Power Share: Eco Feedback and Energy Trading System

Telma Sofia Ribeiro Correia
telma.correia@tecnico.ulisboa.pt

Instituto Superior Técnico, Lisboa, Portugal

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Abstract

The way we have been using and producing energy so far has been contributing to climate change and global warming. Now more than ever, the European Union (EU) countries need to find measures to cut consumption, increase the penetration of renewables energies, and improve efficiency. Besides top-down initiatives from policy-makers and governments, the transition to a low carbon economy requires the development of solutions that involve and empower people by changing their attitude toward energy. The work presented here, leverages and combine different technologies - namely Eco–Feedback, Energy Trading and blockchain - to develop a system that could be used by citizens, and especially solar Photovoltaic (PV) owners, to cut consumption, optimize their production and finally play their part in reaching the EU sustainability goals. Specifically, the main goal of this work is developing an end-user application for energy trading, that uses blockchain as a payment method and contemporarily provides Eco-Feedback (EF) through a low-cost and easy to use system. This project is implemented as part of SMart IsLand Energy systems (SMILE), an EU H2020 funded research project, and will be pilot tested as a future business model for one of the solutions developed in the scope of SMILE. The one month pilot test, during which 9 households in Madeira Island will use the application, has a twofold goal: 1) Assessing users acceptance of energy trading in Madeira Island in order to understand if it could be a viable future business model for the SMILE project; 2) Evaluating users understanding and attitudes toward adoption of blockchain as a payment method.
Keywords: Eco Feedback, Renewable Energy, Energy Trading, Blockchain

1. Introduction

The way we have been using and producing energy so far has been contributing to climate change and global warming. In 2016, the largest contributor to the Portuguese emissions was indeed the Energy sector (accounting for almost 70% of total emissions)[41] . Reducing consumption, increasing the share of renewables in the energy mix, and improving efficiency [9, 10, 11], are among the main measures established by the EU in order to achieve its long-term goal of reducing greenhouse gas emission and thus turning Europe into a low-carbon economy [8].

Several solutions proposed in the areas of Human Computer Interaction (HCI) and Information and Comunications Technology (ICT) can be adapted to help reach the above–mentioned sustainability goals. Power Share, which is the work described here, leverages on some of them - namely Eco Feedback Technology (EFT) and Energy Trading (ET) via blockchain - and was implemented as part of SMILE, an EU H2020 funded research project.

1.1. Eco-Feedback Technology

Reducing energy consumption is a critical step in lowering greenhouse gas emissions. Nevertheless, many people are not yet open to change their energy consumption patterns. This is mainly because, despite energy monitoring and billing, households are largely unaware of the magnitude and impact of their own consumption. Energy is indeed perceived differently to other resources: it is invisible and its abstract nature leads people to underestimate the amounts of energy involved in their daily domestic practices [20].

ICT research developed several technologies for supporting behavioral change towards sustainability, and EFT - i.e. a technology that ”provides feedback on individual or group behaviors with a goal of reducing environmental impact” [19] - is one of them. EFT aims to make consumption visible in terms of scale and impact, and its effectiveness (savings ranging from 5% to 15%) has been demonstrated by over 40 years of research in multiple fields, from environmental psychology to HCI [29, 14, 19].

1.2. Energy Trading and the blockchain

Due to decreasing prices of solar PV equipment, the number of prosumers - “considered as regular households that consume and produce their own energy” [6] - is growing exponentially. In Portugal, for instance, in 2015 the number of residential prosumers was 62.000, and it is expected to reach quota 88.000 by 2020 [12]. Till now, prosumers had a limited control over their surplus energy. They could buy a Battery Energy Storage System (BESS) to store the surplus energy and use it later or sell it back to the electricity supplier against payment of a fixed fee.

Nowadays, thanks to the development of blockchain technology, prosumers can finally sell their surplus energy to neighbors who are in an energy deficit. Blockchain consists in ”an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way. The ledger itself can also be programmed to trigger transactions automatically” [31], through the so–called smart contracts. Despite Peer–to–Peer (P2P) technologies, energy trading was already possible without blockchain. Such technologies could provide great benefits to the energy industry and has the potential to disrupt the market. Blockchain technology is indeed ”the only solution for a full P2P market” [38] and is especially needed when there are multiple parties transacting in near real-time, as it is the case of the energy sector. Through blockchain, third-party intermediaries are no longer required, which, in turn, leads to a decrease in transactions costs and time thus allowing small subjects, like prosumers, to enter the energy market. P2P energy trading does not only represent an opportunity for prosumers but also for consumers,Distribution System Operators (DSOs) and Transmission System Operators (TSOs). Indeed, blockchain technology enables dynamic pricing, flexibility, and adds transparency. This way, customers have more control over the price they sell their surplus energy for and can benefit from instant billing settlement. Ultimately, smart contracts on the blockchain can be used to balance demand and supply. Therefore, such a system has the potential to increase grid balance [7] and share of renewables in the energy mix, while radically changing the energy market.

