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Embedding Internet-of-Things 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 core of the engineering design, in a physical world with a large number of diverse technological artefacts. The real world, however, also includes a huge number of social components—people, communities, institutions, regulations and everything that exists in the human mind—that have shaped and been shaped by the technological components. Smart urban ecosystems are examples of large-scale Socio-Technical Systems (STS) that rely on technologies, in particular on the Internet-of-Things (IoT), within a complex social context where the technologies are embedded. Designing applications that embed both social complexity and IoT in large-scale STS requires a Socio-Technical (ST) approach, which has not yet entered the mainstream of design practice. This chapter reviews the literature and presents our experience of adopting an ST approach to the design of a community-oriented smart grid application. It discusses the challenges, process and outcomes of this apporach, and provides a set of lessons learned derived from this experience that are also deemed relevant to the design of other smart urban ecosystems.

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1 Introduction

The traditional science and engineering philosophy is dominated by technological determinism, the idea that technology determines societal development [35, 45, 52]. Within this reductionist view, technologies are core to 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 (STS) view [56] that argues that technological and social development form a “seamless web” where there is no room for technological determinism or autonomy of technological systems [14]. 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) [45], since the man-made world also comprises a huge number of social components—people, communities, institutions, regulations, policies and everything that exists in the human mind—that have shaped and been shaped by technological components [22, 56]. 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 [33]. This focus on Socio-Technical (ST) interconnectedness becomes even more visible in new emerging technologies [33].

Smart cities, for example, use technologies such as Internet-of-Things (IoT) within a large complex social context in which they are embedded to facilitate coordination of fragmented urban sub-systems and to improve urban life experience [17]. The rise of IoT has important ST implications for people, organizations and society. Although connecting devices is technically possible, little is known about the implications [50]. An ST perspective can be insightful when looking at dynamic technological development and when considering sustainable development [50]. Although STS have been studied for decades, ST approaches are relatively new to the design and systems engineering communities [2, 38, 45]. Such approaches are not widely practised despite growing interests [2].

This chapter reviews the literature and presents our experience of adopting an ST approach in designing a community-oriented smart grid application called *YouPower*. It discusses the challenges, process and outcomes of this design experience, and provides a set of lessons learned that are also deemed relevant to the design of other smart urban ecosystems.

2 Designing 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 only in the natural world [59]. The term “socio-technical” embodies both a research perspective and a subject matter [34]. 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—all these views are valid [61]. Figure 1 uses the notion of system levels to illustrate this difference of perspectives in STS [59, 61]. Notably, the levels in Fig. 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 [59]. 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 [62], 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 drawn 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 [59]. The higher a level of view, the higher its degree of abstraction, and the less deterministic and predictive it becomes. With the levels of these different perspectives in mind, the STS view can be articulated as the recognition of three fundamental properties as follows [45].

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 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 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

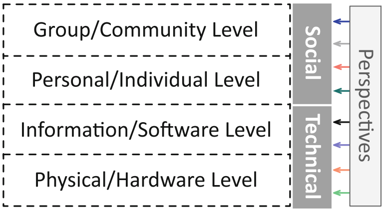

Fig. 1 Levels of STS viewing from different perspectives: the levels are not different systems but overlapping views of the same system [59, 61]

> (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 [34]. 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 [45]. The levels of perspectives and the three fundamental properties of STS aforementioned help researchers to organize, categorize and allocate their inquiries and knowledge.

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

Understanding the Design Problems or Situation Designing 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 do not allow to straightforward determine what systems boundaries to choose, what issues to address and what aspects to consider regarding the design [4].

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 [11]. As will be discussed later in this 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, a designer investigates questions such as what are the corresponding goals to achieve (or problems to tackle) [11, 58] and associated requirements to fulfil [62], 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 [2]. Table 1 provides a set of such questions categorized by the three STS properties and associated to the levels of focus. 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 [2, 38]. 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 the technical design [60]. Figure 2 illustrates the relation of requirements at different levels [62]. Each level unveils requirements that cumulate level by level. The requirements at one level affect not only that level but all those below it [62]. For example, a communal requirement may add new requirements at the personal level which in turn affects software and

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

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 interactions?
		What are the goals, constrains and requirements, if any, of the elements?
Contextual embeddedness	Group/community	What are the situational and temporal conditions where the behaviours and interactions take place?
	Personal/individual	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	What are the community (or institutional) goals, constrains and requirements?
	Personal/individual	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 categorized by weighted 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

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 a "ST gap" emerges [60].

