]. Designers therefore need to address the possible impediments

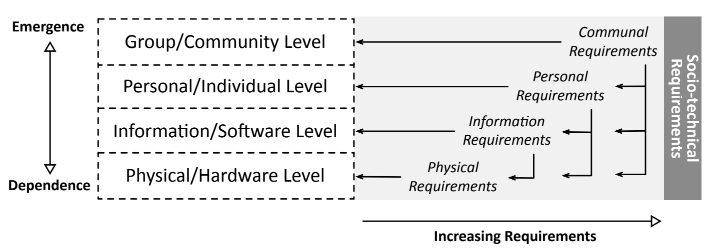

Fig. 2 Levels of socio-technical requirements [81]

to implementation (and change process) already from the beginning, and they must play an active role in implementation, and develop solutions through small incremental steps [50].

Design Process and Design Artefacts The design process of STS is often conceived and implemented as a participatory decision-making process where problem owners, shareholders, users, developers and other stakeholders are actively involved to represent their interests and negotiate agreements. Designers should be working *in* the context of an STS as an insider, not outside of the system as a bystander, with the intention of changing or improving some part of that system [BC].

The evolutionary nature of STS means that what matters more in the design is the design process itself rather than the "final status" of the system [62]. When an STS keeps evolving and exhibits emergent behaviour [48], any designed "final status" soon becomes a transitional state. An important goal of the design process is to make the design relevant to the evolving context where the technology is utilized [62]. This is not a pure technological inquiry but an ST one that demands human-centred design, progressing by iteration and "muddling through" [50].

The interdisciplinary nature of STS calls for interdisciplinary teams. Although this need has been widely accepted, working in an interdisciplinary team remains a persisting challenge. It is group work of the most challenging sort, especially when those involved are in fields far apart intellectually as well as physically [6]. Despite efforts at creating teams across disciplines in the design process, interdisciplinary integration is often poor and disciplinary borders have been largely maintained [4]. Some common issues include [4, 6, 50]: (1) difficulties concerning the logistics of group interactions at management level; (2) failures in understanding and communication due to methodological, disciplinary, language, cultural and value differences; (3) personal challenges related to gaining trust and respect of others working in different disciplines, and (4) institutional impediments related to incentives and priorities given to disciplinary versus interdisciplinary work. One discipline has to fully understand (at least at an conceptual level) and appreciate what the other disciplines can do in order to ask them to deliver something that assists the analysis and design during the development process [4].

The design artefacts can be aligned to achieve specific goals or effects across all four levels of views (shown in Figure 1) through which designers wish to intervene in STS. They can be, for example, hardware, software artefacts, a new idea of human-computer interaction design, rules for behaviour, policies, social programs, and any combination of them. Good solutions are often balanced "satisficing" solutions between different requirements that will be acceptable to and used by end users as well as delivering the expected benefits to stakeholders [4, 50]. As mentioned earlier, designers should not stop at the design stage but play an active role in implementation, developing "evolving" contextual solutions through iteration [50]. Acontextual and detemporalized general solutions are actually self-limiting [59]. In addition, the solutions should be accompanied by a thoughtful change process that is concerned with, among others, sensitising stakeholders for awareness and constructive engagement taking into account social and organizational issues [4].

3 Internet-of-Things and Smart Grids as Socio-technical Systems

The International Telecommunication Union defines IoT as the worldwide network of interconnected objects uniquely addressable based on standard communication protocols – an engineering definition focusing on the technological aspect of IoT. Since IoT is expected to have a massive impact on society and wider cultural milieu, its ultimate status should accordingly be a human-centred STS, despite the fact that how the IoT landscape will look like in the future is yet uncertain [2, 30, 49, 62, 70]. In addition to object-object interaction, the IoT design must also consider human-object, human-environment and human-human interactions [30, 31]. As an ST ensemble, IoT should be integrated into society to build new communities of empowered users with an emphasis on contextual design, so that IoT will be adapted to different psychological, social, legal, policy factors considering actual adoption possibilities (in contrast to designing intrusive technology) [49, 62].

A key application area of IoT is envisioned for the smart grids [63]. IoT technologies can collect energy and environmental data, and form high-speed real-time bidirectional connections among consumers, utilities and the electrical grid [83]. The improved data collection and communications can support decision making and in turn improve the overall efficiency of the grid. IoT is also an integral technology in future smart homes, smart buildinsg and smart cities [60, 84, 85]. The IoT devices are expected to cooperate, actively share their energy, and participate in energy management [41].

