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Keywords Feed-in tariff ; Distribution System Platform ; Peer-to-Peer ; Blockchain

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Digitalisation and New Business Models in Energy Sector

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Abstract *This paper reviews digitalisation in energy sector by looking at the business models of 40 interesting new start-up energy companies from around the world. These start-ups have been facilitated by the rise of distributed generation, much of it intermittent in nature. We review Artificial Intelligence (AI), Machine Learning, Deep Learning and Blockchain applications in energy sector. We discuss the rise of prosumers and small-scale renewable generation, highlighting the role of Feed-in-Tariffs (FITs), the Distribution System Platform concept and the potential for Peer-to-Peer (P2P) trading. Our aim is to help energy regulators calibrate their support new business models.*

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1. Introduction

Digitalisation in the energy sector involves the creation and use of computerised information and processing of the vast amounts of data which is generated at all stages of the energy supply chain. It promises a lot for every segment of the energy ecosystem: households, prosumers, distribution, transmission, generation and retail and is frequently stated as likely to lead to a transformation of the energy system. It is often associated with 'smart' energy, the Internet of Things (IoT) and Blockchain technology. The main aim of digitalisation is to improve efficiency. It enables better, cheaper and faster monitoring, recovery and maintenance of the assets and components through 'smarter' grids. Smart households facilitate households' own solar energy production. The Internet of Things (IoT) will integrate smart appliances for savings and grid services. For instance, smart charging of Electric Vehicles can be a key provider in demand response. Blockchain which involves decentralised transaction verification will potentially empower individual customers to trade power and make payments in a seamless way. Digitalisation can help with better network and congestion management, assisting with the renewable generation intermittency problem, allowing more effective network monitoring and more efficient network operation. It also provides digital platforms for demand response, and Peer-to-Peer (P2P) energy and carbon credit trading.

According to energy regulator in Great Britain, Ofgem (Office of gas and electricity markets), British households spend around £1,117 per year on gas and electricity with a total expenditure of around £30 billion annually (Ofgem, 2018a). Businesses, charities and public bodies spend a further £20 billion each year (Ofgem, 2018a). Digitalisation in energy sector brings new opportunities to the

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corporates, entrepreneurs and start-ups to provide solutions and create new businesses in this sector. At this point new business models come forth to grab a share of this total amount of existing energy expenditure. "*Business modeling is about finding a systematic way to unlock long-term value for an organization while delivering valuable products and services*" (Cuofano, 2019). Business model theory helps analysts to conceptualise and assess business ideas. This paper reviews and compiles numerous new business models in the energy sector by presenting 40 start-ups worldwide and gives special attention to Blockchain based solutions. The aim of the paper is to provide some insights which might be useful to energy sector regulators faced with many new companies seeking to profit from the digitalisation of the energy sector. Should these companies and their business models be encouraged is a key question for regulators with a statutory duty to protect energy customers from monopoly pricing and to promote competition, at the same time as ensuring security of supply and advancing decarbonisation.

In the assessment of these companies we made use of four business model dimensions:

- Value Proposition (What are they offering?),
- Targeted Customers (Who are they targeting?),
- Value Creation/Value Delivery (How are they planning to create and deliver their service?),
- Value Capture/Revenue Model (What are the sources of their expected revenue and How are they planning to create this?).

Even though the gas sector is an integral part of the energy business, this paper will focus on the electricity sector. Therefore, from this point on, energy trading and other discussions about energy will only stand for electric energy. The rest of the paper is organised as follows. Section 2 summarises distributed energy generation and digitalisation in the sector. Section 3 briefly reviews Artificial Intelligence (AI), Machine Learning, Deep Learning and Blockchain applications in energy sector. Section 4 discusses the rise of prosumers and small-scale renewable generation, highlighting the role of Feed-in-Tariffs (FITs), the Distribution System Platform concept and the potential for Peer-to-Peer (P2P) trading. Section 5 reviews the (longer-term) business models of 40 noteworthy start-ups in energy sector from around the world. Section 6 discusses how the regulators should support new business models. Section 7 concludes the paper with a summary of our findings.