As mentioned earlier, large-scale STS are often "systems of evolution" rather than "systems of revolution" [2, 38]. Significant changes in a system should be accompanied by a well designed and managed change process where feedback is returned for analysis and adaptation [2]. For this, a good understanding of the existing system and work/operation processes is necessary to design and plan the change

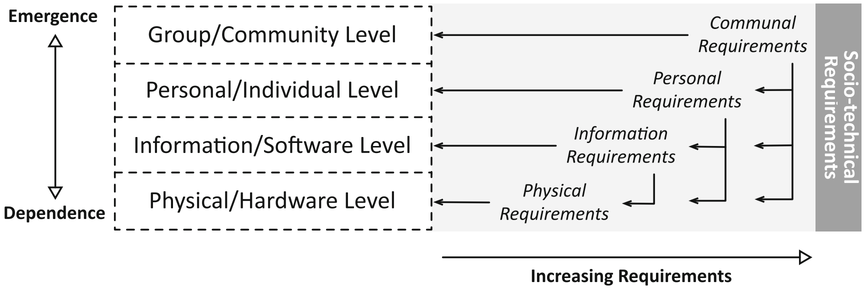

Fig. 2 Levels of socio-technical requirements [62]

process. Many core difficulties in complex projects stem from implementation of the design in the real world [38]. Designers therefore need to address the possible impediments 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 [38].

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 [4].

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 [50]. When an STS keeps evolving and exhibits emergent behaviour [36], any designed "final status" soon becomes a transitional state. An important goal of a design process is to make the design relevant to the evolving context where the technology is utilized [50]. This is not a pure technological inquiry but an ST one that demands human-centred design, progressing by iteration and "muddling through" [38].

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 [5]. Despite efforts at creating teams across disciplines in the design process, interdisciplinary integration is often poor and disciplinary borders have been largely maintained [2]. Some common issues include [2, 5, 38]: (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 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 [2].

The design artefacts can be aligned to achieve specific goals or effects across all four levels of views (shown in Fig. 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 [2, 38]. As mentioned earlier, designers should not stop at the design stage but play an active role in implementation, developing "evolving" contextual solutions through iteration [38]. Acontextual and detemporalized general solutions are actually self-limiting [45]. 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 [2].

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

This section presents the EU CIVIS project[1] as an illustration of designing STS. The project took place under EU's interest to address the societal challenges of energy efficiency. The vision of smart grids and the use of IoT and 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. In the following, we review the literature about IoT with regard to smart grids and STS, provide an overview of the design situation, and then discuss the collaborative design process and the main outcomes.

3.1 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—a 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 although how the IoT landscape will look like in the future is yet uncertain [1, 20, 37, 50, 54].

A key application domain of IoT is envisioned for smart grids [50]. IoT technologies can collect energy and environmental data, and form high-speed real-time

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

bidirectional connections among consumers, utilities and the electrical grid [63]. 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 buildings and smart cities [15, 46, 64, 65] where IoT devices are expected to cooperate, actively share energy, and participate in energy management [31, 39]. In addition to object-object interaction, the IoT design must also consider human-object, human-environment and human-human interactions [20, 21]. As an ST ensemble, IoT and smart grids should be embedded into society to build new communities of empowered users with an emphasis on contextual design, so that the technologies will be adapted to different psychological, social, legal, policy factors considering actual adoption possibilities (in contrast to designing intrusive technology) [37, 50].

For more than two decades, energy transition has shifted the energy domain towards decentralization and distributed renewable sources [43, 53]. This transition can be attributed to several intertwined facts: (1) the increasing awareness of the inherent complexity among energy systems, societies and the environment [7, 55], (2) the widespread diffusion of new enhanced technologies, such as IoT, and their hybridization with modern ICT [42, 47], (3) the pursuit of national and supranational energy policies promoting low carbon emission, energy efficiency and sustainability [12], and (4) the emergence of new actors such as energy cooperatives and energy communities in the energy value chain [57], and the transformation of traditional actors such as housing associations and amateur energy managers [23]. Under these conditions, many new challenges and possibilities emerge, particularity from an ST perspective [50].

3.2 An Overview of the CIVIS Project

For the CIVIS project, an ST approach was in prospect by design from onset in the project goal and team composition. The goal in large was to provide ICT support for social participation in smart grids to manage communities and support energy services in the domestic sector. The project team had the ambition to increase citizens' energy awareness, promote environmental 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 [26–28]. The research attention was oriented towards the potentials and challenges of citizens' collective actions, pro-social values and sense of community. 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 ST challenges in the project from multiple perspectives.

