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Abstract

A P2P electricity market was modelled to process transactions every 20 seconds, and a simulation tool was created to obtain the total daily money flows between a consumer-prosumer pair. The inclusion of a DSS is also considered in the modelled system and simulation. The simulation results showed that the inclusion of a DSS is always beneficial for all parties in economic terms: consumers and prosumers could save up to 6.4% and 49 % consecutively.

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Abstract

Current electricity distribution systems allow prosumers to sell their surplus electricity back to the Distributed Network Operator (DNO). The export tariffs at which these sell-backs take place are considerably lower than the feed-in tariffs, offering little incentive to prosumers to sell their surplus energy. A peer-to-peer (P2P) electricity market where consumers and prosumers can interact by selling and buying energy between them at a premium rate that is lower than the standard feed-in tariffs but higher than the export tariffs is proposed. Such a system was modelled to process transactions every 20 seconds, and a simulation tool was created to obtain the total daily money flows between a consumer-prosumer pair. The inclusion of a Distributed Storage System (DSS) is also considered in the modelled system and simulation. The simulation results showed that the inclusion of a DSS is always beneficial for all parties in economic terms: consumers could save up to 6.4% on the cost of their electricity while prosumers could save up to 49.1%. A DSS could generate an income flow for the DNO of up to 6.9p/day per each consumer-prosumer pair.

Novel economic modelling of a Peer-to-Peer Electricity Market with the inclusion of distributed energy storage - the possible case of a more robust and better electricity grid.

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HIGHLIGHTS

- P2P electricity market architecture with dynamic computed tariffs was proposed
- A simulation of the money flows between all parties of the system was created
- Initial simulation results showed likely savings for both, prosumers and consumers

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ABSTRACT

Current electricity distribution systems allow prosumers to sell their surplus electricity back to the Distributed Network Operator (DNO). The export tariffs at which these sell-backs take place are considerably lower than the feed-in tariffs, offering little incentive to prosumers to sell their surplus energy. A peer-to-peer (P2P) electricity market where consumers and prosumers can interact by selling and buying energy between them at a premium rate that is lower than the standard feed-in tariffs but higher than the export tariffs is proposed. Such a system was modelled to process transactions every 20 seconds, and a simulation tool was created to obtain the total daily money flows between a consumer-prosumer pair. The inclusion of a Distributed Storage System (DSS) is also considered in the modelled system and simulation. The simulation results showed that the inclusion of a DSS is always beneficial for all parties in economic terms: consumers could save up to 6.4% on the cost of their electricity while prosumers could save up to 49.1%. A DSS could generate an income flow for the DNO of up to 6.9p/day per each consumer-prosumer pair.

1. Introduction

In our current urban environment, cities are usually provided with electricity by the so-called National Electricity Grids. These grids are powered by large plants (e.g. coal, nuclear, gas, wind etc.) and the electricity produced is transported using long transmission lines to the end consumers. This conventional approach is known as Centralised Distribution.

In recent years significant advances in renewable energy technologies have considerably reduced the cost of small-scale energy generation systems. This has resulted in a rising number of consumers producing electricity locally within their premises and selling any surplus energy back to the grid. However, the sell-back tariff is substantially lower than the feed-in tariffs as our current electricity grids were not designed to function in this way.

The factors mentioned above have opened the door to a new generation of trading solutions that seek to improve the operation of current electricity grid. This paper presents a model that explores the potential of a peer-to-peer electricity market. This is a system that would allow end-consumers with local generation of electricity to instantaneously sell their surplus energy to other end-consumers within the same network, making use of smart meters along with the internet and possibly technologies such as Blockchain.

This approach seeks to increase the sell-back tariffs for end-consumers that produce electricity locally, while at the same time decreasing the feed-in tariffs for the other end users that buy the electricity surplus.
The objective of this paper is to provide an initial conceptualisation of a novel peer-to-peer (P2P) electricity market by addressing the following research question: What are the main influences of the consumer - prosumer oriented technological innovations?

Accordingly, this work will provide a literature review and state of the art of P2P electricity markets in Section 2.

Section 3 will firstly describe the model architecture and considerations of current electricity market distribution. In addition a description of the proposed novel electricity market architecture and the introduction of a distributed energy storage system will also be discussed. This is an opportunity for the small-scale producers to avoid the initial cost of buying local energy storage units while giving an opportunity for the Distributed Network Operators (DNOs) to generate revenue in an 'instantaneous' rent-of-storage basis.

Section 4 provides the modelling and simulation of 16 different P2P market scenarios and considers both the economic and practical limitations of said models. . Section 5 provides consideration and recommendations for the regulation of the new market design. Section 6 sums up the main conclusions.