2. Distributed Generation and Digitalisation

A key driver of digitalisation is the increasingly distributed nature of electricity production. This has a number of important characteristics which give rise to new business opportunities. Electrical energy is produced within the electricity distribution grid at many more nodes than previously. The energy is often intermittent and poorly matched (today) with demand. The nature of the energy produced creates issues with national and local power quality necessitating more attention to frequency regulation, voltage support, local network congestion (and hence constraint management) and reserve capacity.

Distributed generation is increasing in many parts of the world. Solar PV generation in the world has grown with a compound annual growth rate of over 40% for the last 15 years (PV Status Report, 2018). In the United Kingdom (UK), as of March 2019 there are more than one million solar power installations and 93% of these are sub 4 kW ones (DECC, 2019). Similarly, in California, United States, the total capacity of solar PV was around 456 MW in 2009 whilst this figure rose to 7,160 MW in ten years. (California Distributed Generation Statistics, 2019). More than 65% of the solar projects are residential and again more than 65% of the total projects are customer owned (California Distributed Generation Statistics, 2019). Integrating distributed generation, especially when it is at the small-scale prosumer level into existing markets is a challenge.

Increased distributed generation leads to growing attention on how to reduce intermediary costs in the energy trade. Intermediary costs include those associated with metering, billing, administration fees, IT services, banking services and brokerage. Distributed generation, as with solar PV, frequently involves intermittent renewables. Peer-to-Peer (P2P) energy trading is seen as a practical solution to how intermittent small-scale generation can be integrated into the system at low intermediary cost. Within a global context of rapid development of the sharing economy (as exemplified by AirBnB and Uber), P2P models have been applied in various industries, including the energy sector (Munger, 2018). P2P trading of energy can be facilitated by economy wide digitalisation as exemplified by the ubiquity of personal computing, internet use and access to advanced digital technical tools such as artificial intelligence and Blockchain.

Generally, researchers on P2P electricity trade have primarily focused on technology aspects so far due to the fact that this trading system is still at an early stage from a business perspective (Pouttu et al., 2017). Alvaro-Hermana et al. (2016) proposed a new P2P energy trading model between two sets of electric vehicles. Inam et al. (2015) discussed the structure of microgrids in a distributed energy system with P2P electricity sharing. Blockchain technology can be employed in a wide range of applications including: using electric vehicles in grid services for supporting congestion management; registration of energy data in a safe medium as an open ledger; billing, switching suppliers, exchanging capacities and so on (Dena, 2019). Burger and Weinmann (2016) investigated the development of Blockchain technology and its potential in electricity trading. Kim et al. (2016) presented P2P energy loan scheme using a Blockchain-based P2P loan procedure. Recently, more attention has been focused on the social and economic impacts of P2P electricity trading. Giotitsas et al. (2015) reviewed the evolution procedure of energy trading technology and explored its potential influence on the global socio-economic structure. Roy et al. (2016) discussed the benefits and feasibility of P2P electricity trading in the Australian national electricity market looking at its social, economic and technical aspects.

Currently, there are several technical solutions for P2P energy trading schemes. However, whether these technical solutions propose reliable business models is questionable. Therefore, one of the goals of this paper is to compare and summarise emergent P2P energy trading models from a business model point of view. Existing energy trading systems are generally based on traditional energy contracts that are cleared centrally and transactions have to be completed with the help of grid companies. Bilateral contracts (Gao et al., 2017) , hour (or day) ahead markets (Ela et al., 2018), ancillary services markets (Gurgaon, 2018) and capacity markets (Khan et al., 2018) are commonly used forms of traditional energy trading. On the other hand, increasing digitalisation in energy sector yields opportunities in decentralisation and deepening of these markets via creating new business models.

3. AI, Machine Learning, Deep Learning and Blockchain

Machine learning is an approach to achieve artificial intelligence. By using algorithms and using determination and prediction in daily life, machine learning uses expert human judgement to teach algorithms to perform tasks on large amounts of data after being 'trained' on smaller amounts of data. Deep learning is a technique for implementing machine learning. It breaks down tasks and connects distributed tasks to drive machine learning in ways that independent algorithms can collaborate with other algorithms (Copel, 2016). To summarise, Machine Learning is one of the ways to implement AI, and Deep Learning is one of the tools of achieving Machine Learning. Given the large amounts of data capable of being generated by the electricity system in real time (e.g. instantaneous electricity supply and demand at every node of the electricity network) energy is a promising area for AI.

