Blocking the Grid: An Ethical Assessment of Blockchain Applications in Peer-to-Peer Energy Trading

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ABSTRACT
Peer-to-peer energy trading has arisen as a solution to rising demand for green energy and a desire to bypass the current model of centralized electrical utilities. Currently the field is unfocused, with many different approaches being tested in simulations and trials. Many such trials involve using a blockchain-backed element to some degree in order to ensure transparency and balance. However, the vast majority of these trials are being assessed purely on the bases of material efficiency and cost-value criteria, with very little attention being given to ethical implications of implementing such a system for an essential utility. This paper will discuss the benefits and consequences of using a blockchain-backed system for peer-to-peer energy trading, with references to some of these trials and the implications of their approaches.

KEYWORDS
Blockchain Technologies, Peer-to-Peer Energy Trading, Sharing Economy, Equality, Energy Prosumers, Microgrid Transactions, Price of Anarchy

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1 Introduction

The increase in the development of renewable energy has led to the rise of a new class of utility customer; the prosumer. While this group in theory would result in a grid made up more of green energy, in reality access to these technologies is concentrated among the upper class. In addition, current avenues for people to participate in trading of their energy resources can only be done through centralized and often monopolistic energy companies. Should a prosumer produce more than they consume, a common outcome is for the utility to pay the prosumer for the money, resulting in wealth accumulation in already high income households, with lower income households not benefitting from the network in any feasible way.

The current leading solution to this issue is developing a peer-to-peer energy trading model wherein prosumers consumers can participate in a marketplace with one another. This has in turn made the concept of smart grids and interacting microgrids an increasingly common goal for utilities and prosumers alike. Recreating a utility in such a way presents a unique set of challenges, such as where people will trade this commodity, how electrical load will be balanced, what type of currency will be used, and how the system will be kept secure.

One such solution includes using a blockchain backed marketplace, with some approaches having a blockchain-backed token acting as currency, and others having the load itself be traded using a blockchain-backed ledger system to maintain transparency. Blockchain has been increasingly selected as the backing record system for a variety of applications focused on decentralization, and while many see it as the future of transaction verification, blockchain has also occasionally been used in a way that replicates current power structures rather than disrupting them. Improperly utilized blockchain technologies run the very real risk of simply overengineering extant structures with the added downside of alienating those not already fluent in the technology itself. In something as essential as a utility, this can have dire consequences.

While all ventures in peer-to-peer energy trading are currently deeply theoretical at this point in time, the literature that exists largely focuses on structure and execution, with few if any pieces on the ethical implications of any model, let alone a blockchain-backed one. This paper will act as a review of several such ventures, and discuss the benefits and pitfalls of using blockchain as a basis for a peer-to-peer energy trading model.

2 The Peer-to-Peer Model

Recent years have led to increasing concerns about climate change, and with it an increasing interest in residential green energy generation. This has given rise to a new class of energy user called a “prosumer”, who both generates power to and uses power from the grid. However, it does not seem that the opportunity to be a prosumer is equilateral.

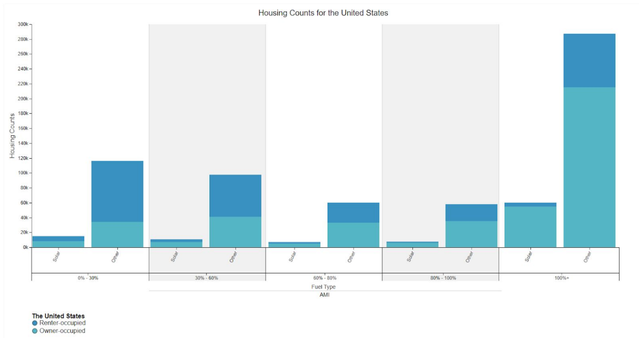

Figure 1: Owner/renter occupied buildings with solar and other heating fuel. [1]

Figure 1 shows information from the LEAD tool, illustrating the relationship between access to green energy for heating fuel and percent of the average median income. More housing units have solar alone as a fuel source in the 100%+ bracket than in all the lower brackets combined. Additionally, 81% of solar heating energy is coming from owner-occupied homes versus 53% of electrical heating energy.

