Pilot study of ‘Our Energy’, an app designed to facilitate self-consumption of community solar photovoltaic systems

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Abstract. Distributed energy from photovoltaic (PV) systems are an important part of the 2000-Watt-Society and Swiss Energy Strategy 2050 targets. However, as more PV is added to the grid, it becomes more important to intelligently use on-site electricity generation. There is also a recent focus on communities as they have better load aggregation potential from multiple tenants to increase overall self-consumption. Additional potentials exists when introducing PV systems in communities from social comparisons or competitions. The first critical step is to have an effective communication platform with real-time electricity production and consumption to show resource availability and usage at the individual and community level. We have therefore developed ‘Our Energy’, a custom mobile application (app) to ‘experience’ what it would be like to have direct access to electricity from solar PV in a community setting. It is designed to facilitate demand side response for users to compare their household energy consumption and associated self-consumption from. This study uses a community based social marketing approach to support the app design, development, evaluation and deployment for a specific user group from a small Swiss city. This paper includes the results from a pilot study where the beta version of the app was tested during two weeks in March 2019 with 32 participants. The feedback helped improve the demand side response strategy along with the real-time statistics for participants to monitor self-consumption and electricity savings potential from Solar PV.

1. Introduction
There is a shift towards an electric society in Switzerland which includes a significant increase in electricity supplied from photovoltaic (PV) systems [1]. However as more electricity is produced from solar PV, it becomes even more critical to intelligently use electricity when and where it is produced to avoid curtailed (wasted) electricity production or grid instabilities [2]. The concept of ‘self-consumption’ from decentralized PV systems has been introduced to help address these concerns. This becomes increasingly attractive especially in combination with electricity demands from electric vehicles, and electric heat pumps for heating and hot water in the residential sector [3].

To now, case studies demonstrate that self-consumption for individual residential rooftop PV systems are as low as 15% and up to 56% [4] depending on total installed PV capacity, geographic location and consumption profiles. To increase these potentials in Switzerland, new regulations make it easier for multi-tenant complexes to form self-consumption communities [5]. Communities inherently have a higher baseline for self-consumption from complementary load profiles [6]; however additional potentials exists when introducing energy strategies in a community setting, particularly around social comparisons, competitions, and goal setting [7]. One example, demonstrates the positive effects of the community context in a study that compares energy efficiency strategies between a competitive, collaborative and control group using smart meter data communicated through a mobile app [8].
competitive and collaborative groups achieved 8.5% and 7.6% energy savings respectively and compared to the baseline, the control group had an increase of 1.3% energy consumption for the same duration. That study shows the short term benefits of the community setting, even though the benefits had almost completely diminished one year after the intervention [8].

The primary difference between community energy efficiency strategies and self-consumption of electricity from community PV systems is the direct connection to a tangible resource. Furthermore, a review of community energy initiatives emphasizes the importance of communities to help integrate distributed energy resources. This is not only from a technical point of view, but also to engage people from their local communities [9]. As the emphasis on community energy strategies increases, more clear definitions are also available. The review by [10] creates a clear distinction between place-based and non-place-based communities with either single or multi-purpose objectives. The case study city for the study described in this paper is considered as a single objective, non-place-based community.

1.1. Objectives
The objective of this paper is to evaluate if the community context positively influences the desired behavior of load-shifting to maximize self-consumption of a shared solar PV system. This is a complex task which requires significant system and metering infrastructure which is not available for the participants of the case study area. Therefore, to study this objective we have developed 'Our Energy' a mobile application (app), where people can ‘experience’ what it is like to have direct access to electricity generated from a share of a community Solar-PV system.

2. Methodology
This study follows the community based social marketing approach [11] widely used for community level sustainability initiatives. This involves an iterative, five step process, illustrated Figure 1. This paper focuses on steps 1-4 where the outcomes of the pilot study are described in the results and discussion and used to improve the full implementation (step 5).