Globally, utilities are undergoing a cultural shift towards an information-based digital economy — where primary processes are digitalised and market flexibility is achieved through technical optimisation (Schoklitsch, 2018). With increasing amounts of data being collected and analysed, the energy industry can have a better understanding of how to make use of and respond to market signals and how it can use digital technologies to address traditional challenges (BNEF, 2017). Clearly, P2P energy trade for smaller players can only be achieved through digitalisation of the energy markets.

There have already been many successful application cases of using digital technologies to solve problems in daily life. Google's DeepMind technology was able to significantly cut electricity consumed at Google's data centres (Shead, 2016). Their algorithms make predictions of the energy consumption more accurately to increase the effectiveness of the data centres' cooling systems. Using this technology, DeepMind has successfully decreased the energy consumption in data centres by 40% and saved a large amount of money for Google over the past years (Jucikas, 2017). This announcement gave rise to discussions on how technology could be applied and transferred to deliver social benefits on a larger scale. Google's DeepMind-National Grid project is one of the good examples. DeepMind uses Artificial Intelligence (AI) technology to predict and balance energy supplies to National Grid in Great Britain. DeepMind claims it can reduce national electricity consumption by up to 10% (Evans, 2016).

Apart from Google, several other big players such as IBM have already been working extensively in this area. Since 2013, IBM partnered with the Department of Energy in the United States to conduct solar energy prediction by using machine learning. IBM has over 200 partners and clients that use their solar and wind forecasting technology (Fehrenbacher, 2016). The technology aims to combine the advantages from a series of forecasting models and integrate massive data sources together to calibrate and improve efficiency and reliability. IBM claims that its advanced algorithm and self-learning weather and renewable forecasting technology achieve 50% more accuracy than the next best solar forecasting model (Jucikas, 2017).

3.1 Artificial Intelligence applications in energy sector

Artificial intelligence is an advanced technical approach to help understand the past, optimise the present and predict the future (Jucikas, 2017). AI will change the way many industries design and deliver their products and services in the future, including energy provision. The utilities sector is currently undergoing a shift from a stable, reliable, and highly regulated environment to a tech-driven, volatile one (ConsultancyUK, 2018).

The power system as a complex structure, naturally faces a security of supply risk in the presence of complex algorithms and equipment exposed to real time operational risks. Due to the intrinsic complexity of the physical power grids, even minor fluctuations might result in catastrophic failures.

There have already been many severe incidents. On 14th August 2003, US experienced the biggest national blackout in history; on 4th October 2006 nine European countries were affected by a large-scale electricity blackout; and on 10th November 2009 Brazilian blackout impacted the daily life of over 70 million people in 18 states. The economic impacts of these extensive blackouts can be billions of euros (Küfeoğlu, 2015). Thus, practical power system engineering requires detailed investigation and proper design to reduce uncertainties. There have, for instance, been accusations of state sponsored cyber-attacks on the Ukrainian Grid made in 2015 (E-ISAC, 2016). These issues create an opportunity for mutual-improvement between power systems developers and AI technology developers. AI and other technical measures can be powerful tools to address problems. Intelligent systems help decision makers to make more sophisticated choices during the design, construction, operation and maintenance phases of power grids. It is expected that AI will be used in smart grid operations, especially in early fault detection and self-healing processes as well as better forecasting and planning with respect to renewable generation.

Currently intelligent systems can be used in electricity markets in different applications such as: (1) alarm processing, diagnosis, and post-fault restoration, (2) forecasting and (3) security assessment (Ramos and Liu, 2011).