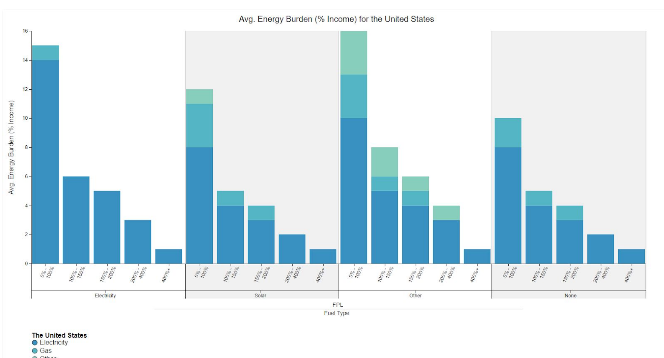

Figure 2: Average Energy Burden across Federal Poverty Level groups and heating fuel type [1]

Figure 2 shows data about financial burden on various rungs of the Federal Poverty Level divided into energy sources. Solar energy is correlated with the second-lowest financial burden among those at 0-100% of the FPL, next to those who have no fuel source for heating at all (and generally lower financial burden across the board).

2.2 Smart Grids and Microgrids

This rise in prosumers has created a need for power infrastructure to work in a very different way than they had before; now power flew into and out of the grid. This situation created an interesting problem for power companies in terms of forecasting. Power grids are subject to Kirchhoff's rule, which states that the power that flows into a system must be equal to the power that flows out. Companies could either choose to depend on the output of prosumers, potentially not being able to meet demand in case of a prosumer's equipment malfunctioning, or choose not depend on this output, likely resulting in wasted generation. Since then, smart grids have been implemented which provide more robust data for forecasting, with excess energy being stored or traded.

This balancing can be done more reliably when organized into a series of interconnected microgrids rather than one large contiguous system. Zhang et al theorizes that the most likely way the grid will be organized in the future is that there will be three tiers of microgrids interacting at increasing scales[2]. However, transferring energy at long distances results in energy loss, so coordination between these microgrids is vital.

This coordination and balancing could be done by a central agent, but this frequently has little benefit to those in lower income groups. Peer-to-peer energy markets make energy a collaborative effort; while it will not install solar energy for lower income people outright, it redistributes the savings in green energy to those in the microgrid. One such approach in order to make this model accomplishable is to have the load and transactions between peers managed by a distributed ledger system via blockchain.

3 Benefits of Blockchain Applications

Blockchain presents many attractive solutions to the hurdles presented by a peer-to-peer system. This system has seen a rapid increase in popularity in computer science circles of late, and it has tremendous benefits for those aiming to move away from centralizing groups for services. Decentralized transactions introduce the concern of "double spending", an occurrence wherein a unit of nonstandard currency can be used several times more than intended during a transaction, causing inflation. In something like a peer-to-peer energy trading network, where this currency could theoretically be electrical load itself, this is unacceptable. Blockchain uses a collected distributed ledger system to solve this problem, where any transaction not found in over 51% of the system is considered invalid. Johanning et al have this to say about blockchain as a peer-to-peer energy solution: "They are the foundation for creating digital assets. Since they also solve the double-spending problem, technology and disruptive potential through 'the creation of a market using a smart contract' is decisive here"[3].

3.1 Ledger Approach

Blockchain makes use of a distributed ledger system to keep track of transactions. Accordingly, many blockchain-backed implementations include using this ledger to track load currently in the system. The fact that this ledger gets distributed allows those with access to it to be conscious of the current supply and demand. Additionally, the ledger allows everyone involved to see the past transactions, which also assists in load forecasting and transparency. Similar, the microgrid approach allows forecasting to occur on a more granular level, increasing the overall accuracy within each group. This results in less wasted generation, which is better both for the environment and savings.

The ledger forecasting also allowed for coalitions to be formed on the basis of generation and usage. While typically some amount of user anonymity is maintained in these trials, the blockchain can potentially recommend users to one another in order to maximize the net social efficacy of the exchange as well as to maximize utility within the system as a whole, as seen in Sid et al's efficiency assessments[4].

3.1.1 Transparency

The major promise of transparency via blockchain can sound contradictory at a glance. As a system, it advertises transparency, but it also claims to be a "trustless" system. The distributed ledger allows all transactions within the chain to be viewable by all engaged in the network, which is transparent, but these systems also typically anonymize the participants in some way, restricting the knowledge exposed about each user to solely their transactions. In this way, a form of trust is formed, but based solely on the behavior documented and not on externalizing factors. Per Wulf, "by establishing a network of transacting parties that trust each other despite anonymity, the technology enables unbiased transactions and eliminates prejudices against minorities[5]". In this way, blockchain can act as an equalizer, protecting marginalized communities from discrimination that may otherwise take place in a peer-to-peer environment.