![Figure 1: Five step iterative approach to community based social marketing [11]](image)

2.1. Select actionable behaviors
The concept of self-consumption is practical to calculate on-site electricity usage, however it is a difficult message to convey to end-users. The user interface of the app therefore incorporates a demand side response (DSR) strategy for load-shifting in response to available solar electricity. The app also includes larger appliances such as electric vehicles and electric heat pumps for heating, cooling and domestic hot water, which have more potential to increase self-consumption.

2.2. Identify benefits and barriers
Many of the citizens in the case study city do not have direct access to solar electricity through a rooftop or community PV system. Therefore the app was designed as a simulation game [12] to reach participants who do not have access to a PV system or smart meter data. Users have the opportunity to simulate their hourly and daily self-consumption potential as if they were directly connected to 5kWp of a shared PV system. There are however drawbacks to this approach, because we rely on daily user participation and self-reported data. There are also challenges to maintain interest over time because participants do not receive actual benefits of load-shifting with solar PV.
2.3. Develop strategies

2.3.1. Experimental study
The study was conducted as a two-week challenge to maximize the use of on-site electricity generated from a simulated PV system. To test the effect of the community, two versions of the app were developed for the pilot study. Half of the participants were randomly assigned to a community system and the other half to an individual system. Users participated on a daily basis by selecting the time and duration of the electrical appliances used in their households. During the pilot study, participants received a daily score for the units of electricity from three pre-defined tariffs (peak, off-peak, and solar). Community participants could see how others perform through a ranking scheme, while individuals could only see their own scores. The individual and community versions of the app also displayed slightly different text in the introduction slides and had distinguishing labels for the PV system.

2.3.2. Design: mobile cross-platform application
The beta version of the app (Figure 2) had three main panels to show the instantaneous household power demand (center) based on the user-input data. Power generated by the simulated PV system was shown on the left panel and power from the grid displayed on the right panel. The app also has a “play” button on the center panel to direct users to the DSR interface to select appliances and specify the time and duration of use. The point’s panel included a daily summary of electricity consumed per tariff in a simplified approach to convey if the time-of-use is good, bad or neutral. The solar-tariff is represented by a smiley-face, the peak-tariff by a frowny-face and the low-tariff by a neutral-face.

2.3.3. Development: mobile cross-platform application
The mobile cross-platform app was developed using Ionic[13]. It includes a remote server for uninterrupted real-time calculations of the PV system power using real-time weather data from the case study city via the Swiss Open Government weather data API [14]. A light-weight framework was developed to display the real-time electricity production from complex surfaces in the application. The framework uses the cumulative sky approach from Perez all weather model [15] and modeled in Ladybug, the plugin for Rhino-Grasshopper [16]. The application also complies with the European General Data Protection Regulation (GDPR).

2.4. Pilot study
We recruited 27 student participants and 5 members from the case study city to test the beta version of the app and to evaluate the overall study during a two-week pilot study in March 2019.

2.4.1. Survey design and deployment
The participants provided detailed feedback through an online, self-administered pre and post participation survey. The objective questions were multiple choice and with pre-defined ranges for each answer, while the subjective questions were given on a 7-point Likert scale. The survey was written to gather general demographic information about the participants and to test their “energy literacy” on technical topics presented in the app including community PV systems and load-shifting. Another set of subjective questions focused on general environmental awareness and interest in renewable energy technologies. A last set of questions focused on how strongly participants rate the sense of community within their neighborhood and if they have (and use) shared facilities. The post participation survey was designed primarily to evaluate the features in the app and if they supported the study objectives.

2.4.2. Quantifying participation and self-consumption
The user data for the two-week pilot study was post-processed to count the number of days each participant entered appliance data. The hourly self-consumption values were also calculated using the method by [17] where, the minimum of the energy demand \( L(t) \) and the PV power generation \( P(t) \) are first calculated at that time step \( t \), by \( M(t) = \min\{L(t), P(t)\} \).
3. Results

3.1. Data analysis
During the two-week pilot study, we collected detailed user data from 32 participants. In total, 17 participants received the community version and 15 participants received the individual version of the app. The community group had higher self-consumption values, particularly during the first 4 days (Figure 3), with an overall average daily self-consumption of 12.3 kWh (14.3 kWh std.) compared to 9.85 kWh (16.57 kWh std.) of the individual participants. The overall average participation of the community participants was 7.8 days (3.8 days std.) while the individual were 6.8 days (4.8 days std.).