4 CIVIS: A Community-Oriented Design in Future Smart Grids

For more than two decades, energy transition has shifted the energy domain towards decentralization and distributed renewable sources [56, 68]. This transition can be attributed to several intertwined facts: (1) the increasing awareness of the inherent complexity among energy systems, societies and the environment [8, 71], (2) the widespread diffusion of new enhanced technologies and their hybridization with modern ICT [55, 61], (3) the pursuit of national and supranational energy policies promoting energy efficiency, sustainability and low carbon emissions [18], and (4) the emergence of new actors such as energy cooperatives and energy communities in the energy value chain [74], and the transformation of traditional actors such as housing associations and amateur energy managers [33].

The CIVIS project[1] discussed in this section as an illustration of designing a STS took place under the European Union's interest to address the societal challenges of energy efficiency. The vision of smart grids and the use of ICT are the main drivers for the project's ambition to reconfigure the relationships among traditional and emerging actors – producers, distributors, retailers, prosumers and cooperatives – in the energy value chain. CIVIS was a three-year project that pursued the design,

[1] http://cordis.europa.eu/project/rcn/110429_en.html

prototyping and real-world piloting of a platform for the improvement of energy consumption behaviour in the domestic sector. The project was structured around three main areas of interest – energy, ICT, and social innovation – and was organized in three broad phases that roughly overlapped with the project years. Each phase ensured a close interaction with the local realities and context of the pilot sites: (I) an exploratory phase, aligned CIVIS' overarching objectives with the local context, (II) a prototyping phase, concerned with the design and development of the platform (from data monitoring devices to the front-end applications), and (III) a piloting phase, for the full scale deployment of the platform in the pilot sites and assessment.

In CIVIS, the possibility for a socio-technical approach was present by design from onset in its formal structure and description. The composition of the project consortium included a diversity of disciplinary profiles – electrical engineers, computer scientists, HCI designers and sociologists – that was necessary for tackling socio-technical challenges in the project from multiple perspectives as discussed in Section 2. In this Section, how CIVIS adopted a socio-technical approach in practice is presented. After an overview of the design situation, the collaborative design process and the main outcomes are discussed.

4.1 A Brief Overview of Design Situation

CIVIS had the goal to increase citizens' energy awareness, promote environmental and social values, improve citizens' know-how about sustainable consumption, and to facilitate citizens to improve energy consumption behaviours in their everyday life together with local communities [36, 37, 38]. These interests were built upon prior research and socio-technical trends regarding smart grids. For instance, research topics linking the potential of Social Networks (SNs) with that of smart grid applications have caught great attention in recent years, following the success of several popular platforms [5, 15, 22, 23, 39]. Some research conducted surveys to understand user needs for energy services combining SNs [64]. Some studied connecting smart meters (or smart homes) for energy management and sharing [16, 69]. Simulation models were developed to study value-added web services [19, 45, 13] and to demonstrate the feasibility of coordination in meeting energy targets [82, 66]. There has been works that visualize smart meter and appliance-level consumption data to enable comparative feedback among households [52, 77, 21].

An overarching goal of the CIVIS project is to integrate the core features of CIVIS design and its underlying infrastructure into rather different contexts, to meet diverse needs and expectations as well as to serve various types of users. This is why the pilot sites of CIVIS – two sites hosted in Italy and two in Sweden – were also deemed as sources of collaborative design and development rather than merely passive recipients of a technology to be tested.

In the two Italian pilot sites[2], the focus at community level was cooperative owned electricity provision to local houses. Two electricity cooperatives, producing and selling 100% renewable energy to their associate members, together with two samples of recruited associate member households acted as the main stakeholders. The regional distribution system operator (DSO), the institutional representatives of the two municipalities, and two local cultural associations participated as stakeholders in different phases of the project, by providing knowledge and support for technical aspects related to energy and households engagement. The CIVIS design in Italy needs to support energy communities in demand-side management[3].

In the two Swedish pilot sites[4], the focus at community level was housing cooperative's energy management in apartment buildings and town-houses. One site included apartment buildings owned by housing cooperatives[5]. Recruited households from the cooperatives, and the cooperatives' board members acted as key stakeholders. The other site was a townhouse area where the local residents' association and some of its member households participated to CIVIS. The design in Sweden needs to support knowledge sharing about energy management practices at building and apartment levels.

