# Peer-To-Peer Energy Trading: Representing the Dynamics of Energy Consumption, Production and Exchange


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November 2019


## Abstract

Nowadays we are witnessing a complete energy transition towards more sustainable sources. However, this process requires substantial adjustments of the current energy systems. One technology, that represents a potential support in this process is blockchain. One of its promising implementations could be peer-to-peer (P2P) energy trading, that has been addressed by many companies and projects globally. Nonetheless, there has been insufficient research performed on the aspect of adoption of such systems with relation to the potential users. This work builds on a study performed with PowerShare (PSv1) platform that was developed in order to answer the question of adoption drivers and understanding of P2P energy trading systems. In this paper further aspects were addressed such as trust between peers in a large community, giving up control over energy data to the DSO and encouraging behavioral change through non-monetary incentives. A P2P energy trading platform (PSv2) comprising of an application and a website was designed and low-fi prototypes were presented to five study participants. Based on feedback received we answered the relevant research questions, created design guidelines for similar platforms and drafted a potential business model together with suggestions for future research.



**Keywords:** behavior change; collective efficacy; P2P energy trading; Sustainable HCI


## Introduction

In the recent years the matter of more efficient energy use and increased amount of renewables in the global energy mix is becoming of higher and higher importance. One of the projects that emerged from this need is the SMILE (Smart Islands Energy System) project, established under Horizon 2020 research programme [1] aimed at introducing new smart grid technologies in three different European islands. Presented paper intends to test a possible business model for one of the solutions tested in the island of Madeira (Portugal) in the scope of SMILE. Presented work is based on a previous project performed in scope of SMILE at Madeira Interactive Technologies Institute – a P2P energy trading platform called PowerShare. We build on results obtained from the first deployment of PowerShare [2], which was meant to assess users' acceptance of energy trading in Madeira at a neighborhood scale.

The main goal of this thesis is testing whether collective efficacy could be a potential driver to foster engagement of large communities in P2P energy trading. Available literature on blockchain-based platforms does not address the barriers towards their adoption. Under this work a gamified mobile application together with a website were designed and tested. The Low-Fi prototypes were evaluated using both quantitative and qualitative approach. Results obtained helped to draw meaningful conclusions regarding the characteristics that engaging, large-scale peer-to-peer energy trading systems should have.

## Related work

This thesis' scope clusters technology, psychology, design and other areas. Due to the topic complexity, there is not a single academic work focusing on this particular matter thus an extensive and multidisciplinary literature review was done in order to get a bigger picture.

### *Blockchain technology*

Blockchain is a Distributed Ledger Technology (DLT) and should be considered as a digital ledger, a distributed database that allows for secure, immutable and anonymous transactions. In a blockchain network transaction data are shared, time-stamped and cryptographically secured from tampering, forming blocks that are then linked together into a chronological chain. Interest in blockchain is spreading across several industries, including the energy sector, which is one of the areas that could be the most revolutionized by the potential of such technology. Blockchain technology appears to be promising for addressing some issues that current energy systems face, such as transitioning towards Distributed Generation (DG) and introducing microgrids (small networks operating anonymously). Opportunities emerging from implementing blockchain in the field of energy are being explored by many start-ups.

**Brooklyn Microgrid** (BM) [3] by LO3 is a project based on decentralized generation in communities where participants can trade energy between each other using the already existing grid. At the core of BM there is an online platform, which serves as a marketplace for both parties and allows them to set their trading criteria by means of a mobile application. The application includes a ranking, where the individual score and achievements of users are displayed and shared with the community. Another example in the energy sector is **Grid+**. Their solution comprises of software enabling cryptocurrency payments and hardware (the Smart Agent) that trades energy on behalf of the user. Automation is at the heart of Grid+ value proposition, everything is managed by a simple AI software predicting energy use. It is purely based on "install-and-forget" concept [4]. Another start-up focused on creating decentralized energy trading communities using blockchain is **Hive Power** [5]. These communities, called Hives, are regulated through smart contracts and composed of "Workers" and a "Queen". The workers are nothing but smart meters representing prosumers (households, institutions). The Queen, on the other hand, gathers and aggregates all this data and communicates it to the Hive. The analyzed business cases provided a general overview on solutions implemented in blockchain-based platforms in the energy field.