2. Literature review and state of the art of peer-to-peer electricity markets

2.1 Peer-to-peer (P2P) economy

The concept of a P2P economy, also known as a sharing economy, relates to a decentralised market where individuals can execute transactions directly, without the need of involvement of a central institution or third party [1].

However, these so-called 'third parties' execute a number of important tasks that are needed for economies to thrive, such as the verification of transactions, and serving as intermediaries between unknown individuals.

In this type of economy, these tasks are accomplished by means of utilising online computer systems i.e. information and communication technology (ICTs). These systems allow for the secure processing of high volume transactions in very short intervals of time.

2.2 P2P electricity markets

Technologies such as solar photovoltaic (PV) panels now allow single consumers (households) to produce electricity locally, meeting part or even all of their own demand. In most cases, there are parts of the day at which the energy produced surpasses the electricity demand. During these times, there is electricity available that could be sold to another consumer in the vicinity. Such a situation gives rise to the potential for a P2P market.

A P2P electricity market is generally composed of consumers and prosumers. Prosumers are consumers that are able to produce electricity locally and therefore, at times, become producers. The ICT system then allows for the buying and selling of electricity to take place in real time [2].

2.3 P2P electricity markets in Europe

Although the idea of a P2P electricity market is still fairly new, there are already a few implementation cases around Europe:

2.3.1 Germany

SonnenCommunity is a P2P electricity market launched in February 2016 that has a heavy emphasis on battery storage; all of the prosumers of this market need to have a battery storage unit produced by Sonnen GmbH. It utilises a proprietary 'virtual pool of energy' so that prosumers and consumers can buy and sell energy even if there are far away from each other. This works by balancing the energy requirements of the grid 'intelligently' [3].

2.3.2 The United Kingdom

Piclo is a company that provides an online platform for P2P energy trading from late 2014. It has received funding from the UK Department for Business, Energy & Industrial Strategy (BEIS). It offers different mechanisms to match local demand with local production of energy such as the use of existing spare network capacity of the UK's Distribution Network Operators (DNOs). It includes a concept of 'Virtual Private Wires' that allow for non-local transactions to be settled by balancing the grid energy requirements [4].

2.3.3 The Netherlands

Vandebron is a company that offers an online platform that allows green energy producers to directly sell to willing consumers, and it does not exactly match the P2P electricity market definition offered above, as the producers and the consumers are not peers just yet (i.e. the producers never become consumers). However, it does allow for the elimination of third party retailers and introduces the use of ICTs in order to facilitate point-to-point transactions [5]. The technology offering by Vandebron could allow for the future support of a P2P electricity market.

2.4 Distributed storage and P2P electricity markets:

Due to the intrinsically intermittent nature of renewable electricity sources, especially the one considered for the modelling process of this project (solar PV panels), any form of battery storage becomes attractive. Over recent years lithium-Ion batteries have become the most popular form of electricity storage due to reducing costs and improved energy densities. This is largely due to their uptake in the automotive industry.

However, even though the most widely known form of local energy storage are residential battery packs – i.e. the use of a local battery storage unit for the dwelling's own internal consumption – larger scale storage units that can be shared between many dwellings can offer important benefits to a P2P electricity economy as they can:

- Alleviate the peak periods of energy demand, allowing to cut down on the usage of rapid response power plants which are usually powered by non-renewable resources.

- Allow prosumers to sell their energy surplus to be stored in these storage units. An incentive for prosumers to do this would be a higher rate of return compared to current normal export rates to the normal grid.
- Allow the DNOs, to maintain and improve their current infrastructure, by providing a new revenue flow by reselling the stored energy that the prosumers generated at a higher price point later on the day. This price point must be higher than the export rate paid to the prosumers but lower than the standard rate of the electricity grid so that prosumers and consumers benefit from it and have an incentive to pay it.

3. Model architecture and considerations

3.1 The current electricity distribution and market architecture

In the current electricity markets, consumers buy electricity from the Distribution Network Operator (DNO) using a distribution infrastructure that has been originally built to distribute energy from central power plants to the end-consumers. The electrical energy that is provided to the consumers is charged at about 12.38p/kWh [6]. Through this paper, this tariff will be referenced as Ts or 'standard tariff'.

In these systems, in addition to consumers, there are also the so-called 'prosumers'. These are consumers that generate electricity locally for example, with the help of a solar PV installation. They use the electrical energy generated locally to meet part or all of their demand. In some cases, during certain times of the day, there is a surplus of energy produced that can be sold back to the DNO at a lower tariff. This tariff is referenced throughout this document as Te or 'export tariff' and currently stands at about 4.85p/kWh [7].