4.2 Collaborative Design Process

The CIVIS design process was theory-driven, human-centred, collaborative and iterative. A literature review was carried early in the project regarding energy intervention strategies and social smart grid applications for the promotion of environmental behaviour change. This provided an initial, broad set of possibilities which had been iteratively assessed, refined and improved throughout the design process with the collaboration and participation of basically all stakeholders affected by it. The rationale behind this approach rested on the conviction that applying a human-centred and collaborative design process to the development of large STS has positive theoretical, practical and ethical implications [27, 9] by, for instance, increasing users engagement, usability and integration into existing local conditions [7, 20, 53]. Along the three project years, the process unfolded as a complex and articulated network of meetings and artefacts which strived to align the interests of different stakeholders involved, from porject partners to local stakeholders and end-users. The project team organized brainstorming sessions and design workshops, and run exploratory and evaluation focus groups with end-users in the test sites. Due to limited space,

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[2] Two municipalities of Storo and San Lorenzo in Trento, Northwest Italy.

[3] For example, moving peaks of electricity demand towards peaks of local energy production or, in other words, improving the self-consumption capabilities of the electric cooperatives and their associate members

[4] The neighbourhoods of Hammarby Sjöstad and Fårdala in the Stockholm area.

[5] In Sweden, those who buy an apartment must join a corresponding *housing cooperative* that owns and maintains the estates. The members of a cooperative annually elect a board that makes energy related decisions on behalf of the members.

the main aspects of the process are summarized as follows. Interested readers can refer to [54] for a detailed study on how the process shaped the main outcomes of CIVIS.

User Stories We adopted the tool of user stories [40] from Software Engineering and adapted it to the socio-technical context of the project. The user stories crossed CIVIS both horizontally (to the scope of the work packages) and vertically (to the needs of the two countries). Each user story identified a realistic scenario, a main scope of the energy intervention, the supporting ICT tools, and the central social dynamics. During the three years, we drafted, refined, merged, abandoned and finalized them as part of our constant work of alignment and negotiation. We discussed them in internal workshops, round-tables with stakeholders, and focus-groups with participant end-users; we circulated them to software engineers and platform designers; we publicly presented them for feedback and used them as frames for collaborative workshops. They represented evolving artefacts that we consolidated in formal versions at the end of every year of activity.

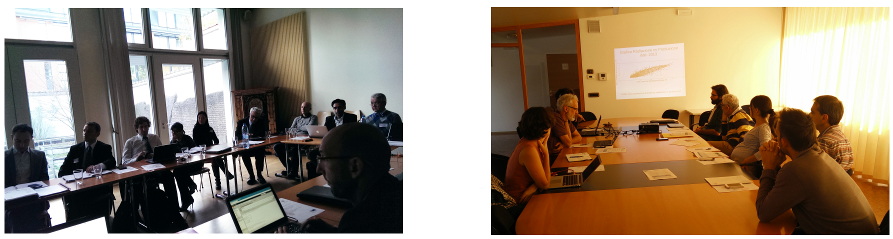

Fig. 3 (a) A moment during one of the first project plenary meetings, where local stakeholders from the pilot sites took part; (b) Stakeholder meeting between some of the technical project partners and local stakeholders in Italy, to discuss the aspects of demand-side management.

Stakeholder Meetings These were held primarily at the level of the pilot sites, by involving CIVIS technical figures and the key local energy stakeholders. Meetings were held quarterly, although at the project's onset and during the most intense 'design phase' of the work, they occurred more frequently. These meetings proved helpful for agreeing on the project overarching objectives at the local levels, but also for understanding the feasibility and rationality of the choices for the social and technical aspects of the platform. For instance, it required long discussions and negotiation about the identification and selection of the energy monitoring devices to be installed in participants households for enabling the proper granularity and availability of energy data. The suitability of these devices could not be assessed at a technical level only (regarding cost/efficiency, type of data, reliability and protocols). The typology of end-users and the housing conditions[6] also played an important role.

Fig. 4 An initial moment of an exploratory focus group in Italy.