### *HCI for motivating pro-environmental behavior*

Understanding people's perception of energy for promoting pro-environmental behaviors is a fundamental topic of interest for Human-Computer Interact (HCI) research, where a lot of work has been done, particularly in regards to eco-feedback technologies (EF) - "i.e. the technology providing feedback on behaviors with a goal of reducing environmental impact" [2]. EF leverages on the motivations that drive people to modify their actions. There are several theoretical models of pro-environmental behavior presented in the literature, among them, the Rational Choice Model and the Norm Activation Model - which are the most commonly used [6] - were considered for designing the final solution proposed here. The Rational Choice Model is considered as “rational-economic” as it is based on an assumption that people get involved in actions that are economically rewarding. The Norm Activation Model speculates that personal drivers such as social recognition or acting according to one’s beliefs can be a motivation to change behavior. An example related to sustainability is making choices that will positively affect future generations such as opting for green energy - a pro-social, altruistic behavior. According with Froehlich et. al [6], some relevant aspects to consider while designing an EF system are: information presentation, goal setting, rewards/penalties and social comparison.

***PowerShare v1***

This work builds on results from previous version of PowerShare (PSv1), which was created in the scope of the H2020 SMILE (The Smart Islands Energy System) project [1]. SMILE aims at testing different smart grid technologies based on the characteristics of the three different islands. Among them, Madeira is a very challenging use case because its electrical grid is completely isolated from the mainland. Local prosumers - i.e. someone that both consumes and produces energy – are not allowed to inject excess production into the grid due to safety reasons. Since this island receives yearly a lot of sunlight, one of the solutions tested includes upgrading selected domestic photovoltaic installations with Battery Energy Storage Systems (BESS) in order to maximize self-consumption. PowerShare draws on a scenario where several small installations are equipped with a BESS and P2P energy trading is possible. The deployment of PSv1 took place in September 2018, involving 9 families of prosumers living in the same neighborhood in Funchal (Madeira). At the core of PSv1 there was a mobile application which, using real production and consumption data collected through smart meters, simulated energy trading between members of the community. Results after the one-month deployment provided the research team with some valuable findings in terms of users’ engagement. Specifically, as reported in [7], PSv1 deployment has helped to shed light on aspects related to motivations for engaging in energy trading, barriers towards the adoption of the system and provided several interesting design insights. Few strategies that could be implemented to design more engaging P2P energy trading platforms, as well as issues that still need to be investigated, were identified and are listed below:

**Automation and technology complexity** - High degree of automation is a popular practice to reduce the perceived complexity of the system. It was concluded that the majority of existing projects rely on the “install and forget” principle, that is to say, they do not require a lot of attention from the user. Nonetheless, the deployment of PSv1 showed that participants were curious about different transaction parameters and wanted to explore them themselves, suggesting that full automation might be less favorable in users’ perception. For this reason, an option of setting criteria manually should be available.

**Data presentation and learning support** - Studies show that users prefer having detailed energy feedback presented in a visual form with simplified wording to increase ease of understanding. At the same time, participants wanted to learn more about their energy habits and explore their options freely, therefore providing more information could keep them engaged.

**Social pressure** - In PSv1 the ranking of best performing members was the most popular feature. Study participants admitted that they enjoyed comparing their score to others and they were willing to do more to get better results.

**Norm Activation Model vs Rational Choice Model** - Leveraging the Rational Choice Model when designing a P2P energy trading system might not turn out effective for fostering users' engagement. Findings show that some participants were willing to get involved only to help their community. This proves that Norm Activation Model could be more applicable for P2P energy trading.

These aspects were sufficient to provide an overview on what has been done so far in the area of HCI for P2P energy trading. However, there are still some research gaps that need to be addressed such as the scalability problem (would users still trust each other in a large community?), DSO involvement (is it a trusted entity and should it be included in such a platform?), inclusive technology (how to involve all family members?).