The number of projects and blockchain startups in the energy area increased significantly in the last years, demonstrating that P2P ET via blockchain can be a viable solution for the development of an actual microgrid - “a local energy grid with control capability, which can disconnect from the traditional grid and operate autonomously” [22].

1.3. Power Share

Power Share project was designed to test a future business model for the pilot of SMILE describe above, therefore, it assumes a scenario where several solar prosumers are equipped with a BESS. The main goal of this project is developing an end-user application for energy trading that uses blockchain as a payment method and contemporarily provides EF through a low-cost and easy to use the system. It is designed to be inclusive, that is to say, it does not target only prosumers but also consumers. By combining ET with EF we aim to:

(1) Foster learning and raise awareness about people energy use; (2) Allow prosumers to further benefit from their surplus energy and foster them to engage in energy trading toward the common good; (3) Increase the share of RES in the energy mix by allowing consumers in need of energy to buy local, green energy from their neighbors. Through Power Share they can have control over price and source of their power.

Specifically, Power Share has a twofold goal:

- On the one hand, it is meant to assess users acceptance of energy trading in Madeira Island in order to understand if it could be a viable future business model for one of the solutions developed in the scope of the SMILE project;
- On the other hand, it aims to evaluate users understanding and attitudes toward adoption of blockchain as payment method.

The application was field-tested in 9 households in Funchal (Madeira), and all transactions carried out through the app will be simulated by the server. This is due to the fact that all prosumers participating in the field-test installed their PV power system after 2014, therefore are not allowed to inject the surplus energy to the grid.

2. Related work and Theoretical Background

2.1. Eco Feedback Systems

EF effectiveness has been demonstrated by over 40 years of research in multiple fields, nevertheless, designing an effective Eco Feedback System (EFS) is everything but simple. Indeed, it requires a deep understanding of people latent motivations for sustainable behavior.

EFSs are learning tools, they provide users with information about the impact of their behavior in order to trigger a learning process, which should lead them to reconsider their daily needs and, ultimately, to use energy in a more ecological way [13].

Control over the feedback, its frequency, and the information detail are some of the main aspects influencing such learning process [14, 13]. **Direct feedback:** available on demand, seems to be the most effective (savings around 5%-15%); **Indirect feedback:** raw data processed by the utility and sent to users, involves a process of learning by reading and reflecting (savings around 0%-10%). The literature suggests the following set of techniques and motivation strategies that should be taken into account.

Information: as a rule of thumb, the better the information is, the higher the chance that people will act in an environmentally friendly way. According to Froehlich et al. [19], to be effective, the information should be presented in an attractive and memorable way, and provided at the time and place the information is more relevant for the user.

Comparison: comparison has been demonstrated to be an effective strategy in fostering behavioral change. In general terms, there are two types of comparisons: self-comparison (comparison between one's current and past data) and social (comparing one's data to that of other households). Social comparison fosters competition [19] and could then strongly motivate behavior change.

Goal Setting: goal setting is a powerful source of motivation and, when combined with feedback, is particularly effective in stimulating environmentally responsible behaviors [19]. The Energy Life application [21] largely relies on such game-like rational, presenting the users with a series of goals, as well as tips to reach them, tailored on their own consumption habits. Also, EnergyWiz app [36] presents a similar feature. Results from the interviews with the users revealed that this feature was their favorite.

Commitment: it has been widely demonstrated that when a person commits him/herself to behave in a specific way, the probability that s/he will pursue that behavior increases [19]. In the field of EF, for instance, public commitment could lead to energy savings of around 20% [34]

Incentive / Disincentives and Rewards / Penalties: according to Froehlich et al. [19] also incentives/disincentives and rewards/penalties can be used as motivation techniques when designing an EFS. Indeed, as pointed out in [21], feedback should not only punish or discourage bad habits but also encourage good ones.

Frequency and temporal granularity: researchers agree that feedback has a positive impact on behavior change. However, it is a way more efficient if given frequently [17]. The real-time feedback is the most effective one [19] since it helps the users making an immediate connection between an action and its impact, thus making the information more relevant for the user [18]. At the same time, the historical detailing of energy consumption is a highly appreciated feature [21, 36] and helps increasing users awareness about their energy patterns [18]. **Media/device:** some of the studies [18, 19, 35] also highlight the importance of the mobility aspect. Households usually value the opportunity to access the feedback and check their energy status via mobile devices.