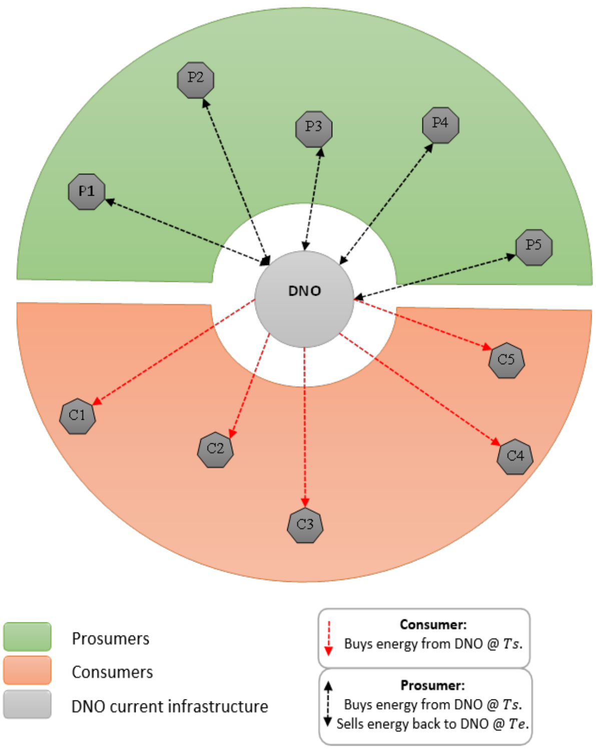

Figure 1: Current electricity market architecture.

Figure 1 illustrates the electricity market architecture.

New models are now emerging that take advantage of the reducing costs of renewable technologies and the advancments in ICT that have the potential to transform the electricity market. Such models aim to reduce the current dependency on fossil fuels by introducing more renewables in the energy mix as well as making current systems more efficient. These changes usually come at a considerable price, which is why this project explores the critical idea of using ICT advances to possibly create a better and smarter electricity market. This is needed toincentivise consumers to become prosumers and potentially relieve some of the pressure on current DNO infrastructure.

3.2 The proposed electricity market architecture

The proposed architecture relies on using the current physical distribution infrastructure, but changes the way the market functions by introducing a new way of buying and selling energythrough frequent and small P2P transactions. These transactions take place 'semi-directly' between prosumers and consumers as well as directly with the DNO.

Some transactions are called 'semi-direct' as they still need to use the DNO's infrastructure,as there is unlikely to be a direct link between the prosumer and the consumer. However, each transaction is processed as if there was. To account for the distances between prosumer and consumer, the model introduces a 'loss percentage' factor as a fraction of energy that is lost during the sale of energy from prosumer to a consumer.

This 'loss percentage' ($loss\%$) of energy also serves as a way to model the fees that the DNO could charge for the use of their infrastructure as a platform for these transactions to take place. If the fees are proportional to the energy being sold/bought, then they can be modelled on a percentage basis.

The proposed system uses an 'ICT layer' that works closely with the DNO in order to match production and demand of electrical energy within a node or area. The ICT layer finds a customer that requires energy in the vicinity of a prosumer that has a surplus of energy. The prosumer sells this surplus of energy accounting for losses, at a premium rate Tpc. This rate sits at the average of Ts and Te so that it becomes attractive to both prosumers and consumers.

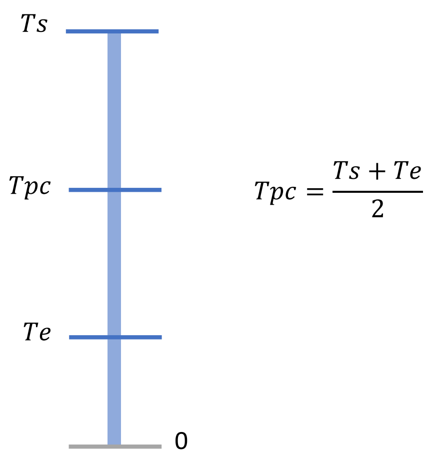

Figure 2: Different tariffs in the proposed energy market

Figure 2 illustrates the relationship between the different tariffs that exist in the proposed electricity market.

The premium tariff Tpc is attractive to prosumers as they would otherwise sell their energy surplus to the DNO at Te, and it is also attractive to consumers as they would normally buy energy from the DNO at Ts.

If during certain moments, there happens to not be any demand of energy from the matched customer, the prosumer can still sell the remaining surplus energy to the DNO at Te, as normal.

Similarly, if there is no surplus energy available from the matched prosumer, consumers can still buy energy from the DNO at Ts.