3.2 Building Resilient Communities

It is also argued that using blockchain in this model will lead to more resilient grids and communities. Microgrids backed by blockchain make managing load relatively simple, which logically leads to fewer brown-and-blackouts. To the same end, power primarily comes from the community itself, meaning sources are localized and easier to access and repair than the remote generation and equipment generally encountered in traditional centralized models.

Additionally, by having blockchain-backed microgrids, communities are encouraged to invest in themselves rather than in centralizing agents. As seen in Figure 2, people at 0-100% of the Federal Poverty Level carry the most financial burden in terms of energy spending, which also means they gain the most proportionally from the lower energy prices and decreased waste that blockchain allows. Increasing the financial independence of lower-income communities in turn allows them to be more financially resilient as well. By shielding marginalized communities from discriminatory trading practices while also increasing the overall wealth in said community, a blockchain-based model shows a lot of promise in terms of the ethical and social implications of peer-to-peer energy trading.

In their review, Johannig et al note the following: "While most projects did not remark on either the social context or community building, those that did were rather passionate about it" [3]. The community based perspective is not a popular consideration amongst the case studies, with many other case studies focusing solely on the ethical benefits behind green energy utilization. While this focus is not concerning on its own, it may not be a compelling argument to potential users who view green energy as too expensive a prospect for them to realistically participate in. In order to make peer-to-peer energy more interesting for these people, it would be more productive to emphasize the aspects that would affect their daily life, rather than more big picture concepts. Someone may suspect that green energy options would be inaccessible to them, but being told that peer-to-peer energy would result in fewer blackouts and allow for more income to be invested in their community may be more compelling.

That being said, some of the case studies seemed to be very aware of the ethical implications that peer-to-peer had in regards to building resilient communities. Power Ledger, a group reviewed in Johannig et al, advertises as such: "Human energy will change the face of the energy system because instead of being focused solely on profits, it will focus on the broader needs of communities, on aspirations for independence and co-creation, and the long term sustainability of energy creation and consumption" [9]. By being able to move away from the profit-based model seen in many monopolistic utilities, peer-to-peer energy allows for prosumers to instead make choices dependent on what is best for their community specifically rather than prioritizing the needs of the many over the needs of the few, as well as not having to worry nearly as much about what choice will turn a profit.

Vlux, which is another reviewed group, also keeps the community aspect center-stage in their whitepaper. They advertise the blackout resilience, but they also emphasize the social cohesion such a system would allow for, discussing how prosumers can support community groups both by trading load with them, as well as backing them financially with the income saved from local generation[10].

As these are both messages espoused by two currently-running, blockchain-backed, peer-to-peer energy trading companies, there is reason to believe that building resilient communities is an actual concern of some of the groups aiming to roll out this technology. If this vision is properly rolled out, then blockchain-backed peer-to-peer models have a lot of potential for increasing the quality of life for disadvantaged communities through decreasing the proportion of income spent on utilities and also allowing that excess income to be reinvested into their communities.

4 Concerns of Blockchain Applications

To the general population, blockchain is not terribly well understood, especially when one disentangles it from cryptocurrency applications. While one of the goals of such a model involves a trustless network of users, the users themselves still need to be able to have to trust in the network itself for the model to have any validity. This is doubly true for a basic utility such as power, so at the very least a widespread implementation of a blockchain-backed model would require adequate education of those engaged, a point that was not brought up in any of the case studies reviewed when discussing potential for a wider rollout.

Trial runs for peer-to-peer are still in their infancy, especially in regards to blockchain. In a comparative review of such trials, Park et al claimed that "it is still difficult for individuals to freely trade electricity, and the scale is also rather small"[6]]. While the blockchain-specific trials have typically made it easier for transactions to occur, this approach still presents several concerns for engineers to tackle.

4.1 The Blockchain Trilemma

Figure 3: The Blockchain Trilemma. [7]

In a way, blockchain is at odds with itself. The Blockchain Trilemma was a concept introduced by the founder of Ethereum, Vitalik Buterin, to describe the issues blockchain technologies had with balancing their goals in regards to scalability, security, and decentralization. While the concept was originally introduced to describe cryptocurrency environments, these issues expand to the core of all blockchain-backed technologies.

Scalability typically refers to the number of transactions a blockchain can process in a certain amount of time. Namely, due to the distributed ledger network, the more nodes are in a given blockchain means more distributed ledger copies need to be updated for each transaction.