Focus Groups These activities involved potential and actual participating household members, recruited for the project, and they were run as collective discussions. Usually they lasted around two hours and included between six to eight discussants. In case of the exploratory meetings, the scope of the discussion was intentionally broad and it aimed at revealing possible latent needs or expectations, as well as discussing explicit ones. More importantly these were used to get first-hand knowledge about the social and cultural environment where the platform was to be deployed. On the contrary, the evaluation discussions had more specific focuses and involved concrete artefacts (e.g. an interface mock-up or app prototype) as a basis. For instance, exploratory meetings helped us put in due perspective some of the features we initially taught would be welcomed by end-users, such as "sharing" of energy performances or measurements typical of social network platforms. In our contexts, it was both difficult to grasp the meaning of such a feature, but it also raised concerns to privacy. At the same time, the intermediate evaluation activities allowed us to spot limitations of our data visualizations (e.g. oversimplifications of energy data through a certain type of charts), and of the engagement and participatory process itself[7] (e.g. expectation of more frequent interactions with the project).

Fig. 5 (a) Beginning of group activities in one of the first workshops held in Italy and focusing on user requirements; (b) One of the group outcomes for mapping energy consumption habits at home.

[6] In italy, participants were older and less tech-savy, living in independent, large houses; while in Sweden participants were relatively young and more tech-savy, but living in smaller apartments in residential buildings.

[7] A study of the end-users appreciation of the engagement and participatory process in the Italian pilot sites is published in [12].

Design workshops These workshops involved concrete, hands-on activities done primarily with participant household members. Occasionally a few workshops took place among project partners or had a broader target. As it is typical of collaborative design approaches we adopted different workshop methodologies (*e.g.* brainstorming, future scenarios, collages, usage simulation) to suit diverse needs in the different phases of CIVIS. Ultimately, they allowed to identify the end-user requirements[8] for the platform front-end as well as improving and tailoring the interface layout. For instance, for the module of *Action suggestions*, the workshops were relevant for adjusting the various tips for energy conservation to the local contexts of use. These were in fact quite different between the two countries, and certain tips had no meaning when delivered to one or another country or they needed a different rationale for their presentation.

In general, a constant work of alignment took place at a high level of abstraction mainly thanks to the use of user stories as key boundary object among stakeholders, expertises and local contexts. At a more concrete level, a set of platform features was prototyped in simple mock-ups and also used as a basis for discussion. These underwent iterative rapid prototyping which produced wireframes as better visual guides that could be more effectively communicated to end-users. Prior and after each iteration, exploratory activities on how to proceed and evaluation sessions for their outcomes took place in different venues and with different stakeholders. TABLE X provide a brief overview on the relationships among the various activities of the collaborative design process and their influence on CIVIS platform design viewed through the perspective of a socio-technical approach.

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4.3 Main Outcomes of the Design Process

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4.3.1 YouPower: An Open Source Social Smart Grid Application

Combining smart sensing and web technologies among others, YouPower is designed as a social smart grid application (developed by the CIVIS project as a hybrid mobile app) that can connect users to friends, families and local communities to learn and take energy actions that are relevant to them together. The app encourages an energy-friendly lifestyle and can be linked to users' energy consumption and production data for quasi real-time and historical prosumption information. The

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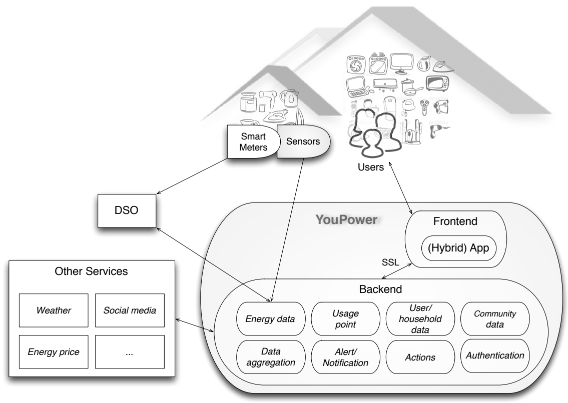
[8] A preliminary analysis of these emerging requirements in the Italian pilots is presented in [11].

platform as a whole (shown in Figure 6) is mainly composed of (I) the *energy sensor level services* mainly dealing with energy data collection, and (II) the *energy data level and social level services* mainly dealing with energy data analytics as well as user, household and community management among others.

Fig. 6 The CIVIS project platform overview. DSO (Distribution System Operators); SSL (Secure Sockets Layer)



Energy Sensor Level Services The CIVIS project installed hardware (smart plugs and sensors) and software required for appliance-level energy data collection. The hardware/software choices differ in the two sites due to the local context. For example, *Smappee*[9] for 40 households in Stockholm, and *CurrentCost*[10] for 79 households in Trento. Trento also installed Amperometric clamps for PV prodcution measures. Household-level energy data of the pilot sites in both countries is measured by smart meters and provided by local DSOs.

