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Energy Communities and Sharing Economy Concepts in the Electricity Sector: A Survey

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***Abstract*— Due to high penetration of Distributed Renewable Energy Resources and their inflexible dispatch nature, modern and future electrical grids are facing technical challenges. New participants can offer the flexibility required by the grid through investments in Energy Storage and Demand Response capabilities, however, traditional and Peer-to-Peer business models are insufficient to take advantage of such flexibility. This article provides a comprehensive review on the concept of Energy Communities, their technical and economic motivations, available resources in the literature, trading schemes, and benefits for the grid. Furthermore, this review describes the policy framework in the European Union to make Energy Communities a reality. Moreover, a brief survey of related projects over the world is presented, along with a discussion of future research opportunities in this area.**

Keywords*— *Sharing Economy, Energy Communities, Business-to-Business (B2B) markets, Flexibility, Ancillary Services, Demand Response.

I. INTRODUCTION

The energy sector has been traditionally managed in a centralised way where a limited number of participants are involved. As energy needs to be transported long distances from big generation centres, there are four main businesses associated with the path the energy has to follow to arrive for the final consumer: generation, transmission, distribution, and supply.

Things started changing with the appearance of alternative sources of energy: it is now possible to generate electricity with more easy-to-access primary sources of energy (i.e. sun's radiation, wind, sun's heat, etc.), ultimately making it possible for the energy sector to shift towards a more decentralised scheme [1]. There is no need to transport electricity over long distances. With a reasonable investment, any given user can generate and consume electricity in its property at a better price, virtually eliminating the four main businesses of the centralised scheme.

Additionally, it is technically viable to produce electricity beyond the user's own needs to provide for nearby users, extending the benefits to others. However, different users are normally connected physically through the centralised scheme's grid, this means the centralised scheme sets the rules for that provision of electricity, generally making the idea of producing extra electricity impractical. It is not profitable for the small generator given the regulations that protect the interests of the centralised scheme as discussed in [2].

Framed in this, it is important to explore alternative business models for these users to aggregate their resources, and level with the traditional participants within the energy sector both technically and economically.

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II. MOTIVATIONS

A. Technical and network infrastructure impacts

- Local energy trading will facilitate energy exchange from nearby agents thus helps reducing transmission distances for electrical energy and corresponding reduction in electrical energy losses.
- Reduction in line and transformer loading are expected as a result of more localised balancing of demand and supply. This will help reduce network congestions if local energy trading effectively balance demand and supply at the distribution level.
- The need of infrastructural upgrades and installation to cater the increasing load demand in a conventional way. Peer-to-peer (P2P) energy trading will remove such need as local energy exchange between prosumers reduces the burden on conventional generation resources and hence on existing lines.
- There are operational impacts of these energy trading system on to the existing grid, energy exchange between consumers, producers and prosumers will significantly change the power flows in a way that it will impose hard technical constraints over the network. If there are significant changes in system power flows because of local energy trading, this will affect distribution network voltages, network congestions, system protection, fault recovery and reliability. Detailed modelling and simulation of the distribution networks will be necessary in order to assess these technical impacts, and to provide confidence that local energy trading will not cause adverse impacts to power supply reliability.

B. Economic and sustainability impacts

- The consumers will observe reduced costs of electricity. This will be a result of possible removal of some of the intermediaries in the electricity market (e.g. the Bank Payment Service Provider, Electricity Retailer and Traders). The savings from removal of intermediaries together with the feed-in tariffs for local, small-scale renewable generation will significantly reduce costs.
- Consumers will have more alternatives to choose the provider of electricity with new business models available in the energy market. Decentralised electricity market structures typically involve many smaller prosumers and energy communities becoming active market participants.
- Local energy trading will offer effective energy balancing, and will reduce dependency on traditional

generation. This is envisaged to improve energy security and independence. This is also relevant in the case of isolated and island systems, which are located in the periphery of the electricity networks, and are much more vulnerable to supply disruptions.