Another overarching goal of the CIVIS project was 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 technologies to be tested.

In the two Italian pilot sites,[2] the focus (at the community level) was cooperative-owned electricity provision to local houses. Two electricity cooperatives, that produce and sell 100% renewable energy to their associate members, together with two samples of recruited associate member households were 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 needed to support energy communities in demand-side management.[3]

In the two Swedish pilot sites,[4] the focus (at the 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 were 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 needed to support knowledge sharing about energy management practices at building and household levels.

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 three project years. Each phase ensured a close interaction with the local realities and context of the pilot sites: (I) an exploratory phase, aligned and refined CIVIS' objectives with the local context, (II) a real-world 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.

3.3 Collaborative Design Process

The CIVIS design process was theory-driven, human-centred, collaborative and iterative. A literature review was carried out early in the project and later updated regarding energy intervention strategies and social smart grid applications for the promotion of environmental behaviour change. This provided a broad set of initial design ideas which had been iteratively assessed, expanded, refined and improved throughout the

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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.

design process with the collaboration and participation of stakeholders affected. 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 [3, 18] by, for instance, increasing users engagement, usability and integration into existing local conditions [6, 13, 40]. During 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 project 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 pilot sites. Due to limited space, the main aspects of the process are summarized as follows. Interested readers can refer to [41] for more detail on how the process shaped the main outcomes of CIVIS.

User Stories User stories [30] were used and adapted it to the ST context of the project acrossed 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 energy intervention, supporting ICT tools, and central social dynamics. During the 3 years, user stories were drafted, refined, merged, abandoned and finalized as part of our constant work of alignment and negotiation. They were discussed in internal workshops, round-tables with stakeholders, and focus-groups with participant end-users; circulated to software engineers and platform designers; publicly presented for feedback and used as frames for collaborative workshops. They represented evolving artefacts that were consolidated in formal versions at the end of each year during the project.

Stakeholder Meetings Stakeholder meetings were held primarily at the level of pilot sites involving CIVIS key technical stakeholders and key local energy stakeholders. Meetings were held quarterly, although at the project's onset and during the most intense design phase, 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, identification and selection of the energy monitoring devices (to be installed in participants' households to enable the collection of energy data) required long discussions and negotiation. 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 housing conditions[6] also played an important role.

Focus Groups Focus groups involved potential and actual participating household members, recruited for the project, and they were run as collective discussions. Usually they lasted around 2 hours and included between six to eight discussants. In case of the exploratory meetings, the scope of the discussion was intentionally broad

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[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.

Fig. 3 **a** First project plenary meeting where local stakeholders took part; **b** Stakeholder meeting among technical project partners and local stakeholders to discuss demand-side management

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

and was 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 for which the platform was to be deployed. In contrast, the evaluation discussions had more specific focus and involved concrete artefacts (e.g. an interface mock-up or app prototype) as a basis. For instance, exploratory meetings helped some of the features initially thought to be welcomed by end-users, such as "sharing" of energy performances or measurements typical of social network platforms, into due perspective. In our context, it was both difficult to grasp the meaning of such a feature, but it also raised concerns with respect to privacy. At the same time, intermediate evaluation activities allowed us to spot limitations of our data visualization (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) (Figs. 3, 4, 5).

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. Different workshop method-

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[7] A study of the end-users appreciation of the engagement and participatory process in the Italian pilot sites is published in [10].

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

ologies (e.g. brainstorming, future scenarios, collages, usage simulation) were used to suit diverse needs in the different phases of CIVIS. End-user requirements[8] were identified for the platform front-end as well as for 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, continual alignment took place at a high level of abstraction mainly due to the use of user stories as key boundary object among stakeholders, expertise and local contexts. At a more concrete level, a set of platform features were 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 2 provides 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 an ST approach.

3.4 *Main Outcomes of the Design Process*

The main outcomes of the CIVIS collaborative design process include (1) an open source social smart grid application called YouPower [25], and (2) community engagement approaches that were implemented during the change process of the project [10, 24], both contextualized to the local situations.

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[8] A preliminary analysis of these emerging requirements in the Italian pilots is presented in [9].