Security refers to the distributed safety of the network in general. Due to its structure, blockchain is susceptible to something called a 51% attack. Part of blockchain's fraud resistant nature means that if less than 51% of nodes register a transaction, it is considered invalid and wiped from the distributed system. However, should a specific entity have control over 51% of nodes in a network, fraudulent transactions could easily be entered into the ledger without any issue. One can avoid this issue by having a diversified node population, but this leads to issues with scalability mentioned above.

Decentralization focuses on the core of blockchain - the trustless distributed ledger network. Blockchain technologies are supposed to allow participants to not have to trust in a centralizing body to validate transactions. However, in order to be cognizant of security concerns and flaws in the blockchain, a centralization agent of some form is frequently required. For instance, a common solution to security concerns involves having multiple blockchains essentially managing the same data, but this would then require some additional body to cross check the two ledger systems and decide which one is at fault during an attack.

The trilemma is of vital concern to peer-to-peer energy trading. One of the main benefits of such a model would be to take full advantage of the decentralization blockchain allows and move away from having to get power through a utility. However, several proposed models depend on interactions between microgrids to deal with scale[8][4]. If each microgrid works off of its own blockchain, then decentralization must be ceded where these grids overlap. These smaller microgrids also introduce security issues, as it's very possible for a rental company to own a high proportion of properties within a certain geographic area, opening up a possibility for a 51% attack. If the entire grid works off of one chain, scalability issues come into play, which could lead to humanitarian issues in cases of blackouts where many transactions may occur at once.

While most of the case studies reviewed for this project attempted to fix one of these problems, none of them did it without falling victim to the trilemma and worsening another issue. Currently, the trilemma does not seem like something that can be overcome or "beaten" and instead must simply be balanced according to what is best for its current application.

4.1.1 Balancing Privacy and Transparency

In order to better illustrate this concept, an assessment will be done on Lu et al's proposed peer-to-peer model, which tries to prioritize privacy (and therefore, security)[12]. The authors opt to manage this privacy protection by developing a new mode of encryption and comparing it to PETCON, a consortium blockchain model that is gaining in popularity that balances the trilemma well. Their new system makes use of a dual-level ciphertext that requires decrypting before a user can participate in the auction.

This model does a good job of illustrating the difficulties that engineers of these systems have to keep in mind when balancing user privacy, system security, and overall transparency of a process within a trustless system. In theory, it makes sense that if a system is indeed trustless, one does not need to know the identities of other trading users. However, depending on the scale of the microgrid, protecting privacy can become very complicated, especially if the user pool is restricted.

Complete anonymity can also be difficult when transactions are concerned, as it is expected that at some point identifying information will be in the blockchain if only to connect an account to a bank for monetary transactions. The authors' method involves dual encryption as well as the inclusion of both accounting and arbitration nodes to keep track of transactions. While these inclusions are not unique to their approach, but have an additional element of the chain calculating out the credit score of users as a part of transaction arbitration, which raises the stake of data security even more securely.

This credit score inclusion may make sense in a transaction application, but it also introduces the question of how transparent a system can or should even be. Electricity is an essential utility, and even those with bad credit need access. If credit scores play into the user data, this model begins to run the risk of violating ethical guidelines in favor of maintaining transparency into users. At the same time, it also makes sense that in a peer-to-peer trade one would want to know the reliability of those involved in an auction before they agree to complete a transaction. While the approach the authors take makes sense, it also severely raises the stakes of a privacy breach to not only reveal a person's identity, but also their credit information.

They implement their dual-encryption methodology to help make the changes of such a breach unlikely. This method does succeed, but as the blockchain trilemma suggests, a trade off occurs in the realm of the model's responsiveness.

As seen in Figure 4, the dual encryption model does not perform better than PETCON, but only by a marginal amount. This marginal increase in time may not seem significant, but even PETCON's baseline performance is already not considered efficient enough to completely depend on. Furthermore, the new model follows a similar curve as PETCON, meaning it is also unlikely to scale and better than its predecessor.

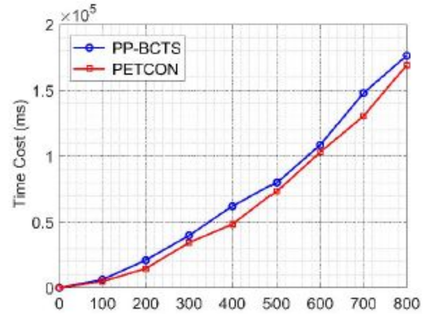

Figure 4: Relationship between number of transactions and overall time cost to system. [12]

Lu et al's model helps to illustrate the push and pull factors in peer-to-peer trading systems between balancing privacy concerns with transparency into the marketplace. However, it also helps to show how difficult it can be to navigate the blockchain trilemma; while it makes sense that one would want to prioritize privacy protection, it comes at the deficit of performance, resulting in poorer scalability.