- The implementation of such local energy trading systems will involve certain costs which may include the cost of installing additional metering hardware and home energy management devices, and information and communication technologies based services for the local energy trading platform. It is important to consider that implementation of such systems and associated hardware should be viable economically and also feasible cost-effectively for large scale implementation.
- New business models will reduce resistance from incumbents in the energy industry whose business models may be threatened by local energy trading. This is a step forward for entities such as Distribution System Operators and Transmission System Operators to encourage the further development of Distributed Energy Resources and to adjust their business models accordingly. In contrast, direct P2P local energy trading platforms could provide a significant threat to the business models of electricity retailers, traders and bank service providers.

III. A Sharing Economy

The fact that traditional schemes of energy generation linger despite more environmentally friendly alternatives is attributed not only to technical and regulatory reasons, it is human behaviour, as discussed in [3]. Since the environment is a common good, individuals are encouraged to abuse it for their individual profit and to neglect its maintenance and renewal, ultimately sacrificing common interests, and their own future individual interests (i.e. when a finite resource like the environment is shared, it is abused as an infinite resource).

Nonetheless, it is possible for individuals to manage efficiently common resources by creating bottom-up institutions where rules are stablished and the use of shared resources is organised for long-term sustainability [4]. This concept is known as a Sharing Economy, it has precedents in various sectors and it is based on prioritising social benefit, environmentalism and governance of individuals and communities over profit [5]. However, for the energy sector the concept of a Sharing Economy is new.

IV. Energy Communities

Framed within the concept of Sharing Economies, an Energy Community is defined as a form of community-driven institution taking social control of shared energetic resources through decentralisation. Individual consumers, producers and prosumers located in an enclosed topology can create such space to develop independent initiatives, to actively contribute towards a more sustainable paradigm.

As governments commit to sustainability goals on a national level (e.g. fulfilling a set percentage of the energy requirements of the country using renewable energy resources), Energy Communities can develop their own goals and plans to achieve them, driving change locally through the aggregation of resources. This means that users within a community can enjoy the benefits of the energy transition beyond the economic perspective, while they willingly acquire a number of responsibilities as well, the more active their participation is [4].

A. Resources within an Energy Community

Resources can be owned individually and managed by the community, or they can be owned and managed by the community; regardless of the ownership, the resources are agreed to be dispatched centrally following a set of rules agreed upon the creation of the community. Any element that can directly or indirectly change how power flows in and out of the community is deemed as a resource, the most common are:

1) Distributed Renewable Energy Resources: According to the literature, renewable energy generation comprises energetic resources that can be renewed within the lifespan of a human being [6, 7], this includes geothermal heat, waves, tides, wind, sunlight, etc. As discussed before, some renewable energy sources have an important advantage over traditional generation schemes: availability of the resource near consumption centres. Since most of the renewable energy resources that will be found within an Energy Community depend on weather conditions, forecasting plays an important role [8-10].

2) Energy Storage: It is clear that one of the great challenges with distributed generation is how in general it requires flexibility from the system operator to respond efficiently when facing instant unbalances between supply and demand [2]. Implementing energy storage technologies, can potentially counteract these sources of uncertainty as seen in [11]. Storage units are commonly found within the installation of an individual user, however communitarian storage resources are a growing possibility [12].

3) Demand Response: Normally, a utility user has regular patterns (based on their daily routine for residential users, or their products and services lifecycles for commercial and industrial users), this user is considered to have demand response capabilities if it is able to make changes to these consumption patterns based on economic or technical constrains [13]. The objective is generally to maximise savings or optimise usage of energy generated on-site. This results in multiple benefits for the user and the system operator, as discussed in [13, 14].

4) Energy Management Systems: Energy Management Systems (EMS) are control, communications and measuring systems used to operate the individual variables in a Microgrid [17]. In general, it is an algorithm that based on current conditions from sensors, can control variables in the system to achieve the desired state [18]. If this application on Microgrids is scaled to an Energy Community and the inherent rules are treated as constrains for the EMS, all the available resources can be managed with minimum supervision. Considering that an Energy Community includes several consumers and prosumers, the first objective of an EMS is to match supply and demand within the community, and distribute benefits to achieve social welfare (e.g., the EMS can schedule resources when the system has demand response capabilities, and storage units if available). Different approaches for this are available in [19-24].