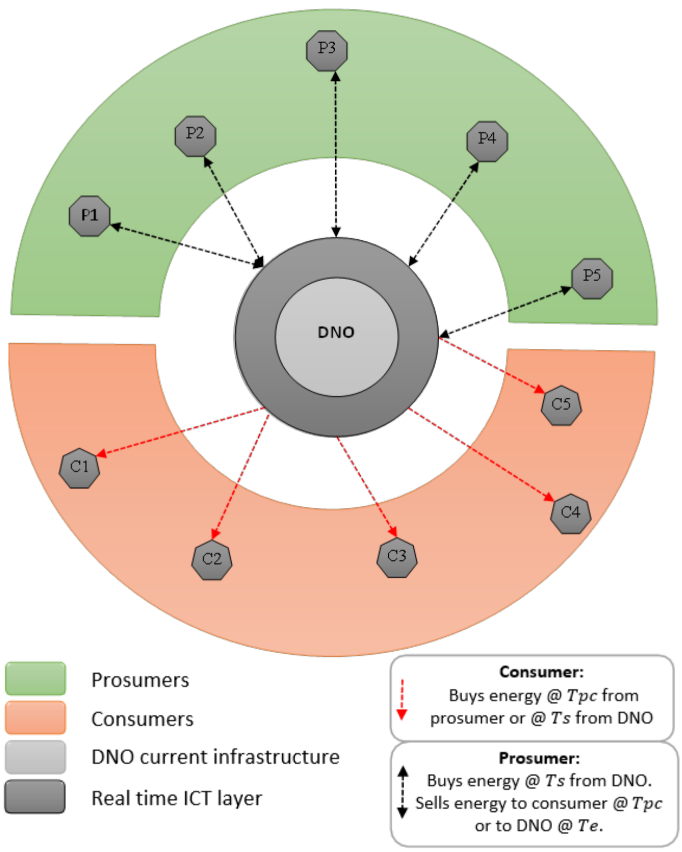

Figure 3: Proposed P2P electricity market architecture.

A diagram illustrating the proposed P2P electricity market is shown in Figure 3.

In the architecture shown in Figure 3, the main feature is the 'Real-time ICT layer' which is part of the system that would work closely with the DNO to match prosumers with consumers and execute the transactions in 'real-time'. In reality, the system settles transactions every 20 seconds as will be detailed in the next section.

3.3 The advantage of a Distributed Storage System (DSS)

It is important to emphasise that in order for the proposed P2P electricity market to function, the current DNO's infrastructure is needed. Therefore, an incentive should exist that allows for the DNO to maintain its infrastructure i.e. a revenue flow.

For this reason, the idea of a Distributed Storage System (DSS) is introduced. The DSS is meant to be spread across the DNO infrastructure and allow for certain storage capacity in the form of batteries. Prosumers then can sell their surplus energy to the DSS if there is not enough consumer demand at a certain time, instead of selling it back to the DNO directly.

This approach makes sense if the selling tariff at which the prosumers sell energy to the DSS is still higher than the exporting electricity to the grid (export tariff Te); and if the tariff at which the consumers and prosumers buy energy from the DSS is still lower than Ts:

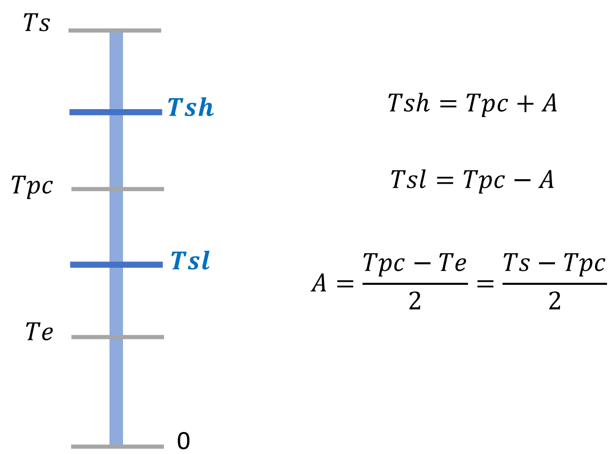

Figure 4: All tariffs involved in the final proposed system (including DSS).

The two new tariffs, Tsh and Tsl, are the tariffs at which the DSS's transactions are settled.

The DSS buys energy from prosumers at Tsl, stores it, and sells it back to either a consumer or a prosumer at Tsh. This way, for each unit of energy that is bought and sold by the DSS, a revenue of $Tsh - Tsl$ is generated. This is an approach that allows the DNO to benefit from the system architecture. This is a desired outcome since the DNO is in charge of the maintenance of the necessary infrastructure for the proposed system to function.

