YouPower – An Open Source Platform for Smart Grid User Engagement

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***Abstract*—The abstract goes here.**

I. INTRODUCTION

YouPower is an open source platform designed to explore the potential and challenges of supporting social participation, awareness and engagement of smart gird users for energy conservation and load shifting[1]. Combining smart sensing and web technologies among others, YouPower features a social smart grid application (developed 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 goal of the project is to make energy more visible, to promote environmental and social values, to inform users' know-how about sustainable consumption, and to facilitate users to take energy conservation and load shifting actions in their everyday life together with local communities [1]–[3].

Research topics related to merging the strength of Social Networks (SNs) with that of smart grid applications have caught much attention recent years following the success of several popular SN platforms [4]–[8]. Some conducted surveys to understand user needs for energy services combining SNs [9]. Some studied connecting smart meters (or smart homes) as SNs for energy management and sharing [10], [11]. Simulation models are developed to study demand side management taking into consideration SN aspects [12]–[14] and to demonstrate the feasibility of coordination in load balancing [15], [16]. There are also works that visualize smart meter and appliance-level consumption data, and provide comparative feedback among households[17]–[19]. Our research interest expands on the related work, and places an emphasis on smart grid user communities and collective actions.

[1]http://www.civisproject.eu, https://app.civisproject.eu.

The research is performed within the framework of the EU FP7 CIVIS project. It has test sites in Stockholm (Sweden) and Trento (Italy) with domestic energy consumers. In Sweden, those who buy a home officially own the right to inhabit the estate and must join a corresponding *housing cooperative* that owns and maintains its estates. The test site in Stockholm is composed of **sixteen(?)** housing cooperatives, each of which has annually elected board members who make energy related decisions on behalf of the cooperative members. In the case of Trento test site, two local *electricity consortia* produce and sell renewable (hydro and solar) energy to consortium members. Household rooftop PV panels are also common in this region. The consortia are highly interested in load management to optimize the use of local renewables and reduce dependency on the national supply. These two types of communities are at the center of YouPower design. The rest of this paper presents the design process of YouPower, gives an overview of the platform, and discusses in more detail its design concept.

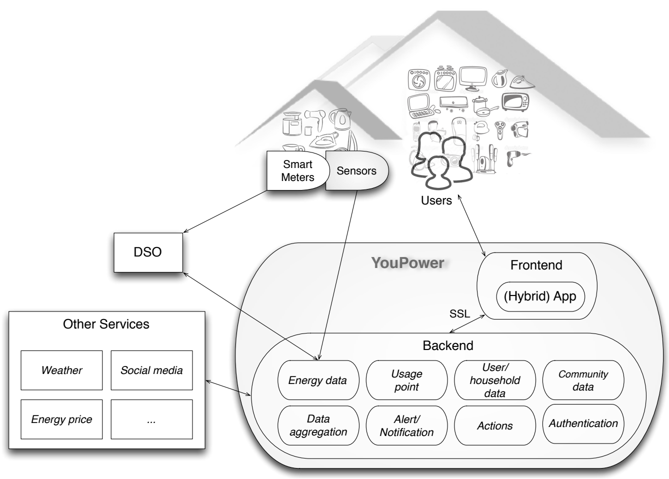
II. DESIGN PROCESS

The design process of YouPower is theory-driven, user-centered and iterative. We first researched literature on intervention strategies and social smart grid applications directed at promoting environmental behavior change. This provided an initial set of design ideas that had been iteratively refined and improved throughout the design process. Applying a user-centered design process can lead to more acceptable, satisfying and effective designs [20]. This increases the potential of the intervention and may help increase user engagement with respect to the sense of relatedness to the application [21]–[24]. We organized brainstorming sessions and design workshops with both project partners and users (focus groups) from test sites. A set of features was first prototyped in simple handcrafted mock-ups used as a basis for discussion, and then underwent iterative rapid prototyping which produced wireframes as better visual guides that can be more effectively communicated to users. These wireframe prototypes and later the software prototypes, had been evaluated in iteration by a study with participants during an environmental event in

Helsinki [25], by focus groups at test sites, and by groups of students and colleagues. Literature research with regard to environmental and social psychology as well as energy intervention had been performed in more depth along with the user studies carried out. Based on those and the design experiences of the project team, a set of design guidelines had been developed. After each study, the design was refined, improved and gradually implemented, resulting in the current version of the application.