The projects in this field combine many EF techniques like real-time feedback, which is one of the most effective [19]. The Sustainable Interaction with social Networks, context Awareness and Innovative Services (SINAIS) project introduced machine learning algorithms to identify the source of energy consumption, however, despite users appreciated the opportunity to better understand what appliances consume more [35], after one-year deployment, the decrease of energy usage was not significant. This result supports the hypothesis that EFSs are not effective in the long term because, as suggested by results from SINAIS, after a while people lose interest in the system which becomes "just another electric device" [35]. Another important lesson learned is that EFSs must be designed to adapt to different users (and, consequently, different behaviors, needs, and interests). For the same reason, as demonstrated in several of the studies reviewed, the mobility aspect is extremely important. Users want indeed to access their data quickly and from virtually everywhere; that's why commercial EFSs like Sense [3] and Efergy [2] provide users also with a mobile application. Ultimately, it is important to point out two main weaknesses of EFSs. On the one hand, the cost. EFSs available on the market are quite expensive and this could explain their low adoption rate. On the other hand, the fact that their effectiveness decrease in the long-term [35], which suggests the need for thinking about solutions that could keep users engaged and interested in the system over time.

2.2. Energy Trading Systems using blockchain

The blockchain is a technology for P2P platforms that have a decentralized storage to record all transaction data. This technology came into the public in 2008 when a publication by Satoshi Nakamoto was launched describing Bitcoin, as a P2P electronic cash system that enables online payments to be transferred directly without an intermediary [33]. Bitcoin is one application of the blockchain concept, the first and the most known one: "Blockchain is to Bitcoin, what the internet is to email. A big electronic system, on top of which you can build applications. Currency is just one." - Sally Davies, Financial Times Technology Reporter [42]. However, this technology has great potential in many sectors, not only in the financial one.

The blockchain concept relies on the decentralization idea. A decentralized storage and decentralized business without the need of a trusted third party are the base of this technology. A short time ago, all money transactions were executed by trusted third parties like banks and governments, resulting in extra costs for the customers. The role of those entities is to authenticate both participants of the transaction (the emissary and the receptor) and keep the record as a confirmation of the transaction. In this digital world, it is even more important to securely store the record of the transactions in order to prevent any malicious activities.

The transactions are carried out between peers who can be providers, consumers or both. The data that contains all the relevant information about the transaction is stored on a distributed ledger and all peers store the block of data locally. A distributed ledger is a distributed database that records, shares and synchronizes transactions in different locations. It is efficient, resilient and reliable.

Ideally, all of the transactions have a smart contract behind. Smart contracts define the rules related to the transaction, like a transactions protocol that executes the terms of a contract [40]. Each transaction is encrypted and distributed to individual computers and each member of the network stores the data locally. Each block is verified using hash algorithms and associated with a hash that is unique and is related to the information on the blockchain. If the information on the block is changed after the transaction, the peers cannot verify the block because the correct hash is not produced anymore, and the block is discarded.

The continuous verification is called mining and is performed by the members of the network. The mining is necessary to ensure that everyone agrees on the order of the transactions. Each block is like a package of transactions and is associated with a timestamp, a nonce and a reference to a previous block (i.e. the hash of the previous block) [33]. All these blocks connected form a blockchain that is constantly growing and represents the state of the ledger.

To establish that consensus, both proof-of-work and proof-of-stake are used. In the **proof-of-work** approach, each block is verified by a large group of peers before storage using algorithms that associate a unique hash (ordinary or cryptographic) to the block. The verifying task is very complex because it is necessary to find a hash that corresponds to the block content. The block cannot be changed without re-doing the work and if a new block is added to the chain after this one, all blocks after this need to also re-do the work [33]. This process requires a lot of energy. If the majority of peers verifies a block content it can be added to the blockchain, otherwise, it is discarded. This majority decision is represented by the longest chain, which means the one with the greatest proof-of-work effort invested [33].

Proof-of-stake approach is simpler than the proof-of-work approach because it requires that users prove ownership of their own share (stake). So, if a user owns 10% of total data he just needs to be mining 10%. This reduces the complexity of the task and is less expensive in terms of costs and energy consumption [16].

The current main disadvantage of the blockchain technology is the performance. The blockchain technology implies heavy calculations, the mining process explained above, to generate and verify the signature of each block. Due to its decentralized nature, an extra effort is necessary to ensure a consensus exists in the network. Consequently, the total amount of computation that a blockchain requires per node in the network is very expensive in relation to a centralized database. The fact that blockchain is a recent technology can be seen as disadvantageous because it is necessary for a new technology to have existed for a longer period of time in order to increase cultural adoption and trustworthiness. The large energy consumption in Bitcoin blockchain is a relevant problem, but this problem was reduced with the emergence of the Etherium approach which uses three times less energy than Bitcoin because it uses the proof-of-stake method to verify transactions.

The advantages of the blockchain technology are bigger than the disadvantages. The main advantages include lower costs, faster processes and greater flexibility because no more third parties are needed and no central point of failure exists once the storage and communication are fully decentralized. All the time and money spent to prevent tampering in centralized databases is not necessary anymore, because in blockchain the storage is not centralized. Other significant advantages are the control that users can have over all the information and transactions, the consistency and availability of the data, the trustworthy process of each transaction, the faster transactions and the lower costs per transaction.