Table 2 A simplified view of the relationships among type of activities the stakeholders involved in the collaborative design process and their influence on CIVIS platform design—viewed through the perspective of a socio-technical approach. Aspects that had a specific link with one of the two pilot countries (Italy ITA Sweden SWE) are reported in the table

Type of activity main stakeholders involved	Social levels	Technical levels
Stakeholder meetings Project partners, institutional local energy stakeholder	• Endorsement and preparation of recruitment strategy for participant households • Refinement and public endorsement of participatory energy budgeting (ITA)	• Definition of main energy targets: demand-side management (ITA), energy knowledge sharing (SWE) • Refinement of energy optimization models and feasibility of a time-of-use signal for demand-side management • Selection of optimal energy monitoring devices: CurrentCost (ITA), Smappee (SWE) • Understanding of DSO energy data structure and availability • Understanding of existing energy/ICT infrastructure • Availability to invest "energy bonus" for participatory energy budgeting (ITA)
Focus groups Recruited household members	• Understanding local context: strength of local community groups and associations reinforcing the idea to promote joint actions through the platform • Emerging concerns about privacy • Emerging concerns about anonymity related to energy data comparisons (ITA) • Exploration of "ICT literacy"	• Exploration and rejection of social networking features • Refinement of the understanding of ICT devices availability, type and use
Co-design workshops Recruited household members, institutional local energy stakeholder, project partners	• Requested interface features: real time and historical data for PV production (ITA) • Definition of PEB policy documents (ITA) • Collaborative content-generation sessions for Housing Cooperative module (SWE)	• Exploration and rejection of social networking features • Refinement of the understanding of ICT devices availability, type and use
	• Assessment and usability feedback on all module mock-ups, leading to improvement of interface designs	

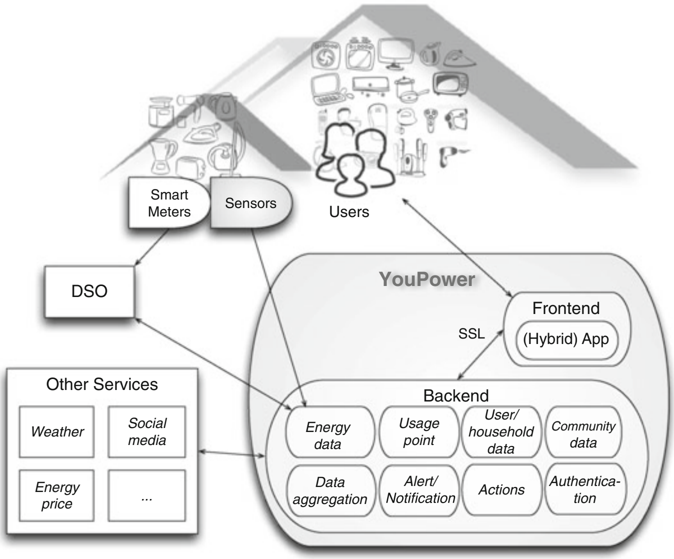

Fig. 6 The CIVIS project platform overview. DSO (Distribution System Operators); SSL (Secure Sockets Layer)

3.4.1 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 [25, 29]. 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 CIVIS platform as a whole (shown in Fig. 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.

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 production measures. Household-level energy data of the pilot sites in both countries is measured by smart meters and provided by local DSOs.

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

[10] http://currentcost.com.

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 modules: (1) *House Cooperatives* (contextualized and deployed to the Stockholm pilot sites); (2) *Demand-Side Management* (contextualized and deployed to the Trento pilot sites); and (3) *Action Suggestions* (contextualized and deployed to all pilot sites). They are discussed in the following paragraphs.

3.4.2 Housing Cooperatives

This module is designed for the community of housing cooperatives[11] in the Stockholm pilot sites [23]. 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 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 (Fig. 7a) at cooperative levels, making the impact of energy actions visible to users. Energy use is divided into district heating and hot water, as well as 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 related cost. Trusted energy or building management companies can be given editing rights to add energy reduction actions taken on behalf of the cooperative. Actions taken are depicted per month and are listed below the graph. Clicking on an action provides more details. 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.