III. YOUPOWER OVERVIEW

Figure 1 gives an overview of the CIVIS YouPower platform. It is 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.



DSO (Distribution System Operators), SSL (Secure Sockets Layer)

Fig. 1. YouPower Platform Overview

(I) *Energy sensor level services:* 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 local circumstances. For example, *Smappee* for 40 households in Stockholm, and *CurrentCost* for 79 households in Trento[2]. Trento also installed Amperometric clamps for PV prodcution measures. Household-level energy data is measured by smart meters and provided by local DSOs (Distribution System Operators).

(II) *Energy data level and social level services:* These services are provided by the YouPower app and its back-end. The design of the YouPower app (and its back-end) consists of three self-contained composable parts: (A) *House Cooperatives* (contextualized and deployed to the Stockholm test site); (B) *Demand-Side Management* (contextualized and deployed to the Trento test site); and (C) *Action Suggestions* (contextualized and deployed to both test sites). They are discussed in Section IV.

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IV. DESIGN CONCEPT

Given time and resource constraints, the YouPower app can not be developed all-in-one cross-platform (for phones, tablets and computers). We chose to design the front-end as a hybrid mobile phone app, i.e. its UI design has layouts that suit phone screens, since mobile apps can be more easily transformed to web browser versions, while the reverse is more difficult. The back-end of the YouPower platform will remain mostly the same independent of the front-end alternatives.

A. Housing Cooperatives

This part of the YouPower app is designed for the Stockholm test site that has sixteen housing cooperatives (*Bostadsrättsförening* or *Brf* in Swedish). Similar housing ownership and management models exist in a number of EU and non-EU countries, which allows potential wider application of the design. In Sweden, a housing cooperative annually elects a board which manages cooperative properties. The board 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 part of the app 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.

1) Linking energy data to energy reduction actions: The design links energy data with energy reduction actions taken (Figure 2), both at cooperative levels, making the impact of energy actions visible to users. The energy use is divided into heating & hot water (from district heating), 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

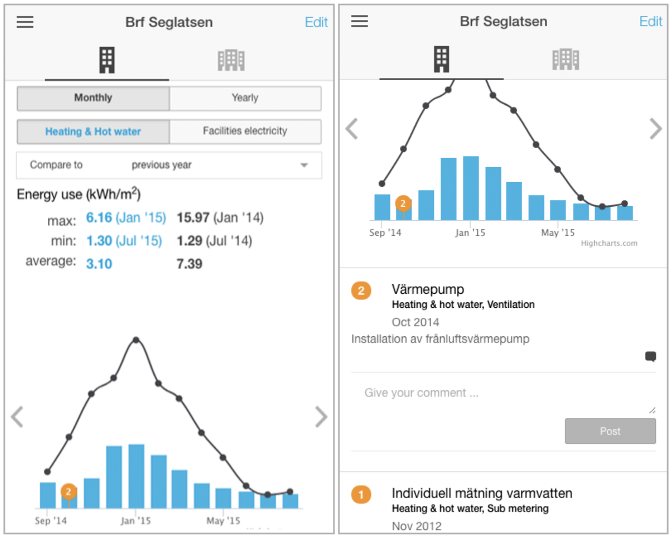

Fig. 2. Heasting & hot water use graph. Blue bars show the current year's use per month; the black line shows that of previous year. Energy reduction actions taken are mapped to the time of action and listed below.