2.2.1 Integration in the energy sector

Traditionally, the Electrical Power Systems are controlled via a top-down approach where central authorities are responsible to manage the energy distribution in the grid. Lately, new decentralized approaches are being investigated in order to create a full transparency and to allow micro producers and consumers to reap the full economic benefit of the energy sharing system without the participation of central authorities. The Blockchain could be applied to the energy market providing a secure decentralized network to share energy [26]. There is an especially high potential for energy trading, automation of processes and new business models [25]. Another novel application is the use of cryptocurrencies in the payment system. The storage of energy data can also be re-designed to work over blockchain technology with smart contracts and verification of transactions ensuring the integrity of the data and trust between the grid participants [28]. For example, in a smart grid, a producer who has more energy than he needs can automatically sell the excess energy via a smart contract to neighbors who want to buy energy. This example can be done in the reverse order, i.e. consumers can automatically buy energy from other producers.

The concept of a blockchain based distributed controller for the efficient share of Energy Storage Systems (ESSs) has been proved showing that the concept is applicable, scalable and economically feasible [28]. Also, secure and privacy-friendly protocols were designed for trading and billing in Smart Grids [5] and can be applied.

2.2.2 IOTA and the Tangle

Since increasing the consumption of renewable energy is one of the main goals of the present work, it would have been inconsistent to not use an efficient blockchain platform. After some research, the IOTA distribution ledger technology has been identified as the most suitable solution for that purpose. IOTA is an open-source distributed ledger, which differs from blockchain concepts like Bitcoin or Ethereum, since it uses "The Tangle", a Directed Acyclic Graph (DAG) characterized by high scalability and low resource requirements. The Tangle eliminates one of the biggest drawbacks of blockchain, that is to say, it removes fees [27]. Since IOTA cryptocurrency is open source and blockless, users can make transactions on the network for free. In addition, this cryptocurrency is very well rated in terms of market capital (10th place, at the time of this writing `https://coinmarketcap.com/`). The absence of fees is extremely important, especially when we are talking about micropayments, like in the case of P2P energy trading. While in traditional blockchain transactions are grouped into blocks and stored in sequential chains, the Tangle is blockless and no third party is needed. Individual transactions are interconnected in a DAG. For example, let's take a scenario where A, B, C and D are different nodes of the network, and A wants to communicate with D. In a traditional blockchain network, which is sequential, the transaction between A and D needs to be distributed and validated by both B and C before it gets to D. On the contrary, on the Tangle A, B, C, and D are connected in a braid-like fashion, thus, when A needs to communicate with D, it sends the data directly to D while synchronizing (almost) instantaneously B and C. Consequently, the energy spent for the proof-of-work is reduced, since consensus is established only by the participants making transactions instead of miners.

The main idea of the Tangle is that, when a transaction issued by a node arrives, it must approve at least two previous transactions. This way, users who issue a transaction are also contributing to the security of the network [37]. After a transaction is performed, it is broadcasted in the network and validated by the active members of that network. To keep the state of the network a consensus protocol is used, which decides if a transaction could be safely considered confirmed or not.

To sum up, the main feature of IOTA are: (1) Data Transfer through the tangle in a secure and authenticated way; (2) Everything as a service: anything with a chip can be leased in real time;(3) Scalable ledger.

2.3. Research projects and startups

Several projects have been launched with the goal of building a distributed energy system. According to the Event Horizon 2018 Startups report, about 41 startups are developing blockchain-based energy applications (25 of them in Europe), nevertheless, after a quick search, a lot more blockchain startups working in the energy field can be found [23]. In this scenario, Etherium seems to be the most used blockchain protocol [4].

The author considers using Etherium as a disadvantage since Ethereum transactions have fees (to "cover" the computing power needed for the proof-of-work). To overcome this issue, Power Ledger, for instance, has developed the EcoChain, a more sustainable blockchain, while Omega Grid uses proof-of-authority consensus model instead of proof-of-work.

Electron[15], Omega Grid[24], and Power Peers[39] are energy trading projects that act like an intermediary between energy suppliers and all possible consumers. At the time of this writing, only Brooklyn Microgrid [32], Power Peers and Omega Grid have successfully reach the market. Power Ledger[38] project is well documented and a lot of experiments have been done so far to test the platform. Nevertheless, it has not been launched to the public yet, so it is hard to evaluate it.

Only Power Peers, Power Ledger and Brooklyn Microgrid have as main target micro producers and consumers. Focusing on the local community first is a promising strategy since each community has its own cultural attitudes and motivations toward engaging in P2P energy trading, which should be taken into account when designing such systems. This can be considered an advantage because all the markets have specifics constraints like grid stability, infrastructures architecture and also the cultural differences in the user's behavior. On the contrary, platforms like Electron[15], Leap [30] and Omega Grid focus on using blockchain to target energy market problems, like Demand Side Response (DSR), thus opening up space for retailers and electricity companies.

3. Implementation

The system was designed as a mobile application for android.