Energy Data Level and Social Level Services These services are provided by the YouPower app and its back-end. The design consists of three self-contained composable parts: (1) *House Cooperatives* (contextualized and deployed to the Stockholm pilot site); (2) *Demand-Side Management* (contextualized and deployed to the Trento pilot site); and (3) *Action Suggestions* (contextualized and deployed to both pilot sites). They are discussed in the following subsections.

Housing Cooperatives

This part of the YouPower app is designed for the community of housing cooperatives[11] in the Stockholm pilot sites [34]. Similar housing ownership and management models exist in a number of EU and non-EU countries, which allow potential wider application of the design. A housing cooperative annually elects a board

[9] http://www.smappee.com

[10] http://currentcost.com

[11] *Bostadsrättsförening* or *Brf* in Swedish.

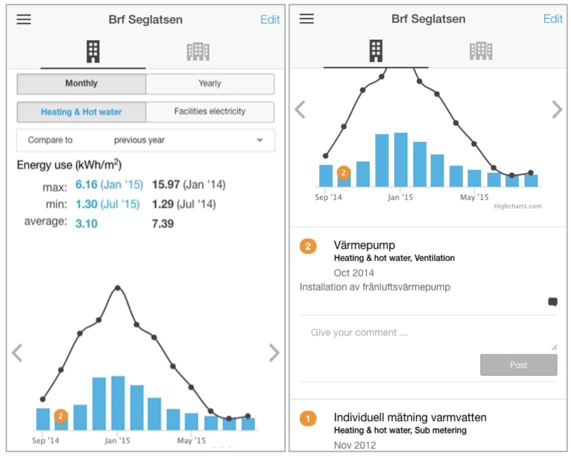


Fig. 7 Heasting & hot water use graph. Blue bars show the current year's use per month; the black line shows that of previous year. Energy reduction actions taken are mapped to the time of action and listed below.

which manages cooperative properties and decides on energy contracts, maintains energy systems, and proposes investments in energy efficient technologies. Since board members are volunteers who may have limited knowledge of energy or building management, this module aims to support board members in energy management, in particular energy reduction actions. Cooperative members can also use the app to follow energy decisions and works of the cooperative. Additionally, the app can be of interest by building management companies working with housing cooperatives. The information presented in the app is visible for these user groups and shared between housing cooperatives. This openness of energy data is key to facilitating users in sharing experiences relevant for taking energy reduction actions.

Linking Energy Data to Energy Reduction Actions

The design links energy data with energy reduction actions taken (Figure 7) at cooperative levels, making the impact of energy actions visible to users. The energy use is divided into distrct heating & hot water, and facilities electricity in apartment buildings. Users can switch between the views per month or per year to show overall changes. Users with editing rights, typically board members, can add energy reduction actions that the cooperative has taken, e.g., improvement of ventilation, lighting or heating systems, and the related cost. Trusted energy or building management companies can also get editing rights to add energy reduction actions they took on behalf of the cooperative. Added actions appear at the month when each action was taken and are listed below the graph. When clicking on an action in the list, the details of the action are shown. To make the impact of actions visible, users can compare the energy use of the viewed months to that of a previous year. This can be used e.g. by a cooperative to explore what energy reduction actions to take in the future by learning actions taken by other cooperatives and what the effects were in relation to costs.

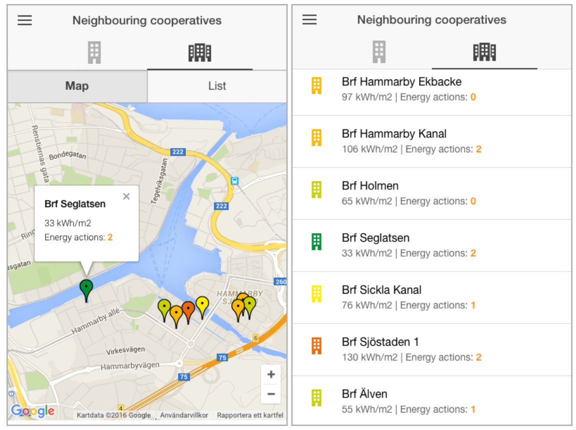


Fig. 8 Map and list view of participating housing cooperatives. The energy performance of cooperatives is indicated by colour and in numbers.