### *Hypotheses and Research Questions*

Based on the above-mentioned findings and with the goal of addressing the existing research gaps, some hypotheses to be tested in PSv2 were proposed:

**H1:** Leveraging collective efficacy increases sense of community among anonymous members in large communities and motivates to engage in P2P energy trading.

**H2:** Norm Activation Model can be used to engage people in P2P energy trading and undertaking selfless actions for the greater good.

**H3:** Gamification of P2P energy trading platforms can make them more inclusive and attractive for different audiences.

In order to test our main hypotheses and explore further those aspects that are still poorly understood (e.g. trust, privacy, technology embedded complexity), we elaborated the following research questions:

**RQ1.** Is collective efficacy a driver to foster a sense of community between unknown peers?

**RQ2.** Would a reward system based solely on encouraging environmental protection and collective effort be motivating enough to engage in P2P energy trading?

**RQ3.** Is gamification a promising design strategy for fostering engagement in peer-to-peer energy trading?

**RQ4.** Do members of a community trust each other despite not knowing who is contributing to a challenge and who's not?

**RQ5.** Are people concerned about sharing their energy data with other members of the network or the energy provider? Would they be willing to trade anonymously?

**RQ6.** Is the full understanding of the technology necessary for its adoption? Are there any concerns regarding blockchain and cryptocurrencies?

## Proposed solution

The platform was separated into two channels - the application and the website - in order to make an easy distinction between fostering engagement through collective actions and supporting learning.

### *Application*

When registering a new account, the user needs to choose whether he/she is a consumer or prosumer. In the case of the latter, some characteristics of their generation asset need to be provided, e.g. battery capacity. The last registration step is adding a Bitcoin wallet number or setting up a new one.

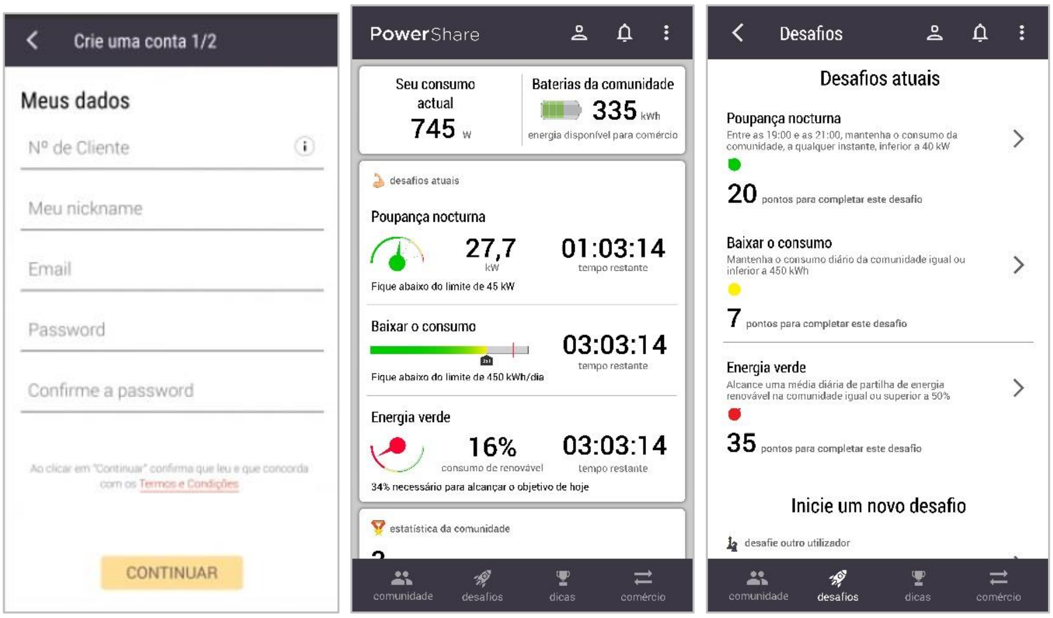


Figure 1*: Examples of application screens (registration, home screen, challenges)*

After successful account creation, a home screen opens. From here, the user can access other features of the app (bottom bar), his/her profile and see notifications (top bar). The home screen comprises of different cards, which, by default, are: real-time data, ongoing challenges, community statistics. The goal of displaying precisely these cards in the home screen was to present the user with the most actionable and up-to-date information that they could act upon.