This final system architecture, including the DSS, is illustrated in Figure 5 below:

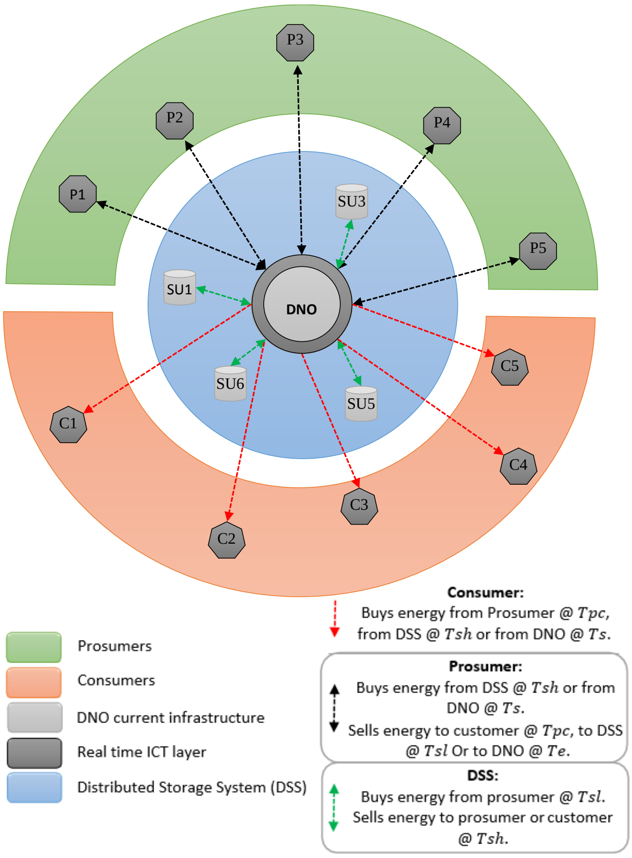

Figure 5: Final proposed P2P electricity market architecture including a Distributed Storage System (DSS).

4. Simulation of P2P Scenarios

4.1 Simulation profiles

For the simulation of the proposed systems, two consumption profiles high and low consumption, as well as two generation profiles high and low generation, were created to match real consumption/generation data from households in the UK [8] [9].

- High consumption profile: a total consumption of 12.6kWh during a day; at the current standard Tariff Ts mentioned in the previous section. This adds up to a total cost of 156.45p (TCh), this value will serve as a base value for comparisons in the next section of this paper.

- Low consumption profile: A total consumption of 5.2kWh during a day, adding up to a total cost of 64.29p (TCl), this value will also serve as a base value for calculations in the next section of this paper.

- High generation profile: Designed to match a total daily energy yield of 3.6kWh.

- Low generation profile: Designed to match a total daily energy yield of 1.5kWh.

The above profiles allowed for the following consumer and prosumer types to be created:

- Consumers type H: Consumers that are assigned the 'high consumption profile'.
- Consumers type L: Consumers that are assigned the 'low consumption profile'.
- Prosumers type HL: Prosumers that are assigned the 'high consumption profile' and the 'low generation profile'.
- Prosumers type HH: Prosumers that are assigned the 'high consumption profile' and the 'high generation profile'.
- Prosumers type LH: Prosumers that are assigned the 'low consumption profile' and the 'high generation profile'.
- Prosumers type LL: Prosumers that are assigned the 'low consumption profile' and the 'low generation profile'.

Considering all the consumer and prosumer types, the match of a consumer with a prosumer could be made in eight different ways, as described in the table below:

		Consumer-Prosumer combinations			
Consumer types	L	**L-LL**	**L-LH**	**L-HL**	**L-HH**
	H	**H-LL**	**H-LH**	**H-HL**	**H-HH**
		LL	LH	HL	HH
		Prosumer Types			

Table 1: All eight consumer-prosumer combinations.

As illustrated in the table above, each consumer-prosumer combination is labelled using the format 'X-YZ' where X is the type of consumer and YZ is the type of prosumer.

The simulation of the modelled peer-to-peer electricity market was successfully made to recreate transactions in short time intervals; each simulation execution calculated a total of 4320 transactions for a day, which sets the time between transactions to only 20 seconds. PV generation profiles are based on real generation data from existing solar installations in the city of Leeds, UK.

4.2 Simulation particularities

The simulation of the system was mainly written in VBA (MS Excel) and the results generated were the money flows for each transaction between a consumer/prosumer pair during a whole day. It was assumed that a transaction is settled every 20 seconds.

Each of the eight consumer/prosumer combinations (see Table 1) was simulated twice to account for the existence of a DSS.

The simulation raw results are shown in the following section.

4.3 Simulation of raw results

The tables 2 - 6 below show the total accumulated money flow for a complete day (24 hours) of transactions (4320 transactions, with 20 seconds between transactions). Positive values mean money that the consumer/prosumer will have to pay for the electricity consumed during the day.