Despite all participants in the field study aimed at testing the app are prosumers, Power Share targets also consumers. Therefore, the motto while designing the application was "keep it simple", that is to say, easy to use and understand for the wider audience possible.

Power Share allows automated energy tradings between neighbors. It provides users with the opportunity to set the parameters for buying and/or selling energy, as well as to access and monitor data regarding their energy consumption, production (in case the user is a prosumer), and transactions.

The application is connected with Power Share Energy Trading Management System (ETMS) that is responsible for managing users' accounts, managing energy demand and offer, and providing data about the users' overall energy consumption and production. Data are collected through a smart meter, installed in each household participating in the study, which measures production and consumption. The integration of IOTA technology will serve the purpose of carrying out the transactions between neighbors in a decentralized fashion.

3.1. Power Share Application

The first stage was the definition of the requirements and the front-end application design where we design the navigation tree and some basic requirements of User Interface (UI)/User eXperience (UX) were also defined.

The resulting wire frames were subjected to a heuristic evaluation of layout elements, function, and flow, after which possible bottlenecks were identified and removed. Then, a low-fidelity prototype was realized and tested with a small group of researchers and students from the Madeira Interactive Technologies Institute, all with a limited knowledge of energy. At the end of each user test, participants were also asked for comments and opinion about their experience. Through the tests and their feedback many issues were identified and rectified.

On the basis of the above-mentioned results, another low-fidelity prototype was designed and tested with different subjects. The changes made resulted in the improvement of users performance allowing us to start designing the UI mockup.

In terms of flow, we tried to keep the registration process as quick as possible. Creating a new account requires three main steps: (1) Defining users credentials; (2) Input some basic information about the contract with the energy provider; (3) Defining user typology (consumer or prosumer). Before finishing the registration, users receive an IOTA seed[1], which gives them access to their IOTA account. Users are thus asked to set a password for that seed. After that, the user is provided with the opportunity to select the "automatic settings" for the buying and selling criteria. By selecting the automatic settings, users will immediately start trading energy while, if they choose the manual mode, they have to set the buying and selling criteria in "transactions" before being able to trade. Once the user is finally registered, (s)he can access the four main feature of the app fig. 1.

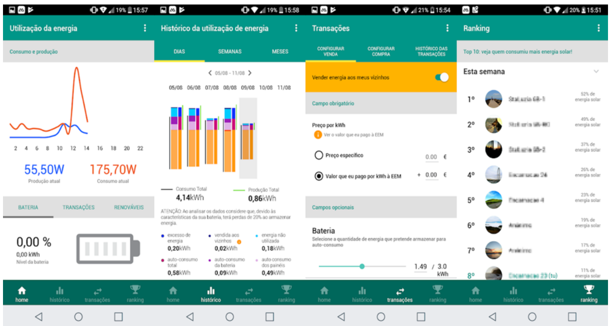

Figure 1: Main Power Share menus

Home: The home (fig. 1, 1st on the left) provides information about the current production and consumption (line chart on the top of the screen); the battery status (amount of energy stored); a summary of transactions carried out that day. Such information is presented through a heat map so to help the user identify at a glance at what time of the day (s)he buys and sell more energy. Further details about each transaction can be accessed by selecting the green arrow on the top of the heat map; the share of RES in the user weekly energy consumption: here the user can quickly check how much RES is using in the current week (donut chart) and how is (s)he doing in comparison to the

[1] In a real case the user could use a seed if he already have one or generate one in the app. For this study we create the accounts and pre-charge them and only ask the user to set out a password to cipher the seed and store it.

other users (ranging from "very good", represented by a smiling face, to "you should do better", represented by a frowning face). The comparison with other users is always coupled with an encouraging sentence, in order to avoid a negative feedback. Data are updated every minute.

Histórico: (fig. 1, 2nd from the left) Through this feature, users can access their own past consumption and production data, with three levels of temporal granularity (days, weeks, months). The information is illustrated through a stacked bars graph as well as a table (on the bottom of the graph, which also serves as a legend to the graph). Not only overall production and consumption are presented, but also their respective breakdown (e.g. consumption is divided in energy bought from the supplier, from neighbours, and from self-consumption), so the user can leverage this information to modify his/her buying and selling criteria (if needed). The graph is always combined with a table which serves as a legend for the graph itself and provides detailed information about energy use so to prevent the user to misinterpret the visualization or, even worst, think there is something wrong with the data.