Comparing Housing Cooperatives The cooperatives that are registered for the app are displayed in a map or list view (Fig. 7b). Their icons are colour 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 build-

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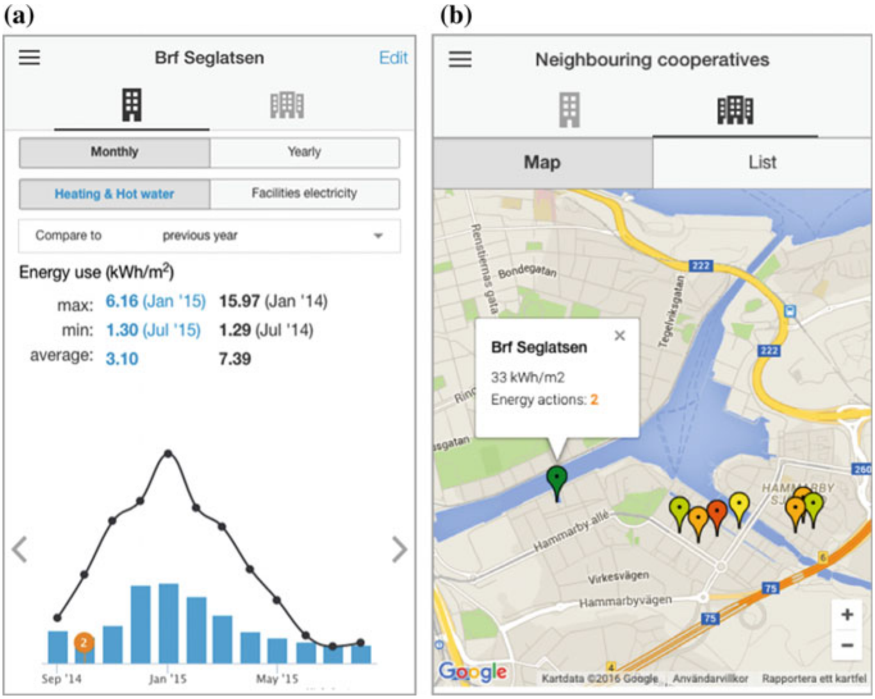
[11] *Bostadsrättsförening* or *Brf* in Swedish.



Energy use (kWh/m²)
max: 6.16 (Jan '15) 15.97 (Jan '14)
min: 1.30 (Jul '15) 1.29 (Jul '14)
average: 3.10 7.39

Brf Seglatsen
33 kWh/m2
Energy actions: 2

Fig. 7 **a** Heating and 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 (not shown); **b** Map view of participating housing cooperatives. The energy performance of cooperatives is indicated by colour and in numbers

ings.[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 (Fig. 8) 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

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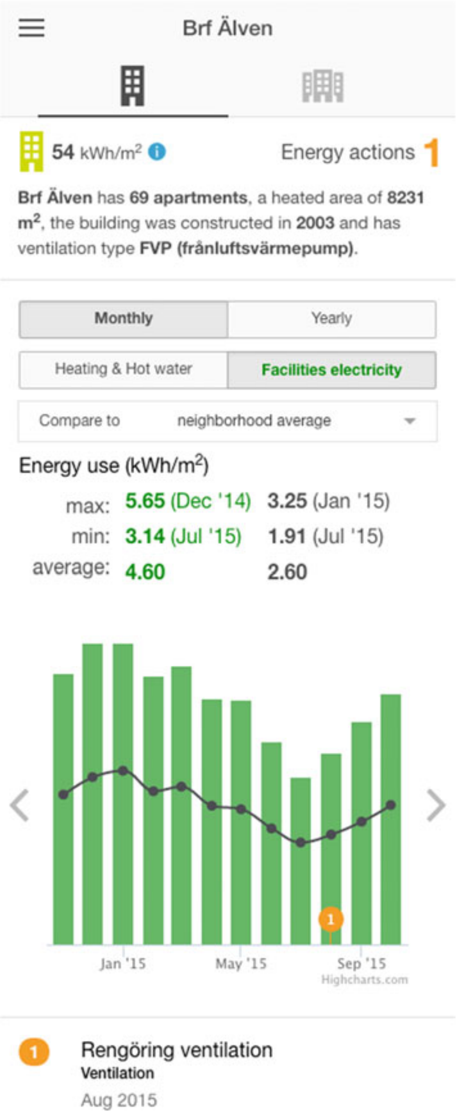
[12] http://www.boverket.se/sv/byggande/energideklaration/energideklarationens-innehall-och-sammanfattning/sammanfattningen-med-energiklasser/energiklasser-fran-ag/.



Brf Älven

54 kWh/m^2

Energy actions 1

Brf Älven has **69 apartments**, a heated area of **8231 m^2**, the building was constructed in **2003** and has ventilation type **FVP (frånluftsvärmepump)**.