4.1.2 Scalability

Scalability is a constant concern in blockchain applications, especially in regards to energy trading. Microgrids help to ease some of the difficulties that can come with managing response time, but microgrids lack a specific population size, making it hard to find a general case solution.

F. Luo et al [8] proposed a system for peer-to-peer energy that included both levels of the microgrid as well as the grid connecting them. Despite this, they also manage to keep their model going without a centralizing agent, making their model a strong example of a true peer-to-peer system.

Among the assessments run on their model dataset, they calculate the average amount of time per task, both as the number of users and number of tasks increase. This dataset illustrates two main points: the number of tasks that these models can generate even with a limited number of users, and the amount of time those tasks can take. The results can be seen in Figure 5.

The relationship between total number of tasks and users is reasonable. It increases at a steady but low slope, but even at six users, hits about 1,750 tasks. This is important to keep in mind when models try to solve issues within the trilemma by adding new levels of encryption or generating more keys for users - adding these tasks will increase the number of tasks significantly, especially as the number of users potentially increases.

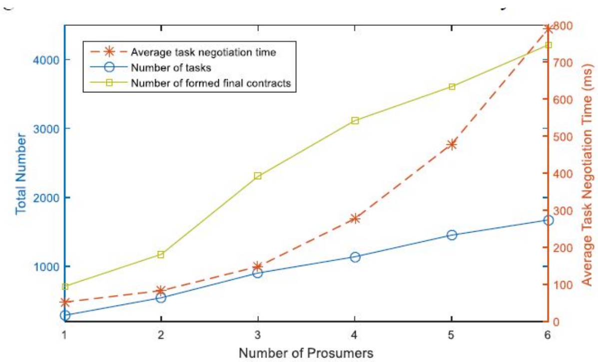

Figure 5: Variation in total number of tasks and final contracts and average negotiation time. [8]

The average task negotiation time hits about 8 seconds by the time 6 users are added to the grid. This number is quite low, as a microgrid is very likely to include more than that amount of prosumers. For example, in Chau et al[4], assessments were run using real-world data from a test run of a peer-to-peer energy system, and they had 31 users at a time. 8 seconds is already a considerable amount of time to process a task when one may be purchasing power in the case of an emergency, but were the trend to continue with 31 users, the task time with this model may take as long as a minute or more, which is unacceptable in a crisis.

Scaling is a common issue across all blockchain applications. Many proposed solutions to issues in peer-to-peer models are fixed simply by scaling up the blockchain to a certain point, or diversifying it, but this always comes at the cost of performance. For some applications, this is an inconvenience, but for an essential utility, the possible repercussions are too severe to ignore.

The blockchain trilemma seems to be an unavoidable aspect of any blockchain application. The solution many attempt when confronted by it is to simply fixate on a single aspect of the triangle. In these and several other case studies reviewed in this research, the other aspects of the trilemma were always sacrificed, frequently in ways that made their model unethical to deploy.

4.2 Price of Anarchy

The price of anarchy is a measurement used to assess how well a system functions assuming a certain amount of selfish behavior within a group. Sid et al. [4] focused their analysis of blockchain-backed peer-to-peer energy trading on taking data from a real world trial and using various cost splitting methods across coalitions to determine the total utility yielded. Equal split meant that all agents paid the same amount regardless of consumption, proportional split meant that agents paid proportional to their consumption, and egalitarian meant that everyone paid the amount needed for them to all receive the same amount of utility.

Sid et al [4] set out to properly quantify the price of anarchy that can be expected in a variety of coalition formations to solve the cost sharing problems. One of the primary benefits of the peer-to-peer model includes price reduction for those involved, but this is only the case if groups are formed in a sensible manner to ensure minimal resource waste. This is best done through optimized forecasting as well as selective coalition forming.

They then operate under the assumption that people will form their coalitions based on what yields the highest utility within reason. This should also allow these coalitions to be stable, as people are likely to exhibit similar energy consumption behavior over time. However, they bring up the fact that under this assumption, if there was more utility to a single agent in isolation, they would elect to not participate in a coalition and essentially hoard their utility.