Transações: buying/selling criteria: (fig. 1, 3rd from the left)

This section is divided into three main subsections: 1) manual definition of criteria for selling energy; 2) manual definition of criteria for buying energy; 3) list of all transactions performed. The core of the application is the manual definition of buying/selling criteria. The only mandatory field here is "price for kWh". The user is indeed required to define at what price (s)he is willing to buy as well as sell energy. In both cases, two are the possible options: 1) a fixed price ("maximum" fixed price in the case of buying criteria); 2) a price tied to the cost of energy he/she buys from the electricity company (in the case of Madeira it is Empresa de Eléctricidade da Madeira (EEM)). The latter option is targeted to consumers that are subjected to dynamic pricing (i.e. have a bi-horária or tri-horária tariff), thus pay energy at different prices at different times of the day. Concerning "energy selling", such price could be equal or bigger to the cost of energy (s)he buys from EEM at a given moment while, regarding "energy buying", the users set a maximum price which could be equal or lower than the cost of energy bought from EEM at a given time. Results from the SINAIS project revealed that many consumers are not aware of the cost of energy and, sometimes, don't even know their own tariff. Therefore, in order to support users in defining the price for the energy they are buying and/or selling, an "information button" was added, which opens up a dialog providing information about the user's tariff and relative energy prices. In both "energy buying" and "energy selling" sections there are then the following optional criteria: (1) Select one or more specific time frames for buying and/or selling energy; (2) Select people you want to trade with (buy from and sell to) among the users in the community. Every time someone joins the community, all users that decided to trade only with specific people receive a notification, so they can include or not the new user among them. (3) Save part of the overall storing capacity of your battery for self-consumption only (this criterion is available only for energy selling).

If users do not set any of the above mentioned optional criteria, (s)he will be notified that, for instance, (s)he is going to buy energy from anyone and at any time. Once all the parameters are defined, the user can start trading energy by using the slider on the top of the screen. In the same way, the user can momentarily disable the trading while keeping his/her settings as such. In The list of transaction users can quickly see their total earnings/expenses and all transactions (s)he carried out. The list could be filtered by date range and/or by type of transaction (buying or selling). Further details about each transaction are also provided. **Ranking** Here it is presented the rating for top 10 users (among those who allowed the app to display such information) with the biggest share of RES consumption. The current user place appears always in the list even if (s)he is not in the top 10.

An overflow menu is placed in the top app bar, which allows the user to access some secondary features: (1) Profile settings; (2) Privacy Policy; (3) IOTA wallet.

The most crucial feature implemented for the purpose of this project is the IOTA payment. As explained before, each user is provided with a seed that gives him/her access to an IOTA account. Such seed needs to be securely stored. Therefore, the user is required to set a password for it and only then, the seed ciphered is stored in the server. For security reasons, the deciphered seed cannot be stored on the mobile device, consequently, payments cannot be fully automated and each time a user wants to access the wallet ("ver o meu saldo"), (s)he is asked for the password set. Once the password is inputted the seed is deciphered and can be used (the seed stays only deciphered in memory, is not stored deciphered in a persistent way). Through the wallet, users can check their account details (e.g.balance; daily, weekly and monthly incomes/outcomes).

The query for balance information could take a while to be executed, depending on IOTA node state. The same might happen when the user generates new destination addresses. With this respect, it should be pointed out that each transaction carried out by the user as seller requires a new address. When (s)he runs out of addresses, receives a push notification and an email asking to generate new addresses. To make the payment, the user has to press the “pagar as minhas despesas” button. If the user has not enough balance, the payment will be rejected by the node.

3.2. Power Share Energy Trading Management System

Figure 2 shows an overview of the ETMS. The Android application is connected with the ETMS, which in its turn is connected with the smart meters providing information about energy production and consumption for each user. Both communications are made by a REST Application Program Interface (API) using the https protocol with authentication.

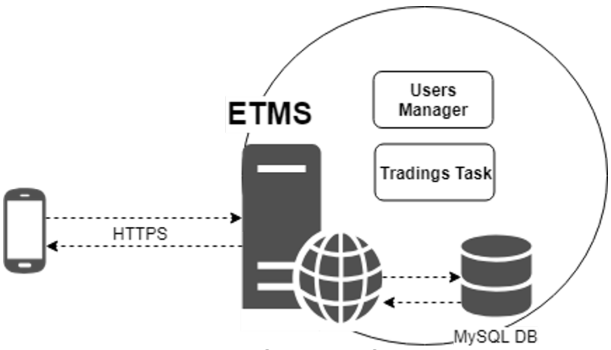

Figure 2: Power Share ETMS architecture

In this system a trading is the combination of three main asynchronous tasks. “Start transactions”, “Verify transactions” and “Stop Transactions”.

Start Transactions: Once a user has set his parameters for trading energy and activated the trading by sliding the switch to the on position, an entry with user id and sales/bough settings id are added in the database (in want_sell or want_buy table respectively). Such a combination of user id/settings id is unique. When the user starts a transaction or turns off the trading switch, this entry is removed from the table. Each minute the system verifies if there are entries in the want_sell table and, for each entry found, the server runs the match algorithm to find a buyer whose demand for energy matches the seller settings - e.g. a seller that offers solar energy to neighbours at the same price (s)he pays energy to EEM (let’s imagine, (s)he has “simples” tariff thus pays always 0,1629 €/ kWh) will match and thus being able to trade with a consumer who has selected a maximum buying price that is equal or higher than 0,1629 €/kWh.