3.1.1 Machine Learning in energy sector

Machine learning as a practical tool to realise artificial intelligence, has a growing number of applications in the energy sector due to its advantages in analytics and computational capability. According to a study from Navigant Research, machine learning is best suited for a series of specific analytical processes, including clustering, regression and classification (Zhou et al., 2018). On this basis, machine learning is widely used in some utilities in fields including customer segmentation, pricing forecasting, fraud detection and predictive maintenance and operation (Bose, 2009). Pacific Gas & Electric, a utility from California, United States, has employed machine learning to increase the accuracy and precision of load reduction prediction for demand side response (Samad and Kiliccote, 2012). Another example is San Diego Gas & Electric, which uses machine learning to conduct anomaly detection to spot hidden system issues from massive data sets (Barreno et al., 2006). Statistics show that machine learning is finding its way to enter the energy market gradually and based on a survey conducted in 2016 by Zpryme and SAS, nearly one-third of utilities in North America were then using machine learning for meter data management (Tien, 2013).

Machine learning can be coordinated with the technology of internet of things (IoT). IoT is an essential tool for smart household appliances and smart building ecosystems. It is crucial that this technology is coupled with AI and machine learning. According to Capgemini's 2017 World Energy Markets Observatory, out of almost 2,900 companies participating in North America's 'Internet of Things (IoT) revolution', 401 are in the artificial intelligence and machine learning category. And out of the region's over $73bn investment in IoT, over $12bn is in machine learning and artificial intelligence (Engerati, 2018).

Researchers from Austria proposed a dynamic approach to solve the electricity procurement balancing issue based on machine learning algorithms. By collecting and analysing public data on clean energy generation and consumption, they applied a simulation for a Dynamic Day-ahead Dimensioning Model in Austria's delta control area, and demonstrated that a machine learning-based dynamic dimensioning model achieved savings in comparison to static dimensioning and procurement, as well as guaranteeing the same level of safety and stability (Essl et al., 2017).

3.1.1.1 Deep Learning in energy sector

During the past decade, the techniques and way of thinking developed from deep learning research has grown rapidly and influenced a wide range of scientific work, especially in signal and information processing (Deng and Yu, 2014). Depending on how the model structures are made and how the techniques are used, deep learning could broadly be divided into three major classes (Kingma et al., 2014):

1. **Deep networks for unsupervised or generative learning**: to conduct pattern analysis of the observed data and capture correlation between datasets when no information about target class labels is available.
2. **Deep networks for supervised learning:** to directly capture the correlation of observations for pattern classification purposes with distributions of classes on the captured data available.
3. **Hybrid deep networks:** to achieve pattern discrimination with data assistance and produce the outcomes of generative unsupervised deep networks.

The energy sector has been one of the successful applications of deep learning. Deep learning helps optimise energy planning by producing more accurate energy consumption forecasts. A group of Brazilian scientists proposed a forecasting model to estimate energy consumption from the customer perspective (Lima and Navas, 2012). This model regards energy usage prediction as a time series regression task and solves the estimation of next month's data based on historical dataset (Berriel et al., 2017). Machine learning techniques have shown strong capabilities in solving problems regarding time series regression analysis and deep neutral networks play a significant role in achieving these promising results. With a million customers (resulting in over 9 million samples) the system was able to predict total monthly energy consumption with 34.6% less error compared to the baseline method previously used by some of the power companies (Berriel et al., 2017).

Artificial intelligence, machine learning and deep learning have been used to help monitor, forecast and schedule energy generation and consumption. At the next section, we focus on Blockchain and its applications in energy markets.

3.2 Blockchain in energy sector

A Blockchain is a distributed chronological ledger that is able to record, validate (via a proof-of-work process) and store transaction information within a 'node' network instead of using a single centralised authority. The most famous application of Blockchain can be the well-known cryptocurrency Bitcoin. Traditionally, the credit card required a complicated and time-consuming validation from a bank. In theory Blockchain could greatly shorten the operation period by removing this central validation, and make transactions happen almost instantly (Anuj, 2017). As a novel technology that eliminates one single central authority by creating a new consensus mechanism, Blockchain technology could be quite useful in energy trading. However, we should mention that Blockchain has some limitations too. One of the most trivial one is the speed of transactions. These transactions might take much longer time that the conventional payment methods such as credit cards or other online payment systems (Forbes, 2018). Other concerns include the lack of regulations surrounding the use of the technology and the energy consumption during the proof-of-work process (Küfeoğlu and Özkuran, 2019).