Compare to neighborhood average

Energy use (kWh/m^2)

max:	**5.65** (Dec '14)	**3.25** (Jan '15)
min:	**3.14** (Jul '15)	**1.91** (Jul '15)
average:	**4.60**	**2.60**

1 Rengöring ventilation
Ventilation
Aug 2015

Fig. 8 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

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

3.4.3 Demand-Side Management

This module is designed for the Trento pilot sites 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 6 min[13] (Fig. 9a). 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 versus production. When smart plugs are installed, users can view the daily consumption (in Wh) of the corresponding connected appliances of their own household for a chosen period. This helps them 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 the peers (Fig. 9b).

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 h intervals for the forthcoming 30 h (Fig. 10a), and are updated every 24 h. 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 frowny face signals otherwise. On a weekly basis, users receive 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 (Fig. 10b). The same information is also provided at the consortia level to enable peer comparison.

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[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.

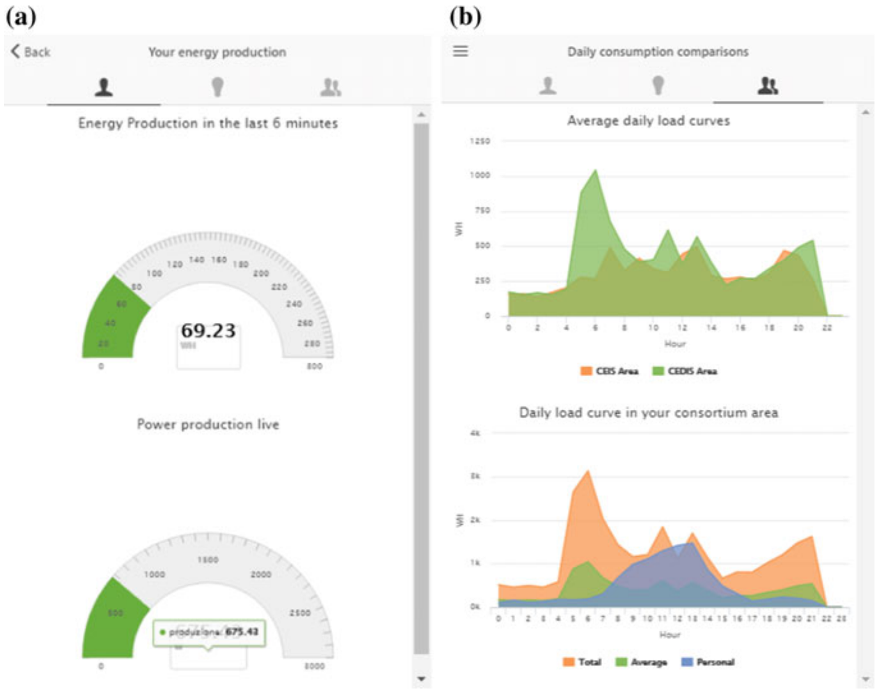
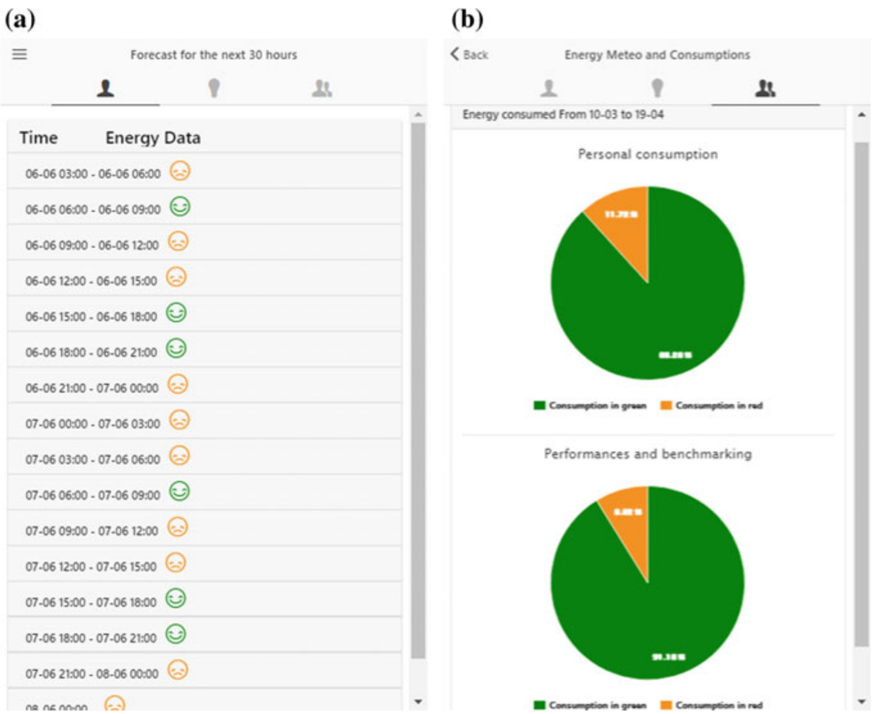