So, by selecting a specific selling price, sellers are guaranteed they will always sell energy for neither more nor less than that price. On the contrary, buyers cannot know in advance the actual amount they will pay for kWh. They are only guaranteed it will never be higher than the one they have set. In order to ensure impartiality, both sellers and matching buyers lists are shuffled. Every time the system finds a match, a temporary transaction is created, while the fields corresponding to the amount of energy consumed (by the buyer) and remaining surplus (of the seller) are updated in the database. The transaction duration is configurable, however, we set one hour as a fixed time to perform each transaction. This choice was made after the analysis of historical consumption and production data of our users which lead us to conclude that, in less than one hour, the amount of energy exchanged could easily be so low that the rounded value presented to the users is likely to be zero.

Verify transactions: A possible scenario is that a seller has the trading on but no energy stored in the battery to sell. For this reason, every two minutes the system runs a verification transactions task. By performing this task, it verifies if the consumed energy in a temporary transaction is greater than zero (the system only verifies transactions running over five minutes). In case the value of a transaction is not higher than zero, it will be immediately stopped. The respective entry in the temporary_transactions table is deleted and want_buy and want_sell tables are again updated.

Stop Transactions: This task consists in stopping all transactions with the duration equal to one hour. When a transaction ends, the system verifies if the energy actually used by the buyer corresponds to the requested amount. In other words, the system verifies if the surplus energy made available by the seller is enough to meet the demand from the buyer and, in case it is not, updates the actual amount of energy traded accordingly. This can be done only at the end of the transaction due to concurrency restrictions, i.e. it is not guaranteed to have data from the buyer and the seller’s meters at the same time. The system is designed to not stop any transaction if data is missing. In case the connection between the server and the smart meter should fail, the transaction won’t be stopped, i.e. none transactions is stopped if the last timestamp received by the buyer and/or seller’s meter is earlier than the end of the transaction.

At the end of each transaction, the system verifies if the seller has any available address for it and, if so, it associates the address with that transaction. If no address is available an asynchronous routine named **Transactions Addresses** task will be performed. This routine runs one time a day. It basically verifies if there are sales without an associated address and, in case it finds some, it will notify the respective users (sellers only) the need to generate new addresses for getting paid. This alert consists in an email and a push notification received directly on the mobile device where the app is installed.

3.3. IOTA integration

Blockchain technology, more precisely IOTA, is used here as a payment system. For this purpose, IOTA Reference Implementation (IRI) was run on a Ubuntu 16.04.4 server equipped with a 6 cores processor and 8GB RAM. Each node on the Tangle runs IRI and needs other neighbors (i.e. other nodes running IRI) to perform a transaction. Our node has three neighbors. In other words, the Tangle works as follow: one node performs a transaction and pays for it by validating two other non-validated transactions, called Tips, following the "Tip Selection" process. Since a user has to validate two transactions to get his one approved an efficient network is required, therefore the more active users in the network the better.

This way we can perform transactions using the Tangle through the IOTA API, having a decentralized network operated by the Tangle that validates transactions between neighbors. Despite there are many public nodes available, we decide to run our own node since, if a public node becomes unstable, we don't have the possibility to fix it and consequently cannot guarantee the transaction will be performed successfully. Power Share relies on this node to perform the payments and the Proof of Work (POW) is done as a service by the application. The POW on the Tangles is simpler compared to, for instance, the Bitcoin POW, therefore it requires less computational power.

The energy traded is paid through IOTA cryptocurrency (MIOTA). For the purpose of our study, a given amount of MIOTA (around 2€) has been pre-purchased for each participant. It is then their responsibility to verify that the balance in their iota account is enough to keep trading. If the user runs out of MIOTA, the system will automatically disable the trading.

As explained before, in order to get paid for the energy sold, the user needs to generate an address and it is his/her responsibility to do so. On the Tangle, one address could receive funds more than once, however, since we sent a transaction with specific address as input, we should never use that address again. Indeed, IOTA uses winternitz one-time signatures, which degrade security exponentially after each use of the same address [1].

4. Results & discussion

The evaluation of Power Share app has three main goals: (1) Assessing the usability of the system; (2) Assessing users acceptance of energy trading in Madeira Island to understand if it could be a viable future business model for the SMILE project; (3) Evaluating users understanding and attitudes toward adoption of blockchain as a payment method. The methodology selected for assessing the aspects mentioned above includes semi-structured interviews (performed after the one-month test) and monitoring users' interactions through the Fabric.io platform. Due to time constraints, the start of the field test has been postponed thus, results from the semi-structured interviews cannot be included in the present document (but will be presented during the viva).

The main topics to be covered during the interviews are: (1)Understanding and perception of the system (e.g. perceived usefulness); Actual use (i.e. how they used the app); (2) Behavioral intention (i.e. their willingness to use the app/system in the future); (3) Usability (e.g. perceived ease to use); (4) Their perception of using blockchain as a payment method.