B. *Trading in Energy Communities*

As discussed in [25], the fundamental categorization of business models suitable for electricity markets are based on which actors participate as active players (e.g. customers, investors, utilities, retailers, etc.). Only three models fit properly with the nature of the electricity market:

- Business-to-Consumers (B2C) models, where the electricity flows in one direction and revenue flows in the opposite direction. In this model, an intermediary is in charge of the financial transaction (i.e. the role of supplier).
- Consumer-to-Consumer (C2C) models, also known as Peer-to-Peer (P2P), where participants have similar interests and values to trade and there is no need for an intermediary. Participants may change their roles, either selling or buying depending on the availability of the asset. Electricity and money flows in multiple directions within the consumer spectrum.
- Business-to-Business (B2B) models, rising within the energy market. Businesses part of this model, act as "platform" companies providing services to different actors such as: new applications of renewable energy sources as [26], smart meter optimization as in [27], intelligent energy storage and energy management as [28], data integration and management in [29], energy balancing platforms as [30], etc. Within the B2B model, revenue flows in multiple directions, in a larger scale compared to the C2C model.

Most residential and industrial users traditionally fit into the category of "Consumer", limiting them to interactions within the B2C and C2C models. When a number of users agree to become an Energy Communities, a new possibility arises to interact within the B2B model. This is the main difference Energy Communities have with Microgrids and Smartgrids, as an entirely new business model is open for participants.

It is important to mention that within these business models, there are various strategies in the literature for the allocation of prices and the assignment of buyers and sellers (e.g., retail oriented markets, vendor oriented markets, Blockchain-based markets, etc.) as seen in [25, 31-34] and optimization techniques to clear the market in one time slot [31-33]. This means that while the possible transactions within the B2C trading model are highly regulated, C2C and B2B models correspond to more open markets where the rules can be agreed upon participants.

There are security concerns for Energy Communities and trading, to address this, research is focusing in Distributed Ledger Technology applications such as Blockchain, with decentralised decision-making processes as discussed in [35-37].

Different interactions between users depending on the business model are illustrated in Fig. 1. Within B2C models like traditional energy markets, transactions of electricity are conducted through the system, this is a highly regulated market with fixed prices for each transaction.

C2C models, as in emerging Peer-to-peer markets, are possible within a Microgrid as a P2P System, outside the Microgrid the transactions are still conducted similarly to the B2C model. Different techniques to allocate Use of Network charges necessary in the B2C model.

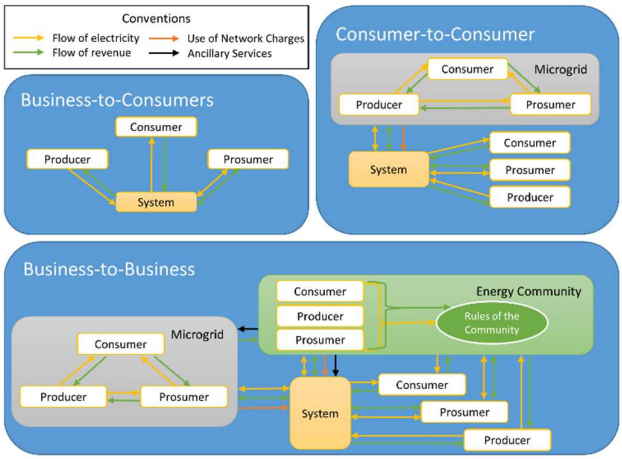

Fig. 1. Interactions between users in different market models *(Business-to-Consumer, Consumer-to-Consumer, and Business-to-Business)*

A B2B model makes it possible for additional interactions as seen in Fig. 1. Following the rules of the community, the remaining resources can be transacted with the system or individual users. Additionally, the Energy Community can sell ancillary services to the System and other participants like Microgrids.