TransActive Grid in the US and National Lifestyle Villages in Australia are successful implementations of Blockchain in energy industry. Electron is another example of the successful operation of a Blockchain-based flexibility platform in the UK. By establishing a platform to connect demand and supply directly, energy Blockchain solves the issue of the lack of 'trust 'between participants and reduces the trading cost by eliminating intermediaries who normally provide such 'trust' (Swan, 2015). Blockchain as a disruptive information technology, is a consensus system that can build trust between transaction parties thus helping to achieve a fair, trustless, transparent and flexible environment.

Particularly, for the energy sector, Blockchain can initiate the shift of the trading ecosystem from a centralised to decentralised one (Allen, 2017), it does this by:

- removing the dependence on intermediaries through direct end-to-end energy trading;
- enabling individuals and communities to start energy production with initial investment gained through crowdfunding;
- packaging a number of energy services (e.g., billing, supplier switching) as an integrated solution at a generally lower price;
- providing a platform to allow energy initiatives such as an integrated system to consolidate a household's daily energy consumption, which might include washing, HVAC and vehicle battery charging.

4. Prosumers and small-scale renewable generation

This section reviews three main approaches that could be used to enhance and support increasing amounts of small-scale decentralised and renewable generation and to facilitate their integration into the electricity markets. We will highlight Feed in tariffs in UK, the Distribution System Platform (DSP) concept from New York and finally, digitalisation in the energy markets and numerous new business models from the world.

4.1 Feed-in Tariffs

Feed-in tariffs (FIT) are certain rates paid for electricity generated from renewable sources fed back into the electricity grid. FITs were first introduced in Germany in 1990s and as of 2018 these are adopted by more than 80 counties worldwide (REN21, 2018). In UK tariff rates are set by the Department for Business, Energy and Industrial Strategy (BEIS).

When FIT first came into effect in 2010, solar photovoltaic rates were between 46.00-52.75 p/kWh for 0-10 kW installations, subsequently they were reduced significantly (Ofgem, 2018b). The tariffs were paid for 20 years and the rates were updated for new facilities on a yearly basis. The main aim of FITs is to stimulate investment in a new technology. However, FITs have been eliminated for new residential solar PV from 1 April 2019 in the UK. Therefore, other options are now needed to promote and support small-scale renewable generation. Note that a key feature of an FIT scheme is that it removes the need for the prosumer to actively 'trade' their electricity because they are offered a fixed price for it which does not vary in time or with network condition.

4.2 Distribution System Platform

The Distribution System Platform (DSP) is the central component of the New York Energy Reform (Reforming the Energy Vision – REV) launched in 2014 by the New York Department of Public Service Commission (NY DPS, 2014a) which sets the basis for the transition to a modern electric utility. REV constitutes a pioneering initiative that helps to build a cleaner, resilient and affordable energy system, stimulating new investments, innovation and improving customer choices. Among the main drivers behind REV were the high cost of traditional solutions for delivering electricity (in contrast with the cost reduction of alternative solutions), changing customer preferences (towards own generation and self-consumption), and a lack of progress on emission reductions. REV mandates the New York's six largest investor-owned utilities[3] to establish DSPs.

DSP is defined as *"an intelligent network platform that will provide safe, reliable and efficient electric services by integrating diverse resources to meet customers' and society's evolving needs. The DSP fosters broad market activity that monetizes system and social values, by enabling active customer and third party engagement that is aligned with the wholesale market and bulk power system"*, (NY DPS, 2014a p. 31). The DSP allocates key capabilities to the conventional electric utility and compensates distributed energy resources (DER)[4] and customers for the services they provide. Under REV, DER remains a non-utility service that is provided by the competitive market, however exceptions may apply if market participants are unwilling to address the need, then the utility can act as the service provider of last resort. DSPs are required to provide specific functions at the distribution level for the integration of DER into the electricity system such as market operations, grid operations and integrated planning system. According to the NYDPS, the electric utilities (investor-owned utilities) are the best positioned to operate the DSP. Having an independent DSP (non-utility DSP) would be redundant, inefficient and unnecessarily costly (NY DPS, 2015). Some of the functions such as those related to system planning and operation are already being performed by electric utilities.