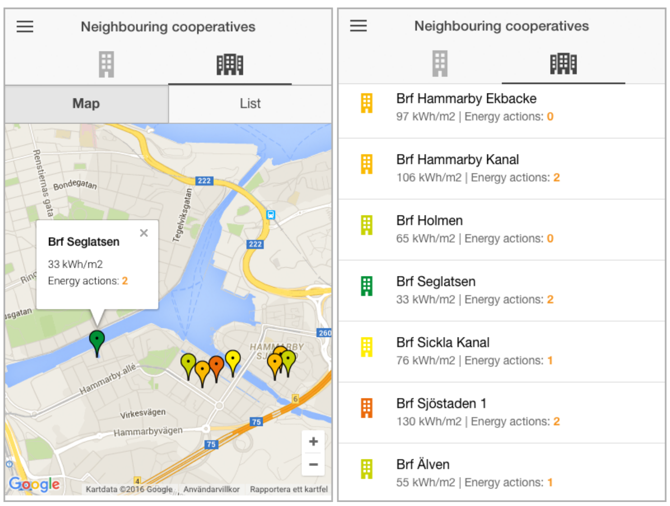

Fig. 3. Map and list view of participating housing cooperatives. The energy performance of cooperatives is indicated by colour and in numbers.

in the future by learning actions taken by other cooperatives and what the effects were in relation to costs.

2) Comparing housing cooperatives: The cooperatives that are registered for the app are displayed in a map or list view (Figure 3). 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[3]. 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

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

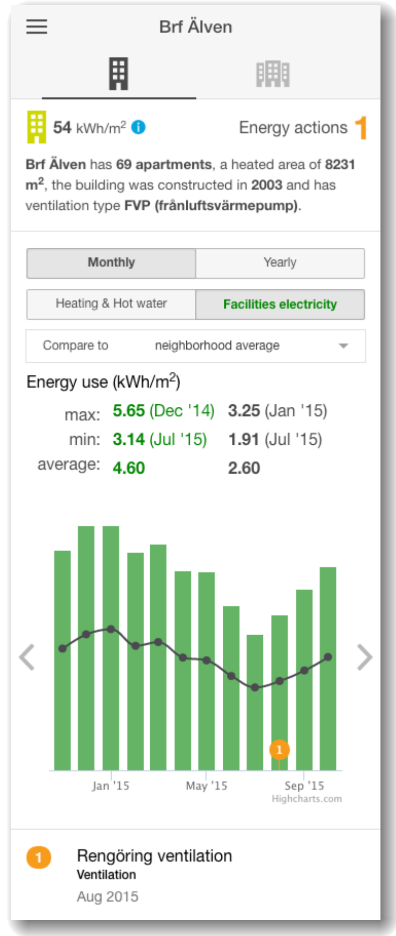

Fig. 4. Facilities electricity use graph. Information about housing cooperatives and actions is displayed at the top. Green bars show the housing cooperative's current year's use per month; the black line shows the average use of all housing cooperatives

between cooperatives in order to understand the difference in their energy performance. Thus, the design also includes information about cooperatives (Figure 4) 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.

3) 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 the cooperatives 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

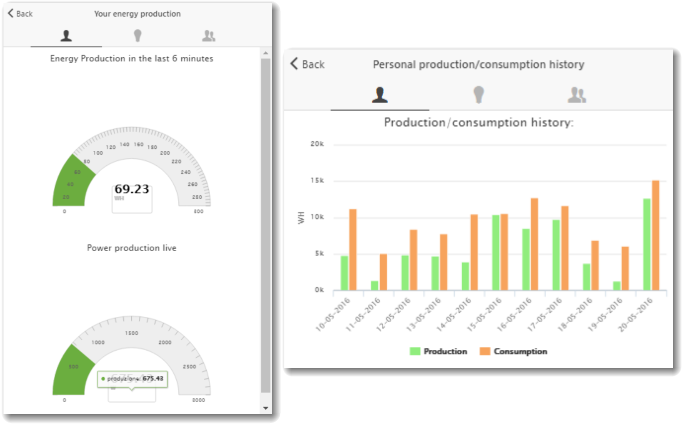

Fig. 5. (a) Quasi real-time meters for household PV production; (b) Household consumption vs. production for a chosen period