C. *Services to the Network*

It is known that new Distributed Energy Resources in a traditional grid are associated with a degree of uncertainty for system operators, and such uncertainty can be counteracted through the clustering of resources, adding some benefits form the diversity of demand and supply from aggregation, as discussed in [39]. However, the appearance of Energy Communities in the electricity sector potentially has deeper beneficial impacts for the grid that require further research:

1) Flexibility in dispatch:

With the high penetration of Renewable Energy Sources, the system is expected to rely more on these sources. The services traditionally provided by the grid side, are now needed to be integrated within these variable Renewable Energy Sources (e.g. frequency control, contingency reserves, voltage control, and demand-supply balancing). In order to maintain resilience and security of supply from these variable Renewable Energy Sources, various changes in existing markets and new technologies have been already proposed in the literature [2].

Currently, if a supply-demand mismatch occurs, it is uncertain how will it be catered immediately in a system with heavily penetrated variable Renewable Energy Sources, since outputs depend on wind speeds or solar radiations. The conventional generation facilities are unable to ramp up or down quickly and efficiently, and lack the ability to take advantage of on a growing influx of wind and solar power to the grid. Rapid shifting with weather, the supply of renewable power can be quite changeable which cannot be addressed by these reserves.

One of the present solution to this is termed as "flexible generations" or "flexible power plants" which aims to keep up with the variable outputs of the renewables. These plants that can start, stop, or throttle up and down quickly and efficiently.

The combined-cycle technology plant in which exhaust heat captured from the burning of natural gas drives a steam turbine can ramp up mega-watts within a few seconds [40].

On the other hand, Energy Storage and Demand Side flexibility can respond promptly to this mismatch and play an important role for future grids with high penetration of Renewable Energy sources [41, 42]. Future implementation of Energy Communities can potentially eliminate the uncertain nature of Renewable Energy sources when there is presence of energy storage and demand response capabilities. The Energy Community's aggregated profile becomes flexible, and it is expected to provide the resilience and security of supply services, reducing the need for "flexible power plants".

2) Demand curve flatting:

If demand response and energy storage technologies are implemented appropriately, important benefits for the system operator are expected, the most important of which is demand curve flatting [39]. The characteristic peaks and valleys from normal consumption patterns in the load curve can potentially be smoothed [43], resulting in a more efficient generation scheme.

If the demand maximum and minimum over a period are drawn near, the generation installed capacity will be used efficiently, meaning less operational costs for the system operator. Additionally, if the difference between load peaks and base load of the system is reduced, so is the requirement for network reinforcements, delaying long term investments in generation capacity reserves [13].

3) Use of Network charges:

Considering that Energy Communities by definition will use the Distribution and Transmission Grids, property of the system operators, it is reasonable to allocate charges for this usage. Authors in [44] tried to define network usage cost allocation policy based on four different categories:

- **Total fees:** This fee is charged on trade made by an agent *n* for buying from or selling to agent *m*. This may be positive or negative depending on whether agent is selling or consuming the energy. This trading fees is focused only on real power trade and include the expenses such as power injection compensation, power losses, maintenance etc.
- **Unique Cost:** This cost depends on the behaviour of the participant which would be reflected equally on each member of the community in a shared economy. Misbehaviour of a few agents may penalize the rest of the community. This cost may be calculated on per hourly basis, and it represents equal sharing between trading agents.
- **Electrical Distance Cost:** It is possible to develop a component of network charge proportional to the electrical distance between trading agents. This will represent that, the longer the distance, costlier the operation due to power losses, equally shared between trading agents. A unit distance fee is expressed in euro per mega-watt-hour per distance unit.
- **Uniform Zonal Cost:** Zonal cost allows to economically isolate an area. The system can be divided into several separate zones and have corresponding zonal unit fees. Each zone could be managed by a different System Operator. To keep the transparency for the participants, this fee must be updated timely.