In order to explore this concept deeper, they decided to run some automated coalition forming on data collected in an industry trial run, and explored three different cost-splitting methods that users seemed likely to engage in. The first was the equal split model, where the cumulative cost accrued in the microgrid was split evenly across all users. This split is relatively simple to calculate, but disproportionately charges those who may only use the microgrid on occasion, while financially benefiting those who use it frequently and may be causing most of the actual wear on the infrastructure. Predictably, this resulted in the lowest amount of total utility to users, and as such should be avoided.

The second method was proportional split, which is a method closer to how costs are split for a user in a traditional grid system. Everyone pays an amount proportional to their use of the grid, which means that no user benefits notably above another, and payment is dependent on the behavior of the individual over the group as a whole. This has the benefit of allowing the user some control over the amount they pay, but actually resulted in only negligible total utility increase across the coalitions formed.

The last option they assessed was the egalitarian split. This cost sharing model is intriguing in that it splits the cost between users in a way that ensures that each user gets an equal amount of utility out of the system. This process has the benefit of keeping in mind both need and ability to inform how much a user pays, and has the additional benefit of yielding a far higher total utility output when compared to the other cost sharing methodologies. However, this method is also the most complex to calculate, meaning that coalitions have to be formed within relatively strict guidelines in order to lose the least amount of utility to the cost of anarchy. When executed appropriately, the utility loss is negligible from the optimum, but the question remains: how does a group execute this appropriately?

Something not assessed in the paper is how likely it is that such a coalition would be organically formed. If it is unlikely, then the only way to form a socially efficient coalition means following algorithmically generated recommendations. While this may be good for the group as a whole, it takes away from the independent choice of users in the grid. Without such an assessment, these cost sharing models are interesting, but seem to lack an important part of the puzzle in regards to how a peer-to-peer model would realistically function.

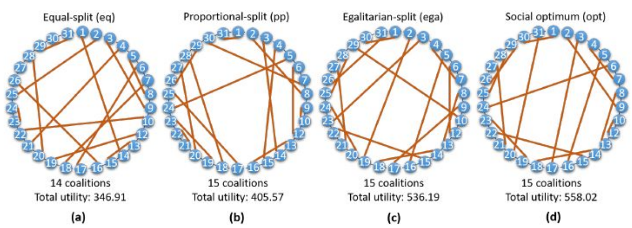

Figure 6: Total utility output with a variety of cost sharing methods [4].

The outcomes of the cost-split assessments are shown above, with the last graphic indicating the optimized coalitions. The loss of utility between the various methods from this social optimum helps us understand the price of anarchy in each situation. In order for the model to be socially efficient, and therefore ethical to implement, coalitions must be formed in a sensible way to minimize the price of anarchy. However, this ideal coalition forming would impede the freedom of agents to select the peers with whom transactions occur, counteracting the freedom of choice peer-to-peer would ideally allow. It could also be argued that this process of guided coalition forming is too close to ceding the decentralization that makes a blockchain-backed approach attractive in the first place.

5 PriWatt - A Case Study

In order to better understand the intersection of blockchain technology benefits and limits and peer-to-peer energy trading models, this part of the essay will cover a theoretical system developed by Aitzhen and Svetinovic called PriWatt[11]. PriWatt's approach involves maintaining the decentralized, trustless trading system, with additional inspiration from Blockchain's protection-protecting messaging system between users, as well as its mining as proof-of-work. The researchers add in their own concept in order to improve the privacy preservation of the system in the form of making use of multi signatures to ensure the validity of transactions. In their paper, they walk through two main scenarios for energy trading: trading full ownership of a prosumer's stored energy to another user, and trading partial ownership with use of a micropayment channel.

Trading full ownership implies trading the entirety of a block of stored energy. When someone wants to sell their power, they are given a transaction address and a message address - generating these per transaction help to keep privacy preserved while still allowing for some communication between buyer and seller. A message then goes out to other members of the smart grid, advertising the auction with the amount of energy being offered.

From here, another user can enter the marketplace and filter by their desired criteria, including price and amount of energy available. From here, they will get their own additional set of message and transaction keys, and can reach out to begin the trade. Once the trade is successfully completed, the energy is passed to the customer and the chain begins to update.