There are three overlapping stages associated with the gradual deployment of DSP and the evolution of the distribution markets: *Stage 1* – Grid Modernisation, *Stage 2* – DER Integration and *Stage 3*- Distributed Energy Markets[5]. *Stage 1* corresponds to a low DER adoption level and is characterised by investments required to replace mainly aging infrastructure and the acquisition of advanced grid technologies. According to De Martini and Kristov (2015), most distribution systems in the USA are currently in this Stage with some exceptions such as California and Hawaii, placed in the second one[6]. In *Stage 2*, with a moderate to high level of DER, there is a need for more sophisticated capabilities and investments in order to capture the potential system benefits. In addition, there needs to be higher coordination between utilities, DER providers and system operators in order to encourage DER participation in the wholesale market. *Stage 3* is characterised by a very high DER level with a possibility of multi-sided (peer to peer) transactions and the need for a formal distribution-level market structure to make this possible. Transactions between local distribution areas are also envisaged in this stage.

The identification of the DSP functional capabilities associated with each stage of market evolution is depicted in Figure 1. It is observed that the complexity of the DSP functions increases over time.

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[3] Consolidated Edison, National Grid, Central Hudson Gas&Electric, New York State Electric&Gas (NYSEG), Orange and Rockland Utilities, Rochester Gas&Electric. The six electric utilities together refer to the *Joint Utilities* which represents activities or proposals the six utilities undertake as a collective, single group (Joint Utilities, 2016).

[4] Under the context of REV, DER refers to a variety of resources such as end-use energy efficiency, demand response, distributed storage and distributed generation; located on customer premises or on distribution system facilities (NY DPS, 2015, p. 3).

[5] The three-stage evolutionary framework was initially proposed by De Martini and Kristov (2015).

[6] Based on the adoption of DER in the USA De Martini and Kristov (2015) suggest for Stage 2 a DER adoption threshold beyond 5% of distribution grid peak load.