V. Policy Challenges

With the creation of the Clean Energy for All Europeans package [45], the new regulation on the governance of energy from the European Commission grounds EU objectives and goals for energy union, and climate action, aligned with the Paris Agreement and the energy and climate 2030 targets for the EU. Every EU member is required to publish a National Energy and Climate Plan (NECP) for the ten-year period 2021-2030. In general, the Commission recommends member states [46] to take action through policy in:

- The building and transport sectors to reduce the 2030 greenhouse gas emissions target.
- Targeting ambitious renewable energy share for 2030 with quantified policies and measures around the heating and cooling sector, the transport sector, as well as enabling frameworks for renewable energy communities and self-consumption.
- Increasing energy efficiency, expressing the contribution as a specific value.
- Specifying measures around energy diversification to reduce dependency on the gas and oil sector.
- Funding innovation and research related to the Energy Union, and creating measurable national objectives for 2030.
- Delivering on the renewables targets and implementing ongoing interconnection projects as measures to ensure regional cooperation, considering United Kingdom's transition out of the European Union.
- Phasing out subsidies, in particular for fossil fuels.
- Further considering different scenarios and their impact on air pollution.
- Addressing the impact of the transition of carbon-intensive populations in the region, providing details on social, employment and skills impacts..

Furthermore, while policy around energy communities across Europe is inexistent, Directive (EU) 2018/2001 dictate member states to create a policy framework to promote and facilitate self-consumption, and the creation and development of renewable energy communities, respectively in Articles 21 and 22 [47]. Many EU member states are on track to create such policy, making Energy Communities a possibility in the near future.

VI. Discussion and Conclusions

As part of this review, the academic and industry sectors were surveyed in search of projects related to the main topics discussed so far. Thirty-seven projects with similarities were found around the world, the most relevant of which are registered in Table 1 with the mapping of topics that each project address.

TABLE I. SURVEY OF ENERGY-COMMUNITY-LIKE PROJECTS

Relevant projects for future Energy Community applications. / Project Name	App/Web based application	Decentralised framework	Community/Co-op Scheme	Distributed Energy Resources	Community Generation	P2P Trading	Power Flow allocation	Energy Quality	Blockchain/DLT	Pool Resource	Auction	Smart Metering	Net Metering w/ DSO	Demand Management	Load Forecasting	Generation Forecasting	User Energy Storage	Community Energy Storage	EV Energy Storage	Aggregators/Aggregation	Dataflow With DSO
Brooklyn MG [48]	X	X	X	X		X			X		X	X	X						X		X
sonnenCommunity [49]	X	X		X						X		X		X		X	X			X	
Electron [50]	X	X		X			X	X	X								X			X	X
Greeneum Net Ltd [51]	X	X		X		X	X	X	X			X			X	X					
Hive Power [52]		X	X	X			X	X	X			X			X	X					
EMPOWER [53]			X	X						X	X	X					X	X			X
WiseGRID [54]	X	X		X								X		X			X	X	X		
Synergy [55]	X	X		X		X			X	X		X	X								
NRGCoin [56]	X	X		X			X		X			X								X	X

From the surveyed projects, it appears current focus is on Decentralisation, Distributed Energy Resources, Blockchain and Smart Metering topics. The largest gaps can be found around Community Generation, Pool Resources, Demand Management and Community Energy Storage.

These topics represent future research opportunities: it is unclear how different technologies (and different arrangements of such) can coexist within a grid in which reliability and security of supply are a priority, especially now that the energy market is evolving. It can be predicted that the impact of such markets is not limited to business models but can be spanned over to the network performance. Further research on development of trading algorithms to facilitate the trading processes without violating the network constraints is required.

Aside from the individual research topics that arise from each resource available within a future Energy Community, it is important to study the impacts of these new participants as a whole in Distribution and Transmission Network planning and operation. With the increase of flexible and inflexible resources, it is expected that power flows across the grid will change, grid assets are expected to be utilised differently, and grid operators will greatly benefit from a comprehensive analysis of such changes.

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