Fig. 9 **a** Quasi real-time meters for household PV production; **b** A household's hourly consumption profile over a chosen day compared to the averages and totals of the consortia

3.4.4 Action Suggestions

This module 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-behaviour gap when it comes to environmental issues. The goal is to facilitate the behaviour change process to bridge the attitude-behaviour gap, making energy conservation new habits integrated in everyday household practices.

Free Choice and Self-monitoring of Energy Conservation Actions Actions are not meant to prescribe what users should do but to present different ideas of what they can do (and how) in household practices. Users can 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 (Fig. 11). After all, users are experts of their own reality. They also have an overview of their current, pending, and completed actions.



Time	Energy Data
06-06 03:00 - 06-06 06:00	☹
06-06 06:00 - 06-06 09:00	☺
06-06 09:00 - 06-06 12:00	☹
06-06 12:00 - 06-06 15:00	☹
06-06 15:00 - 06-06 18:00	☺
06-06 18:00 - 06-06 21:00	☺
06-06 21:00 - 07-06 00:00	☹
07-06 00:00 - 07-06 03:00	☹
07-06 03:00 - 07-06 06:00	☹
07-06 06:00 - 07-06 09:00	☺
07-06 09:00 - 07-06 12:00	☹
07-06 12:00 - 07-06 15:00	☹
07-06 15:00 - 07-06 18:00	☺
07-06 18:00 - 07-06 21:00	☺
07-06 21:00 - 08-06 00:00	☹
08-06 00:00	☹

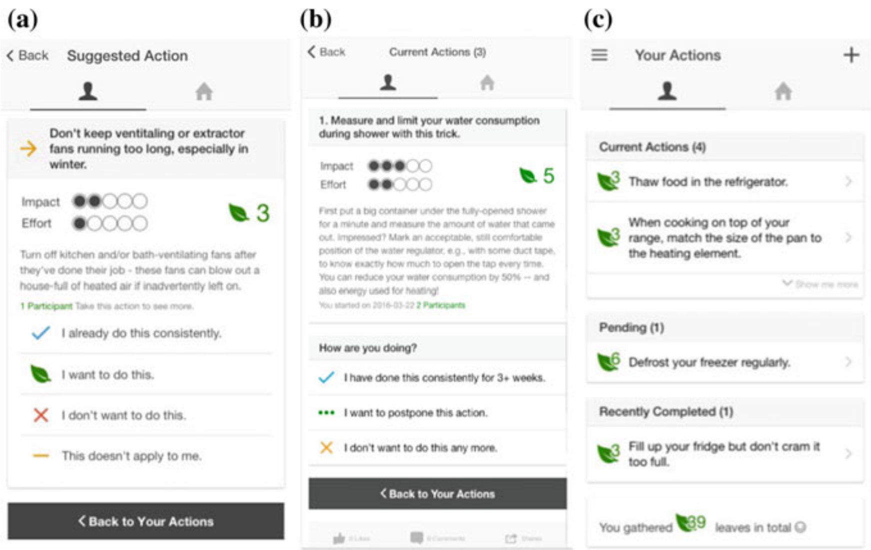
Fig. 10 **a** Dynamic ToU signals at 3 h intervals for the forthcoming 30 h; **b** A household's hourly consumption profile over a chosen day compared to the averages and totals of the consortia

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 [44].

Promoting Motivation and Engagement The design uses a number of elements to promote users' motivation and engagement. 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.

3.4.5 Community Engagement Approaches

Another main outcome of the design process, which also reflects the potential richness of designing for large-scale STS, rests at the level of community engagement. The



Don't keep ventitaling or extractor fans running too long, especially in winter.

Turn off kitchen and/or bath-ventilating fans after they've done their job - these fans can blow out a house-full of heated air if inadvertently left on.