The "Community" feature provides an overview of joint efforts of all users. It comprises of four different categories: community score (level and points obtained), energy breakdown (detailed energy feedback with historical data), $CO_2$ savings and energy exchange (statistics on transactions). User's individual statistics are not available in the application, as it is designed in a way to promote collective efforts instead of individual ones. The "Challenges" feature aims at keeping the participants active and interested in energy trading by gamifying the process and providing them with tasks. The main screen of the "challenges" feature presents a more detailed overview of ongoing tasks and is accessible through the bottom navigation bar. Historical data is available together with past achievements that are provided as an additional impulse to break a record. It is essential to remember that even though it is an individual person using this application, the statistics and challenges displayed are for the entire community.

Even though the user of PowerShare is automatically contributing to the collective goals from the moment of registration, he/she also has the possibility to commit in a more personal way. In the main screen of the "challenges" users are given the opportunity to "open a new challenge" either by challenging another user or giving up some control over their energy data or, in the case of a prosumer, battery. The challenge of sharing energy data with the DSO means allowing the company to analyze user's consumption (and production) patterns. The "battery challenge" would allow the DSO to take control over the battery storage system of the user and charge or discharge it when needed to support grid stability. The aim of this option is to test whether participants would be willing to give up control over their battery for the greater good – balancing the grid, ensuring its stability and providing renewable energy for the entire community, not just themselves. The individual challenges are not compulsory, they serve as a "bonus' for people that enjoy competition or want to contribute even more, but the community challenges open automatically (there is no option to press a button and start a challenge) and everyone is involved – whether with positive or negative contribution. In order to respect users' privacy only nicknames (chosen by them during registration) are shared within the community.

Completing a challenge is rewarded with points that add up until a new level is achieved. All users collect points and everyone gets rewarded regardless of their participation. The reward for reaching a new level is information on how to improve one's energy behaviors. This is a separate feature in the application called "Energy tips". Here users can learn more about how to conserve energy in different aspects of their life. This feature was designed to support learning and curiosity regarding energy savings. Such functionality is often mentioned in studies regarding eco-feedback ([8], [9], [10]) as a desirable and enjoyable one for the users.

Both prosumer and consumer can only enable or disable energy trading that takes place automatically. Prosumers that own a battery also have the opportunity to set the amount (in kWh) of the battery capacity they want to save for self-consumption only. Tariff information is provided together with the user's transaction history in the "Trade" feature. A complete summary of all transactions performed by the user can be accessed on the website and downloaded as a PDF file.

***Website***

The web platform was created as a complementary part for the application. It provides detailed information on energy use of both user and community but also serves for promotional purposes. Once the user is signed in, he/she has access both to his/her personal energy data, that is not provided in the application, and community data with higher degree of detail. All information is presented in a visual form since findings show that such presentation modality is effective for supporting understanding. Visualizations include production and consumption data (also real-time) with different degrees of temporal granularity (days, weeks and months) together with accurate energy breakdown, $CO_2$ savings, number of transactions and battery state of charge over time. Apart from overview, the website provides a comparison option between different periods of time. This feature was designed based on the theory that self-comparison is an effective tool for behavioral change.