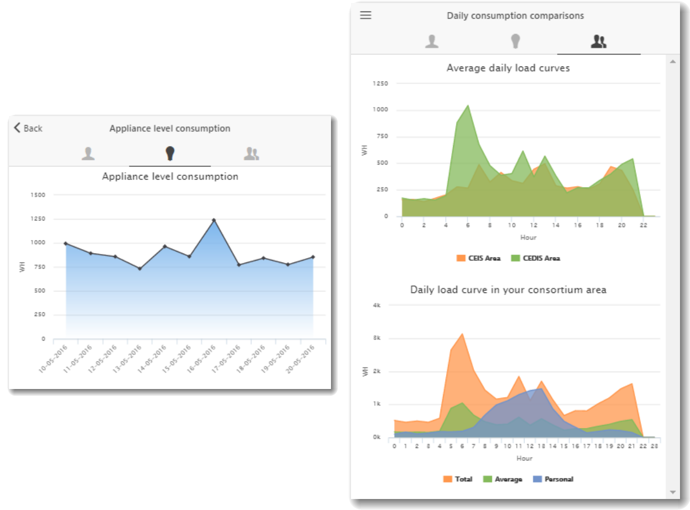

Fig. 6. (a) Daily electricity consumption at the appliance level for a chosen period; (b) A household's hourly consumption profile over a chosen day compared to the averages and totals of the consortia

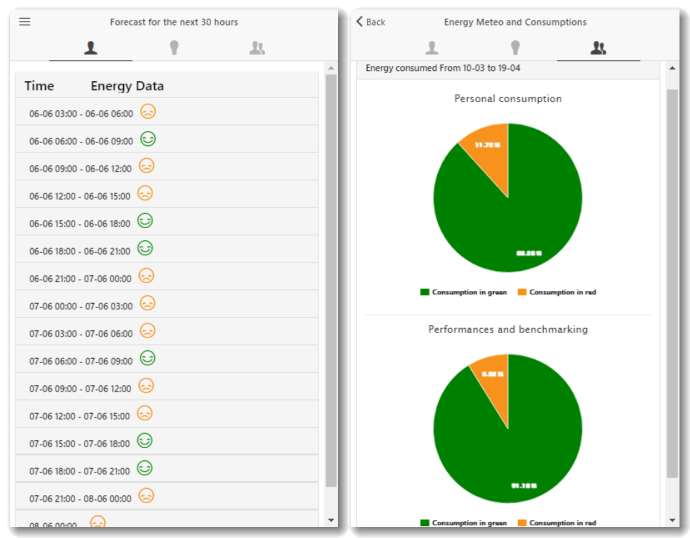

Fig. 7. (a) Dynacmie ToU signals at 3-hour intervals for the forthcoming 30 hours; (b) A household's hourly consumption profile over a chosen day compared to the averages and totals of the consortia

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

B. Demand-Side Management

This part of the YouPower app is designed for the Trento test 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.

1) 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[4]. 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 5). 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 6 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 6 b).

2) 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 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 7 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

[4]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.

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 7 b). The same information is also provided at the consortia level to enable peer comparison.

C. Action Suggestions

This part of YouPower 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.

1) 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 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 8). 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 [26].

2) 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 (Figure 11). Users can also login with Facebook, like, comment, share actions (Figure 9), give feedback (Figure 10) and invite friends. Users are awarded with points (displayed as Green Leaves) once they complete an action, or provide feedback or comments.