Comparing Housing Cooperatives

The cooperatives that are registered for the app are displayed in a map or list view (Figure 8). Their icons are color coded (from red to green) based on each cooperative's energy performance, i.e. from high to low energy use per heated area, scaled according to the Swedish energy declaration for buildings[12]. Users can also see the energy performance as a number (in kWh/m^2), and the information about energy reduction actions of the cooperatives. During stakeholder studies, energy managers in cooperative boards stressed the importance of knowing the difference between cooperatives in order to understand the difference in their energy performance. Thus, the design also includes information about cooperatives (Figure 9) such as the number of apartments and heated areas in a cooperative, a building's construction year, and types of ventilations (e.g. with or without heat recovery). Users can compare a cooperative's energy use per month or per year to another cooperative or to the neighborhood average. The electricity use is also displayed per area (kWh/m^2) to make it comparable.

Sharing Experiences

A cooperative interested in taking an action may wish to know more, e.g. which contractor was chosen for an investment and why or how to get buy-in from cooperative members. The design provides commenting functions for each action added, where users can post questions and exchange experiences. The cooperatives can also add email addresses of their contact persons, which are visible on each cooperative's app page. Sharing experiences certainly also happens outside of the digital world, e.g. during meetings of cooperative boards or with local energy networks. The app aims to support discussions and knowledge exchange also in such situa-

12 http://www.boverket.se/sv/byggande/energideklaration/energideklarationens-innehall-och-sammanfattning/sammanfattningen-med-energiklasser/energiklasser-fran-ag/

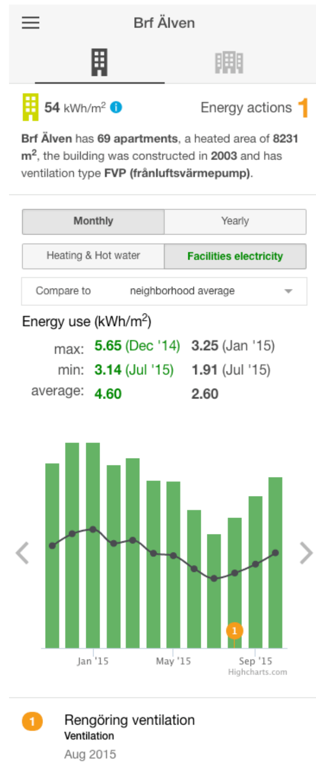


Fig. 9 Facilities electricity use graph. Information about housing cooperatives and actions is displayed at the top. Green bars show the housing cooperative's current year's use per month; the black line shows the average use of all housing cooperatives

tions, where someone can easily demonstrate the impact of an energy investment with smart phones.

Demand-Side Management

This part of the YouPower app is designed for the Trento pilot site and can have wider application. It provides users historical and quasi real-time consumption and production information, and facilitates users to leverage load elasticity in order to maximize self-consumption of rooftop PV productions. Energy data is displayed at appliances (if smart plugs are installed), household, and electricity consortia levels. Consumption at the appliance level enables users to gain deeper understanding of their daily actions and the resulting energy use. Historical and current consumption and production at the household level allow users to compare those two and potentially maximize self-consumption. Aggregated and average consumption at the consortia level informs users of neighborhood energy consumption and allows comparisons. In addition, dynamic Time-of-Use (ToU) signals are displayed to assist users in load shifting during their daily actions.

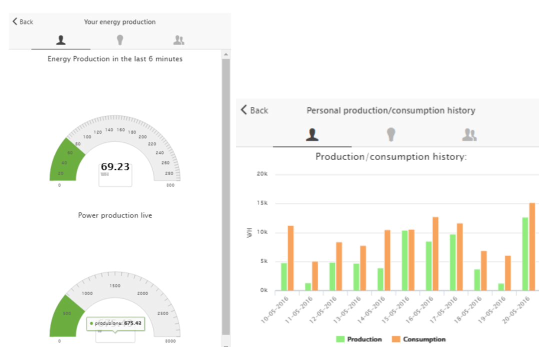
Historical and Quasi Real-time Consumption and Production

At the household level, electricity consumption and PV production levels (in W and Wh) are displayed in quasi real-time and updated for the latest six minutes[13]. This information can also be displayed as a bar chart for a chosen period (in the past) to provide an aggregated daily overview of consumption vs. production (Figure 10). When smart plugs are installed, users can view the daily electricity consumption (in Wh) of the corresponding connected appliances of their own household for a chosen period (Figure 11 a). This helps them to gain better insights into the individual appliance's consumption level and its daily or seasonal patterns. With the aggregated energy data provided by the two local electricity consortia, users can also compare their own households' hourly consumption profiles over a chosen day to the averages and totals of the consortia to gain a sense of their relative performance compared to their peers (Figure 11 b).