Now, what has been glossed over above is the third participant in the transaction - the DSO, or Distribution System Operator. Much of the initial communication between the users actually occurs with the DSO as a proxy. Vitally, the DSO has access to a database which helps them to validate any values stated by the customers and suppliers, so that people could not lie about the amount of energy they had access to. They also generate and have access to two hashes, one that marks the ownership of the energy currently and another that serves as a lock on the energy. This lock allows the system to circumvent the double spending problem both on the customer and supplier ends of the transaction. Up until this point, the DSO could arguably be a program of some sort, but the DSO also plays another vital role: managing claims. Every transaction requires multiple signatures in order to make the exchange complete, and if anyone does not sign, then the transaction is considered invalid. Someone can reach out to the DSO to try and resolve any conflict that has arisen, in which case the DSO will make the call on who is in the right. The transactions are also time locked, so if too much time passes (24 hours in this case), a refund occurs. Because the DSO must facilitate this communication in such a way, it would seem that the DSO must have some human element.

The partial ownership problem proceeds much the same way, but the authors note that by virtue of PriWatt borrowing so much from Bitcoin in terms of functionality, there are concerns about fees on microtransactions becoming overwhelming, as well as deprioritizing auctions that are placed within a certain timeframe as a part of an anti-flood algorithm.

5.1 Benefits

Many of the benefits of PriWatt are self-evident with it being a peer-to-peer energy trading system. Prices are still advertised to be lower than traditional methods, and prosumers can avoid making use of a large centralizing agent like a utility company.

That said, PriWatt acts as a case study in attempting to create a more secure form of peer-to-peer energy system, with the additional benefit of taking advantage of technology already popular in Bitcoin applications. This has a benefit of not trying to duplicate work in building such an application by "reinventing the wheel", and should in theory result in more secure transactions. Indeed, it would seem that with the system they generated, transactions would be extremely secure and fair, with all agents involved having to agree on the transaction terms before an exchange is considered valid.

Additionally, the large amount of randomly generated hashes per transaction makes it very difficult for people to imitate one another or otherwise try and execute fraudulent transactions, either by imitating another or lying about the amount of energy available in a transaction. The inclusion of the DSO also should in theory help to stymie predatory pricing or deals on the marketplace should someone try to take advantage of a dire situation for profit.

5.2 Drawbacks

Despite these benefits, PriWatt presents several concerning problems as well, not all of which the authors explicitly discuss in their assessment of their work.

Among the issues they do discuss, latency is a large concern.

	Centralized	Decentralized
Monitoring rate (s)	2 - 60	30
Protective relaying (ms)	4	600*
Availability latency (s)	5	10
Operational latency (s)	<1	5.3

Figure 7: Performance Comparison for PriWatt.

As seen in Fig 5, while PriWatt was able to have a shorter and more consistent monitoring rate than the stated worst-case for a centralized system, it frequently more than doubled the time necessary for all other aspects of the transaction. This latency, when combined with the anti-flood algorithm that PriWatt borrowed from existing Bitcoin libraries, paints a very concerning picture for what could potentially happen within a microgrid in the case of an emergency like a blackout. It would seem that not only would the best case scenario result in a long wait time to get power back, but potentially the auctions to get said power would be deprioritized in the marketplace, making it harder to locate in the first place. The authors claim the latency is due to relatively low processing power available, but even this solution presents its own issues, which will be discussed later.

The inclusion of the DSO also introduces some issues depending how it is implemented. PriWatt is vague on how they would utilize it, with the main question being if the DSO would be a person or a program. Furthermore, if it is a person, would that person be another user within the microgrid, or would it be a trained outside agent? The very inclusion of the DSO moves away from the concept of decentralization, but would do so less if it was a program that theoretically treated all users fairly. However, a program will also inevitably not always be able to solve conflicts with the full benefit of context and nuance that may arise from a disagreement about something like access to power. Similarly, a person is not guaranteed to be fair in their assessment either, and if the system is truly anonymized, it would potentially be very difficult to hold inadequate DSOs accountable for their actions. The DSO in general also allows for greater security in transactions, but as the trilemma dictates, makes transactions take longer, impacting scalability negatively, and makes the process less decentralized.

In addition, PriWatt makes transactions themselves more secure but fails to ensure much in the way of real security in the system itself. The authors ran through a series of types of security attacks to see how PriWatt handled them, and then judged the level of impact the attacks would have on the system as a whole. While they claim that high impact attacks only seem to have a 21.7% chance of occurring in the first place, a staggering 69.57% of those attacks would have a high impact on the system. These values are extremely concerning, especially when the latency of the system is so high in a best case scenario already. It would seem that a blackout combined with an attack could severely impact the wellbeing of the users within the microgrid.

Most contradictory is the fact that PriWatt makes use of hash solving as their proof of work system. This makes PriWatt subject to the same environmental concerns that Bitcoin has with carbon emissions due to the mining process (which is what the hash solving entails). While this is concerning in isolation, it also directly counteracts one of the main benefits that a peer-to-peer energy system would allow. If increased access and generation of green energy is a part of the ethical benefits that such a system allows, what would be the purpose in then demanding and potentially wasting more generation in order to participate?