		Consumer money flow [p/day]			
	Consumer types	LL	LH	HL	HH
No DSS	L	**63.0**	**62.0**	**64.0**	**63.4**
No DSS	H	**155.1**	**151.8**	**156.5**	**155.3**
DSS	L	**62.6**	**60.2**	**63.9**	**62.9**
DSS	H	**155.0**	**150.2**	**156.5**	**154.4**
		Prosumer Types			

Table 2: Consumer money flows (daily totals) for all 16 simulation runs.

		Prosumer money flow IN [p/day]			
	Consumer types	LL	LH	HL	HH
No DSS	L	**5.4**	**15.0**	**2.1**	**7.7**
No DSS	H	**6.0**	**17.5**	**2.3**	**8.4**
DSS	L	**5.9**	**18.3**	**2.2**	**9.4**
DSS	H	**6.1**	**19.2**	**2.3**	**9.7**
		Prosumer Types			

Table 3: Prosumer money flows IN (daily totals) for all 16 simulation runs.

		Prosumer money flow OUT [p/day]			
	Consumer types	LL	LH	HL	HH
No DSS	L	**55.3**	**52.5**	**141.9**	**129.7**
No DSS	H	**55.3**	**52.5**	**141.9**	**129.7**
DSS	L	**55.1**	**51.0**	**141.8**	**128.4**
DSS	H	**55.3**	**52.5**	**141.9**	**129.4**
		Prosumer Types			

Table 4: Prosumer money flows OUT (daily totals) for all 16 simulation runs.

	DSS money flow IN [p/day]			
Consumer types	LL	LH	HL	HH
L	**2.9**	**18.5**	**0.7**	**9.6**
H	**0.6**	**9.2**	**0.1**	**6.9**
	Prosumer Types			

Table 5: DSS money flows IN (daily totals) for all 16 simulation runs.

	DSS money flow OUT [p/day]			
Consumer types	LL	LH	HL	HH
L	**1.8**	**11.8**	**0.5**	**6.2**
H	**0.4**	**5.9**	**0**	**4.4**
	Prosumer Types			

Table 6: DSS money flows OUT (daily totals) for all 16 simulation runs.

4.4 Final processed-result tables

More insightful results were also calculated using the data compiled in the previous section 4.3.

The consumer saving as a percentage was calculated with the following formula:

$$Consumer\ savings_{x-yz}\ [\%] = \frac{B_x - CMF_{out}}{Bx} * 100 \quad (1)$$

Where:

- '$x - yz$' refers to the consumer-prosumer combination (e.g. L-HL).
- B_x refers to the corresponding base value: $B_L = TCl$ and $B_H = TCh$ (see section 4.1)
- CMF_{out} is the consumer's total daily money flow (out).

As can be seen from equation (1), the savings percentages are calculated assuming that the daily cost of electricity will be lower than the base amounts TCl or TCh the cost of electricity that the consumer would have to pay to the DNO in the current system. This is expected as the tariffs introduced in the proposed system are lower than the standard tariff Ts.

In the case of the prosumer, the calculation of the savings percentage needs to consider the money flows in both directions (in and out) and therefore, included in the following equation:

$$Prosumer\ savings_{x-yz}\ [\%] = \frac{B_y - (PMF_{out} - PMF_{in})}{B_y} * 100 \quad (2)$$

Where:

- '$x - yz$' refers to the consumer-prosumer combination (e.g. L-HL).
- B_y refers to the corresponding base value: $B_L = TCl$ and $B_H = TCh$ (see section 4.1)
- PMF_{out} is the prosumer's total daily money flow (out).
- PMF_{in} is the prosumer's total daily money flow (in).

Applying equations (1) and (2) to the values compiled in the table from the previous section, the following Tables 7 - 8 were produced:

			Consumer savings [%]			
No DSS	Consumer types	L	**2.0**	**3.6**	**0.5**	**1.4**
		H	**0.9**	**3.0**	**0.0**	**0.7**
DSS		L	**2.6**	**6.4**	**0.6**	**2.2**
		H	**0.9**	**4.0**	**0.0**	**1.3**
			LL	LH	HL	HH
			Prosumer Types			

Table 7: Consumer's total daily savings for all 16 simulations run.

			Prosumer savings [%]			
No DSS	Consumer types	L	**22.4**	**41.7**	**10.6**	**22.0**
		H	**23.3**	**45.6**	**10.8**	**22.5**
DSS		L	**23.5**	**49.1**	**10.8**	**23.9**
		H	**23.5**	**48.2**	**10.8**	**23.5**
			LL	LH	HL	HH
			Prosumer Types			

Table 8: Prosumer's total daily savings for all 16 simulations run.

For the Distributed Storage System, which also experiences money flows in both directions (in and out) but does not have a base value, a daily revenue amount was calculated instead, based on the following formula:

$$DSS\ revenue_{x-yz}\ [p/day] = DSSMF_{in} - DSSMF_{out} \quad (3)$$

Where:

- '$x - yz$' refers to the consumer-prosumer combination (e.g. L-HL).
- $DSSMF_{in}$ is the DSS daily total money flow (in).
- $DSSMF_{out}$ is the DSS daily total money flow (out).