1 Participant Take this action to see more.

1. Measure and limit your water consumption during shower with this trick.

First put a big container under the fully-opened shower for a minute and measure the amount of water that came out. Impressed? Mark an acceptable, still comfortable position of the water regulator, e.g., with some duct tape, to know exactly how much to open the tap every time. You can reduce your water consumption by 50% -- and also energy used for heating!

You started on 2016-03-22 2 Participants

Thaw food in the refrigerator.

When cooking on top of your range, match the size of the pan to the heating element.

Defrost your freezer regularly.

Fill up your fridge but don't cram it too full.

Fig. 11 **a** Action suggestion; **b** Action in progress; **c** User actions

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. (Note that the collaborative design process discussed in Sect. 3.3 also contributed to engagement.)

In Italy, a full fledged process named *Participatory Energy Budgeting* (PEB) [8, 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 [16, 51], 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 for the Italian sites, because the notion of collectively managing energy savings emerged during the first exploratory focus groups, and throughout the fist two project years. During the project, this notion has been refined and negotiated into a full-fledged policy frame, with the participation of recruited households and endorsement of the electric consortia involved. 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, 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.

4 Discussion and Conclusion

Collaboratively designed with the stakeholders from different pilot sites, the main outcomes of CIVIS addressed the goals and context of the project at different ST levels. They include the CIVIS platform that consisted of YouPower, an open source social smart grid application, and the corresponding hardware and software installation for energy data collection at participating households from the pilot sites. The deployment was accompanied by community engagement approaches to ensure that the stakeholders were well aware of the key issues and results the project was aiming at, and to develop positive attitude and encourage active participation.

At the Italian pilot sites, self-consumption of local renewable production was promoted at household and consortium levels, while at the Swedish pilot sites, knowledge sharing about housing cooperatives energy management practices was supported among cooperatives' board members and across different cooperatives. To bridge the attitude-behaviour gap of people's environmental values (and attitudes) and their actual behaviour in energy consumption [32, 48, 49], the platform also provided a set of features that could facilitate users' behaviour change process towards sustainable consumption that was implementable in their daily life along their existing practices. A number of lessons learned from the CIVIS design experience that could also be relevant to the design of other smart urban ecosystems beyond the particular case of CIVIS project are discussed below.

First, despite the many advantages already discussed previously, implementing a collaborative participatory design process is highly challenging in practice with an interdisciplinary team in an international setting. The design and development team, together with stakeholders involved, have various professional and cultural backgrounds, possibly speak diverse languages, hold disparate values and principles, work in different styles, not to mention the personal and organizational interests they may withhold. Misunderstandings on terminologies, methodologies and actions may go unnoticed and accumulate until it is very challenging or even critical to mediate the diverging opinions. The full awareness of such issues, frequent and efficient communications, positive and constructive attitude, plus open-mindedness are the keys to make the development process effective and enjoyable.

Second, the relevance, importance and challenge of setting up an engagement strategy or change process for the potential users of the new or modified system should not be underestimated. Engaging people in changing behaviour has much to do with understanding local contexts, people's heterogeneous attitudes, and local cultures. It also needs careful planning and execution. Develop a clear engagement strategy starting from the beginning of the project and let the professionals with the proper skills in this area to interact with the stakeholders.

Third, with respect to STS design and engagement strategies, users and other stakeholders should be provided with accurate and actionable information about how to achieve target behaviour. At the CIVIS pilot sites, for example, people expressed the desire and need to want to do more for a sustainable future. They liked the idea of receiving relevant and contextual suggestions and tips for action. Given the heterogeneity of potential stakeholder groups, understanding them and their interests and needs remains a crucial and challenging part of design that requires careful confrontation with stakeholders directly.

Fourth, consumers' intrinsic motivation for engagement needs to be fostered. Users need to be allowed to freely practice and adapt their course of action. This facilitates the sense of competence and autonomy that promotes and enhances motivation for behaviour change [44]. For example, people in the pilot sites are skeptical about how much monetary gains they can actually have by using less energy in households, but they are driven by intrinsic motives as well as altruistic and environmental values for energy saving. The social and community-oriented features as those designed in the CIVIS project articulate those values.

With the explosive growth of smart devices and smart everything, the coming wave of IoT and the hyperconnected world will soon bring the society into a smart environment where computing is pervasive [19, 50]. Will this smartness bring its inventors and the natural world into a sustainable future? This chapter advocates the potential fruitfulness of IoT and smart urban ecosystems that do not mainly rely on the technological side. Designers and engineers need to indispensably take a human-centred ST approach in developing a smart sustainable future.

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