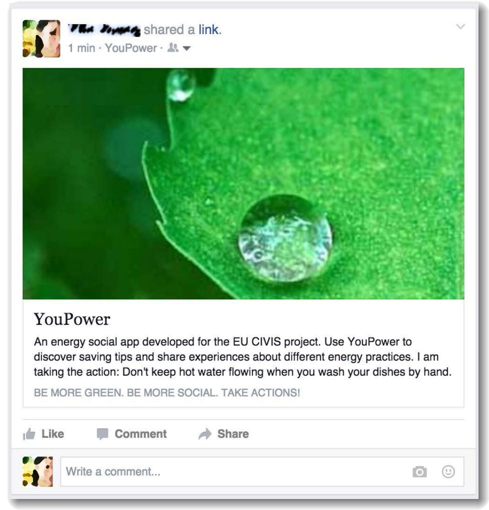

Fig. 9. Facebook share of an action

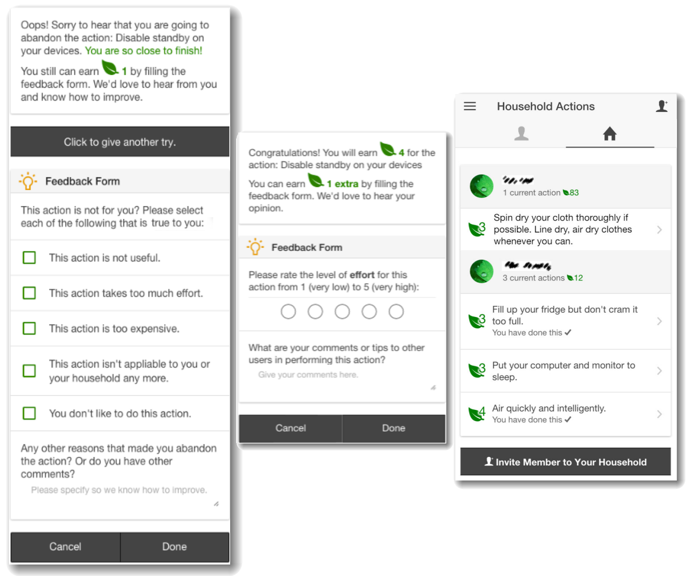

Fig. 10. (a) Feedback form – action abandoned; (b) Feedback form – action completed; (c) Household actions

V. Preliminary Results and Conclusions

Deployment, preliminary results and conclusions

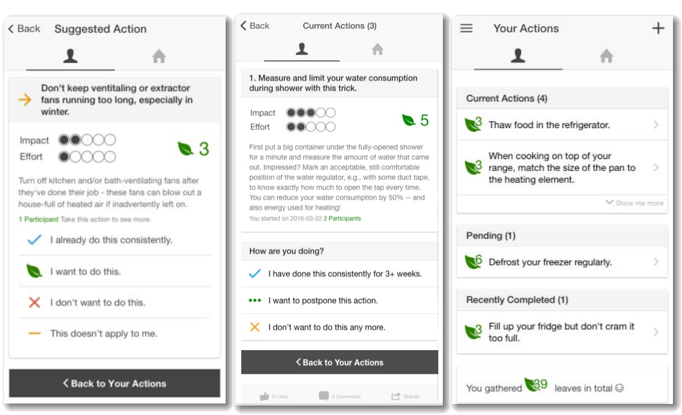

Fig. 8. (a) Action suggestion; (b) Action in progress; (c) User actions

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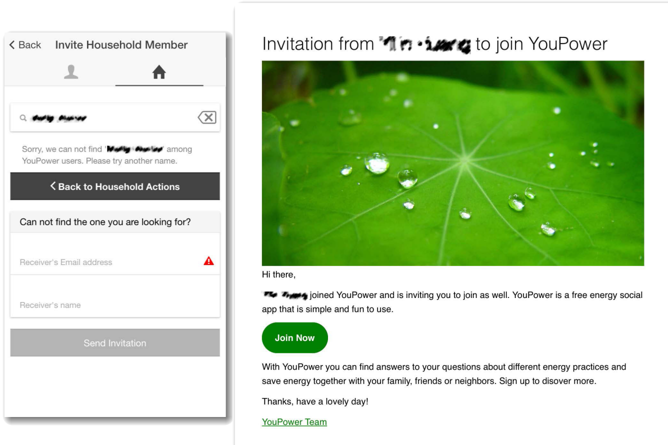

Fig. 11. (a) Invite household member; (b) Email invitation

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