Applying formula (3) using the values reported in the previous section, Table 9 was obtained:

		DSS revenue [p/day]			
Consumer types	L	**1.1**	**6.7**	**0.2**	**3.4**
	H	**0.2**	**3.3**	**0.1**	**2.5**
		LL	LH	HL	HH
		Prosumer Types			

Table 9: DSS's total daily revenue for all 16 simulations run.

5. Feasibility discussion

5.1.1 The more energy a prosumer can export, the better:

From the tables presented in section 4.4, the general trend of the modelled system becomes evident: the higher the prosumer's generated energy is, the higher the economic benefits are. I.e., a higher prosumer generation will result in a higher saving percentage for both, the consumer as well as the prosumer.

Consequently, the combinations that offer higher savings for both consumers and prosumers are the combinations of the kind 'X-LH': the prosumer's low consumption and high generation translates to more energy that can be exported and sold to the consumer at the premium tariff T_{pc}.

This means that this system architecture encourages consumers to become prosumers and also encourages prosumers to increase the amount of energy they can export. The way the system has been set allows for this to happen. This is of significant importance as the proposed architecture is based around the existence of prosumers.

5.1.2 The introduction of a DSS does not negatively affect consumer/prosumer savings:

For all consumer-prosumer combinations, the inclusion of a DSS does not affect negatively the savings of either consumers or prosumers. The data compiled in Tables 7 - 8 demonstrates this: the following two graphs below were made using this data and illustrate this quite clearly:

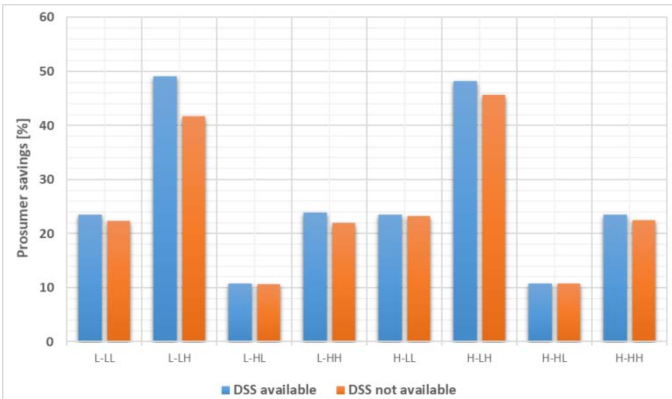

Figure 6: Prosumer savings contrasted against the introduction of a DSS.

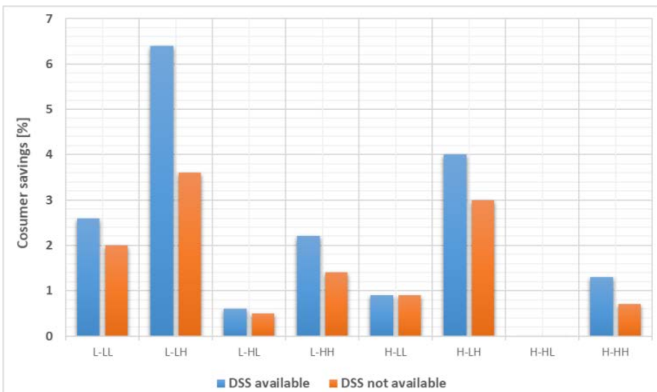

Figure 7: Consumer savings contrasted against the introduction of a DSS.

Notice that the blue bars associated with the inclusion of a DSS are always higher than the orange bars associated with the non-inclusion of a DSS.

This pattern is of great importance, as all DSS's revenue serves as an income source for the DNO, whose infrastructure is essential for the proposed P2P electricity market to function.

5.1.3 Higher savings for pro/consumers also result in higher income for the DNO:

As mentioned above, combinations of the form 'X-LH' offer the highest savings for consumers and prosumers. However, from Table 9, it can also be seen that the DSS income is highest for these combinations. This is important because, as prosumers are able to export more energy, the DNO will see a decrease in the income it would otherwise get by selling energy to the consumers and prosumers. The income generated by the DSS could be a way to mitigate this problem.

5.2 Feasibility

5.2.1 Economic considerations

All patterns identified in 5.1 help to support the premise that the proposed P2P electricity market architecture makes economic sense. As it benefits all participants in the system:

- Consumers could experience savings in the cost of electricity up to 6.4% (as seen in table 7).
- Prosumers could experience savings in the cost of electricity up to 49.1% (as seen in table 8).
- The DNO can benefit from the proposed system by:
    * Charging a small fee for each consumer-transaction that takes place (modelled in the simulation tool as part of the transmission losses 'loss%').
    * Reselling stored energy that is initially bought from prosumers and sell at a later time when needed (i.e. renting storage), table 8 shows that the revenue could be up to 6.7p/day per consumer-prosumer pair in the network.