## Methodology

The study consisted of a demonstration organized at the Madeira Interactive Technology. We first introduced PowerShare to participants, including a short explanation on blockchain technology. The introduction was followed by a video demo showing all main features of the platform. A short, 6-question survey was conducted in order to collect some quantitative data regarding the main research aspects of this study such as trust in unknown peers, feeling of belonging to a community or gamified features. The study ended with a focus group discussion where participants were asked to express their ideas and concerns regarding the platform. Questions were related to challenges and the reward system proposed, sense of belonging to a community and trust in peers, motivations to engage and perception of blockchain technology. Since the platform consists of two channels (application and website), we also asked if they perceived the role of each channel and appreciated having such distinction. The whole study was performed fully in Portuguese. In the beginning participants received and signed an informed consent. The focus group discussion was recorded with their permission. The study participants were invited by the research team. Five people confirmed their attendance and took part in the test (2 women and 3 men). They represented different interests and levels of technology expertise. We recruited 3 prosumers and 2 consumers. Participants' ages ranged from 29 to 49 years. Audio recordings of the focus group discussion were transcribed and used for a thematic analysis with general inductive approach. Participants feedback was analyzed using affinity diagrams, clustering valuable information and identifying main aspects that arose in the conversation.

## Results

The main research questions were addressed in the survey as well as during the focus group discussion. The survey comprised of six 5-point likert-scale items (1 - strongly disagree to 5 - strongly agree). Results are reported below.

Table 1. *Results from the survey*

| Question | Mean result |
|---|---|
| Q1: I consider myself to be environmentally aware. | 3.8 |
| Q2: I understand how the system works and I would be able to explain the application to someone else. | 3.8 |
| Q3: Having a common goal and act as a community would motivate me to engage in P2P energy trading. | 3.8 |
| Q4: I believe points and challenges are a good addition to regular energy statistics and would improve my engagement with the app. | 3.6 |
| Q5: I would feel comfortable sharing my energy data with the DSO (energy consumption and/or production and exchange). | 4.4 |
| Q6: I would feel comfortable trading with anonymous peers. | 4.6 |

Focus group discussions allowed participants to express their doubts and opinions on the proposed solution. All insights were gathered and grouped into main themes.

***Hypothesis 1: Collective efficacy***

Collective effort was confirmed to be potentially effective by most participants of this study: "I've found interesting (...) the awareness of being a community that, as a joined effort, would reduce consumption and help the environment" (Participant 2). On the other hand, one participant said: "I don't consider myself as a part of the community" (Participant 1). However, this participant suggested that if she were to get involved in the community, she would be motivated by more tangible outcomes of the collective effort, such as planting trees. This finding shows that engaging in collective effort might depend on the benefit it can bring. Moreover, participants in the study generally claimed that they would like to know their contribution to the overall score and compare it with others. Knowing whether one's score is lower than the average could possibly further motivate users: "Just to know if it is me that needs to lower consumption in order to improve the community performance" (Participant 3).

***Hypothesis 2: Norm Activation Model vs Economic Rational***

We tried to explore the ways of implementing Norm Activation Model in the design of PSv2. The way challenges were structured did not imply any economic benefits. On the contrary, only kilowatt hours and $CO_2$ saved was displayed in "Challenges" to support the core idea behind the platform, namely collaboration for the benefit of the community and the environment. The answers gathered to the RQ2 suggest that there is still space for improvement: "What disappointed me a bit were the tips, since tips should be something always available, since the beginning" (Participant 3), "A tip is something you can find on Google…" (Participant 5). These comments imply that information is an insufficient trigger to get involved and it should be available at all times to help people do better. Nonetheless, some participants admitted they would like to gain some savings from energy trading in PSv2: "For what concerns myself, the main reason to use the app would be economic" (Participant 4). This proves that complete abandonment of the Rational Choice Model in fostering behavioral change in P2P energy trading might not be effective. Participants expressed the need to have a chance to adjust the price of energy themselves - even though last year, most of them chose automatic settings proposed in the app. Results obtained proved that users would like to have a possibility to set the price of energy.

***Hypothesis 3: Gamification***

Both the individual and community challenges were in general considered interesting, however, one participant stated that "perhaps group challenges should be optional. People should do what they want, engage in individual challenges if they want, for self-growth" (Participant 3). This confirms that generally gamified systems are approved of. However, they should not be mandatory and users should choose what they want to get involved in. In order to better adapt the solution to different lifestyles and agendas, more varied challenges could be designed. A gamified solution would require more varied tasks that can be adapted to different lifestyles and needs.