To assess the system, we decided to run a small pilot in Madeira island, asking prosumers to use the application for a month. Initially, nine households in Funchal participated.

As expected, data collected through Fabric.io show that the most used feature was the home (real-time feedback). According with literature on EF, real-time feedback is the information users are more interested in, thus the application was designed to show this screen by default every time a user launches the app. For this reason, the high score of real-time feedback (which was used over 100% times more than the second most used feature) is not enough to confirm users interest for it and thus needs to be addressed during the interviews. Interestingly, the second most popular feature was the ranking. This result supports findings from previous studies on EF, which demonstrate the effectiveness of social comparison. "Ranking" is followed by "Histórico" (self-comparison). On this respect, it should be pointed out that daily and weekly data received more or less the same attention from users, while monthly data was not very popular (likely because the study lasted only one month).

Despite most of the users selected the "automatic settings" for trading energy, they did access trading settings and a list of transactions several times. This result suggests a certain degree of curiosity from users about energy trading, which definitely has to be further investigated during the interviews. Another interesting result is the lack of interest in the "IOTA wallet", which was the less popular feature together with "account settings". This could be due to the fact that both "IOTA wallet" and "account settings" were hidden compared to the other features of the app since accessible only from the overflow menu placed in the top app bar. Nevertheless, this result needs to be further investigated during the interviews since it could represent a lack of interest or understanding of payment via blockchain.

Users motivations behind results reported above will be investigated during the interviews. Especially, what needs to be clarified is the reason that led the majority of users to select the “automatic settings” for trading energy, since it could be due to a usability issue (during the pilot test, the manual setting task was defined as the most demanding).

No significant correlation has been found between the number of accesses and the day of the week (included weekend vs. weekdays). Also, surprisingly, push notifications and weekly summary did not affect the use of the app.

Each user’s session lasted an average of 2 minutes and 15 seconds. In agreement with the literature on EF, interaction with the system decreased over time.

Regarding the energy trading, we recorded a daily average of 19 transactions, which means more than 2 transactions a day per user. At the end of the study, a total of 349 transactions were performed, the corresponding to about 45.1 kWh of energy shared between the users. Any transaction was effectively paid with MIOTA.

Throughout the study, only one crash occurred, which affected three users. This crash was due to the fact that those users have run a query at midnight; in other words, they were asking the server for data with wrong intervals, thus the server returned an error and the application crashed.

5. Conclusions

Power Share is a complete application, ready to be used. It combines a system for energy trading,has that uses blockchain technology as a payment method, with a low-cost Eco-Feedback system. As an energy trading platform, Power Share automatically matches demand and offer, and perform the payment through IOTA. The use of IOTA is probably the main contribution of the present work. The big advantage of using IOTA for payment is that it simultaneously solves scalability issues and eliminates transaction fees. In addition, IOTA has shallow resource requirements compared to other blockchains.

Power Share differs from most of the existing projects due to the high degree of freedom it gives to users. While much P2P energy trading applications are designed to be as much automated as possible, Power Share gives users the chance to set their criteria for trading energy and provides them with all information needed to make an aware choice (via a detailed feedback about consumption and production).Also, transactions are managed by a fair algorithm, which guarantees that all member of the community will equally benefit from the system.

From a purely technical point of view, integrating blockchain in a system like Power Share is a significant advantage, since it provides a decentralized payment method without a single point of failure, and it is reliable by itself, thus no third parties are needed. As a developer, the author feels the need to point out a weakness of the IOTA technology, that is to say, its immaturity. Between the beginning and the end of this study until the end the IOTA technology has been upgraded, and better documentation and support material for developers released. However, due to its immaturity, several issues have arisen while testing the system. Among them, we should mention the unexpected length (concerning time) of the payment process via IOTA, which occasionally has led to the need for “re-attaching” the transaction to effectively complete the payment. This, from a developer perspective, makes the payment system difficult to implement, while for users could be quite annoying.

5.1. Future Work

Power Share draws on novel technology and therefore there is room for improvements in several aspects. A most significant improvement that could be made regards the matching algorithm. The matching between the buyer and seller could be made more smartly, by considering the historical consumption and production of each user. This should be done by using machine learning algorithms. Another possible upgrade to the system consists in combining blockchain with Internet of Things (IoT), i.e. running the smart contract directly on connected smart devices (smart meters). This would further decentralize the process by removing the communication layer between ETMS and the sensors. Last but not least, the possibility to register multiple accounts for the same household, with different roles (only one admin but multiple users), as well as having multiple households under the same account, would be a nice to have featured in the future. Currently, the application allows each user to register only one account per household. Nevertheless, in a real-life scenario, all members of the household should be able, for instance, to access production and consumption data. At the same time, who also owns a summer house equipped with solar panels and a BESS, for example, should be able to manage that installation too without the need of registering a second account.

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