This study excludes the initial capital cost of the small-scale generators as well as the electronic components and cloud services (ICT) that will be required for the transactions to be controlled in real time.However, small-scale generators such as PV solar installations are already in place and becoming more popular around the world as the price of PV panels continue to decrease. Systems such as the one proposed in this project would definitely help reduce the return on investment (ROI) times as the tariffs at which the surplus energy is sold (Tpc) is higher than the current export tariff (Te).

The possible cost of the ICT equipment and cloud services, on the other hand, is still unknown as P2P electricity markets are still a novel idea.

The last economic consideration comes from the initial cost and maintenance of the DSS, although battery prices are also decreasing worldwide.

These considerations, although they are not considered in depth in this report, are opportunities for further study.

5.2.2 Logistic and infrastructure considerations

The previous section helped to show that the P2P electricity market proposed in this project promotes the increase in the number of prosumers that exist within a network.

This factor could direct entire parts of the current grid to become self-sufficient, or at least increase the percentage of independency that the network has on the centralised plants that currently provide most of the energy consumed.

The inclusion of a DSS could also help the DNO deal with the peak periods of high demand, which would normally been covered by rapid-reacting plants that are often powered by non-renewable sources of energy.

All the above has the potential to increase the portion of the electricity generation mix that comes from renewable energies since the small-scale generators that prosumers install are likely to be renewable, such as PV installations or wind turbines, therefore, resulting in a decrease of the current electricity grid's carbon footprint.

However, the question of whether the current infrastructure can easily be accommodated to maintain the thousands of multidirectional transactions of energy is yet unanswered in detail.

5.2.3 Final considerations and recommendations

The results presented in this paper were obtained by the use of the simulation tool that was created for this project. This has served as a partial first proof of concept which has the potential to improve the current electricity grid.

The proposed system was designed around the idea of providing the right economic incentives as well as benefiting all parties involved, especially with the inclusion of a DSS, which is why this paper recommends this architecture to be the preferred option for further study.

However, there are still many factors that were not extensively considered in this project as they were outside the set aims and objectives. Therefore, it is also recommended that further studies are carried out in order to provide a clearer and more robust understanding of the benefits and difficulties that could arise with the implementation of a system such as the one proposed.

Policy implications and the role of regulations to integrate such a system should be explored.to facilitate innovations to the benefit of consumers and prosumers.

6. Conclusions

Peer-to-peer electricity markets are still at early stages of experimentation, therefore only a few examples have been put in place around the world, such as Vandebron in the Netherlands, SonnenCommunity in Germany and Piclo in the UK. This paper has demonstrated that in the context of a transition to a more sustainable energy system, consumers may be part of social innovations in which they will play more important and active roles in a new decentralised energy system.

In order to generate an adequate input to the simulation tool created for this project, two consumption profiles were created as well as two generation profiles. These profiles were combined to obtain a total of eight consumer-prosumer types. The consumption profiles match the reported (high and low) average consumption of electricity in households in Great Britain (Ofgem) [8], allowing for simulation scenarios that are very close to reality. The generation profiles were created to be realistic by using real generation data from existing PV solar installations in the city of Leeds.

The simulation calculated a total of 4320 transactions for a day, which sets the time between transactions to only 20 seconds. The output of each simulation was the revenue flows for the consumer-prosumer match allowing for the calculation of the savings for each party as well as the revenue generated by the DSS when incorporated.

This paper has demonstrated the importance and impact of integrating smart meters along with the Internet and possibly some technological innovations, such as blockchain technology and digital platforms to become more active by, individually or collectively, storing, buying, producing and selling electricity.

The feasibility of the system was discussed based on the results obtained after the execution of the 16 different scenarios given by the combinations of consumer and prosumer types as well as the inclusion of a DSS. These results showed that the proposed trading system is initially feasible in economic terms, allowing for savings up to 6.4% for consumers and 41.9% for prosumers, as well as generating an income to the DNO of up to 6.9p/day per each consumer-prosumer pair. This can reduce carbon emissions by flexing peak demand and increasing the utilisation of renewables in the energy mix.

Finally, continuing study of this market is encouraged as there are still improvements that could be made to the created simulation tool as well as the further investigation of the initial capital cost that the implementation of such P2P system would require. Energy systems worldwide are undergoing a revolution as incumbent fossil fuel baseloads are replaced with intermittent renewables. P2P markets have the potential to reduce the costs of this revolution to end users.

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