***Trust and privacy***

According to feedback on the challenges, transparency regarding individual performance is needed. People stated that they would like to know who is underperforming and what is their result with respect to the average: "I'd like to compare my performance with the others in order to understand if we are not doing well because of me or is it the others that are over-consuming" (Participant 3). Feedback gathered in the focus group discussion confirmed as well that competition is a motivating aspect. However, there were no concerns expressed regarding users' anonymity - even though only people's nicknames are displayed, nobody mentioned this as a potential problem. Regarding trust issues with sharing personal energy data, energy provider was mentioned too. Participants did not express any concern regarding energy company's participation.

***Technology***

According to the results obtained, no participants expressed the need to fully understand how blockchain works in order to use the app. As long as no additional hardware is needed and everything works well, they expressed no concern regarding trust in this technology. It was proposed to make the message clear about what needs to be done on the user's side to implement the system and what are the benefits from it: "Basically, at the end what matters is money. That's the info we need" (Participant 5). A suggestion followed, that information should be available on demand, mostly for people wanting to explore this subject further.

***Design inconsistencies***

Not all of the results obtained were fully confirming or denying certain hypotheses. Some opinions were contradictory. The most critical insights that emerged are were related to fairness of dependent group contingency (the rewards should not be equal but there should be no penalization) and privacy vs. transparency (no need to know the peers but interest in knowing who is underperforming).

***Additional findings***

During the thematic analysis, further categories not belonging to the topics addressing the main research questions emerged. For instance, regarding perceived target audience - participants of the study said that the system seems to be targeted at people interested in technology and very familiar with it. Raising awareness, providing valuable information and stressing the importance of joint effort for sustainable actions was described as a potential opportunity.

***Design guidelines***

Based on the user study the main design guidelines were specified:

- Collective efforts should be transparent for the users to know how they are performing in comparison to the average and their contribution to the overall score;
- Tasks should be flexible, adaptable to different lifestyles and non-obligatory;
- Rewards should depend on personal contribution;
- Rewards should be more tangible (e.g. discounts) as information is not a sufficient motivation;
- The system should allow users to change settings manually in order to give them an impression of being in control;
- Relevant information should be available on demand for more interested users;

## Conclusions

Answers provided by study participants helped to compose a preliminary set of proper design practices for peer-to-peer energy trading platforms focused on community engagement. Aspects such as collaborative work proved to be interesting, however, participants stated that they would like to know their own contribution and make the scores transparent. As results show, perhaps it would have been better to provide a ranking of the competing members or comparison with the average. Moreover, rewards delivered to everyone were described as "insufficient". Fairness of the chosen group contingency was questioned too, as some members might be contributing more than others. It was suggested that best performing people should receive "better" rewards, such as supermarket discounts.

### ***Limitations***

Despite addressing the main research gaps regarding the adoption of P2P energy trading platforms, this work presents some limitations that need to be mentioned. Firstly, we didn't test a working prototype of the system, so participants didn't have the chance to actually interact with it. The feedback gathered was based on perceptions people had on certain features and aspects of the platform. Moreover, we only recruited five study participants. Despite gathering a lot of feedback from this sample, we are aware that more issues and relevant comments could emerge when testing PSv2 with a bigger group.

### ***Future work***

Based on study results a hypothesis emerged that rewards for active participation in community challenges should be based on individual contribution. Another promising refinement of the system could relate to challenges i.e. making them non-mandatory and more flexible. For instance, higher number of tasks could be provided with shorter time limits, in order to adapt them for people that do not have a lot of time to interact with the application. In order to fully address the hypotheses and research questions regarding PSv2, it should be tested by prosumers and consumers for a longer time. This way they could provide a comprehensive evaluation of all features. Currently the feedback gathered is based on perceived usability of the system and a vague feeling of how collective challenges work. Having a possibility to actively participate and trade energy (even in a simulation) could profoundly change the impressions participants have on the system. Developing a working prototype for the future tests of Power Share might deliver significantly better and more reliable results. Additionally, the next test of the platform should be conducted with a larger sample in order to diversify the potential feedback and adapt the system to a broader range of people.

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