![Figure 3: Two-week average hourly self-consumption values for community and individual participants](image)

3.2. Participant feedback and evaluation
The results of the pre participation survey shows that only one participant out of 32 has direct access to solar PV which was part of their apartment complex. Next, 72% of the ‘energy literacy’ questions were
answered correctly among all participants, indicating a relatively high understanding of the topics presented in the app. Of the environmental awareness questions, the importance to not waste resources was rated the highest (61% reported very important or important) when compared to the importance to conserve electricity at home (35% reported very important or important) and importance that the household electricity is supplied by renewable energy (28% reported very important or important).

There is generally a low sense of community in their living environments even though 82% have shared facilities which are regularly used (only 15% report they never or rarely use them). The participants reported more likely to invest in a community PV system (71% very likely to somewhat likely), than in their own rooftop PV system (45% very likely to somewhat likely).

Regarding usability, all users entered their actual energy consumption in the app (100%), but over 61% did not set it in an ideal way to maximize the solar tariff. Overall, the point scheme had a low to neutral rating for being comprehensible, informative, motivating or useful, although 77% checked their points at least once every 2 days during the two-week study. Nearly 86% reported that the list of the appliances was not representative of their own, since they could not enter an appliance multiple times per day. The two versions of the app (community and individual) were also not completely clear to the user groups, where 22% of the participants in the pilot study did not know if they had the community or individual version of the app. However only 11% did not know whether or not they had a ranking feature.

Lastly, the highest learning effect reported was for the time of use of electricity where nearly 70% agree or slightly agree to have learned something about this topic (19% neutral). Second, over 65% reported to agree or slightly agree to have learned something new about their own electricity consumption (27% neutral). The learning effect of load-shifting was not as high, where only 53% agreed or slightly agreed to have learned something new, (27% neutral and 20% disagreed).

3.3. Improvements for the full implementation

The feedback from the pilot study helped us improve the app and the study for the full implementation, which took place from June 23rd -July 7th 2019. The updated version of the app (Figure 4) now includes an improved DSR user interface (appliance diary), where all appliances can be added multiple times per day. The appliances are also categorized as shiftable, habit and constant to help improve this learning effect. The updated app also includes a simulation of real-time power production for hourly, daily and weekly statistics of self-consumption and savings from PV (the three middle panels from Figure 4), instead of the rudimentary point scheme. The three home panels remain the same, but all other features are updated, including the introduction slides which make it more clear that this is a simulation of a PV system, and the objective is to ‘experience what it is like to have electricity from solar PV’ and observe the potential self-consumption and savings from PV and compare them to others in the community through the ranking feature.

![Figure 4: App modifications for the full scale implementation](image-url)
4. Conclusions
The pilot study included a qualitative evaluation from 32 recruited participants using a pre and post participation survey. The feedback about the usability and objective of the app helped identify specific issues and fundamental flaws in the study design. The most explicit message of the evaluation was that the goal to increase self-consumption of electricity from PV, was not clear even though it was written in the objectives. The rudimentary point scheme for electricity consumed in each tariff was not sufficient to achieve this objective. Many users also did not know that the electricity generated from the Solar PV system was a simulation.

The frequency of participation and average daily self-consumption values indicate a slight increased participation and self-consumption values from participants using the community version of the app. However, the large distribution of results and do not indicate a strong generalizable trend. Furthermore, the qualitative feedback indicates that participants did not fully understand the context of community without a physical point of connection. In the full study we only keep the community version of the app and focus on the learning effect of load-shifting for all participants. All participants are given the same tasks to 1) develop a baseline energy consumption profile during the first week and 2) improve their self-consumption compared to the first week, during the second week. Furthermore, beyond the full study, the concept of community should be enhanced or even tested with place-based communities where participants have a pre-established connection.

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