Dynamic ToU Signals

Dynamic ToU signals are provided to facilitate users' self-consumption of local PV productions. They give clear indications to encourage or discourage electricity consumption at a certain moment based on the forecasted local renewable production level calculated with open weather forecast information (in particular solar radiation data) and the local rooftop PV production capacity. The signals are at 3-hour intervals for the forthcoming 30 hours (Figure 12 a), and are updated every 24 hours. A green smiley face signals a time slot suitable for self-consumption where the forecasted local PV production exceeds the current local consumption, while an orange frown face signals otherwise. On a weekly basis, users get a summary of the proportion of their own household consumption that took place under green or orange ToU signals to allow them to reflect on their levels of self-consumption (Figure 12 b). The same information is also provided at the consortia level to enable peer comparison.

Fig. 10 (a) Quasi real-time meters for household PV production; (b) Household consumption vs. production for a chosen period



[13] For technical reasons such as households' data transfer connections and processing time, there can be up to 2-min delay between the time of actual power measurement and the data displayed.

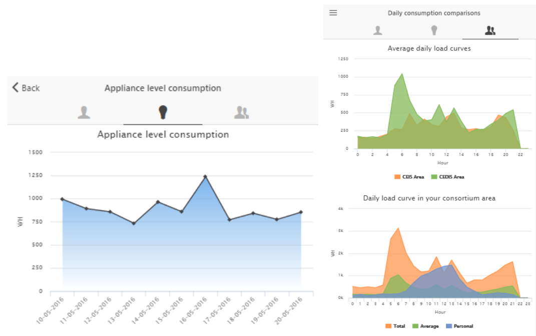


Fig. 11 (a) Daily electricity consumption at the appliance level for a chosen period; (b) A household's hourly consumption profile over a chosen day compared to the averages and totals of the consortia

Action Suggestions

This part of the YouPower app aims to facilitate all household members to take part in energy conservation in their busy daily life. About fifty action suggestions are composed to provide users practical and accurate information about energy conservation. They include one-time actions such as "Use energy efficient cooktops", routine actions such as "Line dry, air dry clothes whenever you can", as well as in-between actions (reminders) such as "Defrost your fridge regularly (in *x* days)". Some suggestions may seem obvious and trivial, but as indicated by literature, people often has an attitude-behavior gap when it comes to environmental issues. The goal is to facilitate the behavior change process to bridge the attitude-behavior gap, making energy conservation new habits integrated in everyday household practices.

Free Choice and Self-monitoring of Energy Conservation Actions

The actions are not meant as prescriptions for what users should do but to present different ideas of what they can do (and how) in household practices. Users can

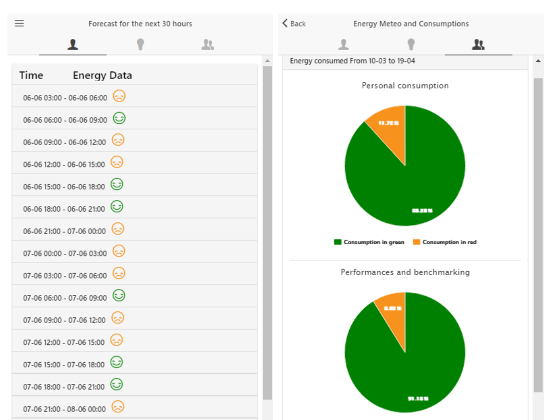


Fig. 12 (a) Dynacmie ToU signals at 3-hour intervals for the forthcoming 30 hours; (b) A household's hourly consumption profile over a chosen day compared to the averages and totals of the consortia

freely choose whether (and when) to take an action and possibly reschedule and repeat the action according to the needs and interests in their own context (Figure 13). After all, users are experts of their own reality. They also have an overview of their current, pending, and completed actions. A new action is suggested when one is completed. When an action is scheduled, its reminder is triggered by time. Users' own choices of actions and the action processes facilitate the sense of autonomy which enhances and maintains motivation [58].