The most likely answer to this is that Bitcoin is already a well established blockchain-backed transaction system, and as such there is a natural draw to working off of it rather than reinventing an entirely new blockchain system. Bitcoin has several libraries and functionalities built into it that makes it seem like a good candidate, but it also all at once fails to properly balance the blockchain trilemma while also contradicting a primary benefit that its application would allow.

The authors do not shy away from the latency issues that PriWatt encounters, but seem to imply that this is a small problem that could be fixed with more processing power. Furthermore, they ignore many of the human impacts that these technical shortfalls would inflict on users, which further illustrates the blindspot that developers of these systems seem to have.

5.3 PriWatt As A Representative

Despite the clear issues with PriWatt, it is also simply one of many blockchain-backed peer-to-peer energy trading systems proposed out in the world. It was the one selected for a deep assessment in this essay because the paper was rigorous enough in its security and latency assessments that it stood apart from many others, while also being very in line with the lack of ethical concerns exhibited in other papers. In this way, it makes for a representative example of papers of its kind.

Most notably, PriWatt makes use of a proof of work system, which is not necessarily a universal concept across proposed systems. Proof of work involved mining to solve complex hash puzzles to receive tokens to be used during transactions. This system means that a 51% attack is dictated by whoever has access to the most processing power, which is an issue even on the large scale of Bitcoin, and would be an even larger possibility in the context of a microgrid. However, proof of work systems based on Bitcoin gives one access to the resources established in that community.

Notably, the main other system rising in popularity in the blockchain world is the proof of stake system. Rather than competition within the blockchain to solve a hash first, the chain is continued algorithmically, choosing users based on the stake they have in the system. While this approach would not allow you access to the more established resources of Bitcoin, this is the system that Bitcoin’s main competitor, Ethereum, uses. In this way, there are still resources developers can take advantage of to help reduce work duplication. In this paradigm, executing a 51% attack requires owning over half the tokens currently in circulation within the system. This is still a potential issue should generation be unevenly distributed within a microgrid, but would likely be more difficult to accomplish than simply being able to have the best computer in a group. Proof of stake also removes the mining process entirely, bypassing the environmental concerns present in proof of work paradigms.

In this way, PriWatt’s issues are all at once not necessarily ground enough to dismiss blockchain-backed peer-to-peer energy trading as a whole, but many the issues encountered within this case study are also indicative of many of the problems plaguing the field. It would seem like a proof of stake system would be beneficial to select over a proof of work system, but then this paradigm comes with its own concerns. Similarly, neither approach can truly escape the blockchain trilemma, and attempts to improve one of the three criteria therien consistently sacrifices the other two. It would seem the future of this field is dependent on the ability of developers to properly balance these issues, rather than attempting to solely solve one over the others.

6 Conclusions

The peer-to-peer energy trading model has a lot of potential as a means of better serving energy prosumers as they become more prevalent. Increasing community access to green energy, which is frequently only accessible to those in higher income brackets, is good for the population as a whole and may possibly lead to more conscious energy consumption. Implementing such a model with blockchain would then also allow for transparency of transactions and an easy way to view the state of the grid as a whole. This would in turn ideally result in lower energy waste, requiring less generation in general, and also allow for communities to be more independent without the need for a centralizing agency.

Enacting this model with blockchain technology would theoretically allow communities to bypass the need for a third party to manage electrical load, but would also introduce a bevy of concerns. While bypassing centralizing agents such as utility companies has a tendency to benefit marginalized communities, a grid solely dependent on blockchain lacks many of the measures in place to assist those who need the help the most.

As a technology, blockchain is not well understood by the general populous, and asking a group to trust it for something as essential as an electric utility without proper prior education is unreasonable. Additionally, the peer-to-peer model is dependent on external batteries to help manage nighttime load, which is not financially feasible for many. Blockchain also has inherent issues with privacy, security, and ability to scale.

While case studies have not ignored many of these issues, they are generally viewed more as stumbling blocks to implementation rather than as ethical issues. Out of interest of furthering the peer-to-peer model, many studies only coincidentally mentioned social repercussions. While not warranting a condemnation of a blockchain-backed peer-to-peer models, further case studies need to assess the barriers to entry such an approach would have to the general public and how to better cope with these issues without falling victim to the blockchain trilemma.

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