Promoting Motivation and Engagement

The design uses a number of elements to promote users' motivation and engagement. The suggestions are tailored to the local context by local partners and focus groups. Each action is accompanied by a short explanation, the entailed effort and impact (on a five-point scale) and the number of users taking this action. The design encourages users to take small steps (and not to have too many actions at a time) and gives positive performance feedback. In addition, users can invite household members, view and join the energy conservation actions of the whole household. Users can also login with Facebook, like, comment, share actions, give feedback and invite friends. Users are awarded with points (displayed as Green Leaves) once they complete an action, or provide feedback or comments.

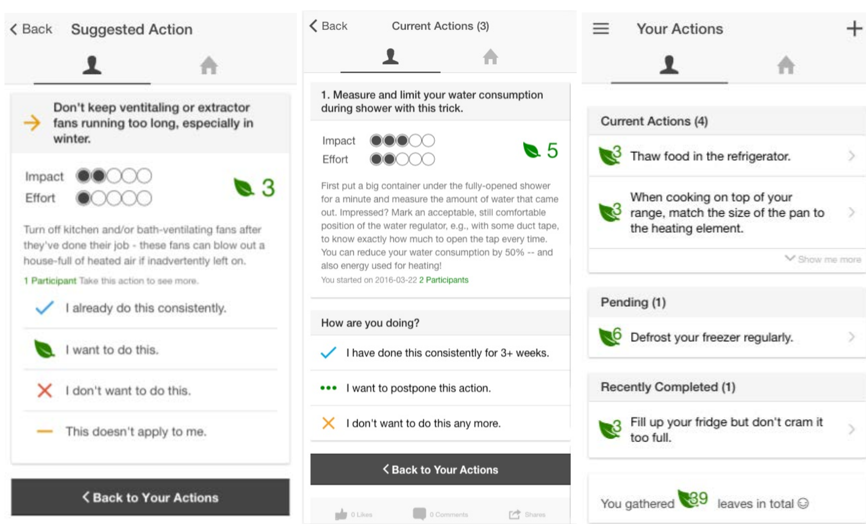


Fig. 13 (a) Action suggestion; (b) Action in progress; (c) User actions

4.3.2 Community Engagement Approaches

Another main outcome of the design process, which also reflects the potential richness of designing for large-scale STSs, rests at the level of community engagement. The ambition to foster energy behaviour change at the collective level of communities (or neighbourhoods), instead of simply aiming for technology adoption at individual level, made it clear the need to design for engagement. In the two national contexts, two different engagement processes accompanied the deployment and testing of the technology. They tried to stimulate the emergence of the social dynamics connected to the change of energy behaviour.

In Italy, a full fledged process named *Participatory Energy Budgeting* (PEB) [12, 10] was run with the twofold goal of subsidizing people's efforts in demand-side management and empowering them to handle their achievements in a collective and transparent way. PEB is a policy frame that relies on a call for tender that defines: the energy budget to be administered; the criteria and procedures to submit proposals for funds request; the procedures to evaluate, select and award the winning proposals; and a roadmap for the process development. Grounded on the community funds model of participatory budgeting [25, 65], PEB promoted engagement and allowed collective decision making around the management and allocation of "energy bonus", which could be collected through the collective effort of shifting electric energy demand towards local production peaks. The PEB and the demand-side management module of YouPower were thought and designed to act in synergy and "reinforce" each other. The more people consumed energy during peaks of local production – foretold and displayed with "green smileys" in YouPower – the more the energy bonuses grew.

PEB can be considered a main outcome of the design process in the Italian sites, because the idea to manage collectively the energy savings emerged during the first exploratory focus groups, and throughout the fist two project years, such idea has been refined and negotiated into a full-fledged policy frame, with the participation of recruited households and the endorsement of the electric consortia. For instance, while the latter vouched for the legitimacy of the process and made the "energy bonus" practically available, the former defined key aspects of PEB frame such as the criteria for eligibility and those ones for final evaluation and award.

In Sweden, the engagement work and app design aimed to complement the already existing community efforts to address energy issues. Meetings were arranged with housing cooperative representatives to discuss experiences of energy reduction actions and how those could be shared through the Youpower app. Furthermore, the app was used as a probe to discuss housing cooperative energy management with other stakeholders who may influence housing cooperative energy use, such as building managers, energy providers, and energy advisers. These stakeholders were already working with housing cooperatives and many had ambitions of supporting housing cooperatives in reducing energy use. By engaging with these stakeholders and learning about their processes and goals, we identified opportunities for the Youpower app to be used jointly by these stakeholders and housing cooperatives to support energy improvement work.

5 Conclusions

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