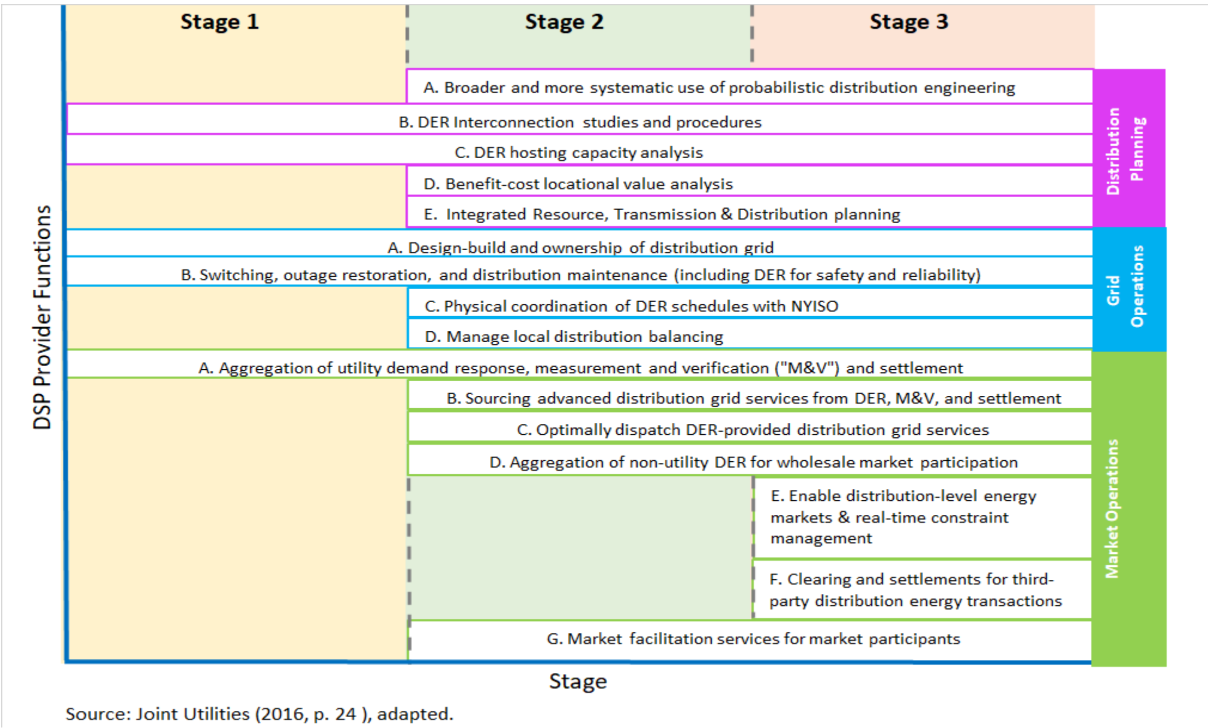

Figure 1. DSP Functions and related Stages

The DSP capability within the electric utility will help the electric utility to focus on helping the distribution system make the most economical decisions and will contribute to the promotion of interoperability and standardisation[7] which are crucial to the development of new markets (NY DPS, 2014b).

4.2.1 Implementation

There are two tracks associated with the implementation of the DSP, Track One (NY DPS, 2015) that relates to the creation of the DSP and functional capabilities and Track Two (NY DPS, 2016a) that adopts a ratemaking and utility revenue model policy framework. We will discuss both briefly.

Track One. Under this track, electric utilities are required by the Commission to fill a distributed system implementation plan (DSIP filings) that explains the way how the DSP functioning (planning and operations) is defined and implemented. DSIP involves a multi-year plan (over five-year period) with filings that need to be updated every two years. Subsequent DSIP shall be filled on a biennial basis beginning on 30 June 2018. As part of the DSIP, electric utilities are required to discuss relevant demonstration projects and incorporate positive demonstration results. Demonstration projects help to test the DSP functions, new technologies, new revenue stream opportunities (for both utilities and third-parties) before their large-scale implementation[8].

Track Two: Set new sources of revenues and earnings for electric utilities that are required to align the utility shareholder's financial interest with consumers' interests. Apart from the traditional cost-of-

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[7] There are many differences across the six electric utilities in New York, in agreement with their specific needs. It is observed different levels of visibility, control and communication networks; diverse geography and demographics; a mix of utility-owned information and management systems and those provided by third-parties, among others.
[8] For further details see the Memorandum and Resolution of Demonstration Projects (NY DPS, 2014c).

service arrangements, utilities can earn revenue through: (1) platform service revenues – by displacing traditional infrastructure projects with non-wires alternatives, (2) earnings adjustment mechanisms – that relate to outcome based incentives, and (3) greenhouse gas reductions – in line with the State's target of 50% renewable generation by 2030.

In terms of the DSP implementation costs, these vary across utilities. For instance, Con Ed has proposed a budget of USD 133.5 million for the DSP in expenses over the period 2016-2020 (Con Edison, 2016).

4.3 P2P energy trading models

One might argue that existing energy trading models have shortcomings that lead to inefficiency. Central authority and intermediary processes such as brokers impede information exchange and trading efficiency. Thus, a new energy trading platform could:

- Remove or reduce intermediaries' costs (e.g. broker services) which make existing transactions complex and expensive;
- Increase efficiency by setting up data collecting standards to allow process consistency and the facilitation of inter-organisational collaboration;
- Reduce risk of fraud and invalid transactions.

P2P electricity trading is a mechanism where producers can also be consumers and the energy produced by one prosumer (function as both producer and consumer) can be shared with another prosumer. Such an exchange scheme is quite similar to the way people share data online but with different sharing content. Unlike Business to Customers commercial trading cases, where a small group of suppliers control the majority of sources, all participants in the platform have the ability to utilise it and trade energy with each other. The energy prosumers can be regarded as an additional way to balance electricity network that allows excess energy to be used within the microgrid (Park, 2017).

Moreover, some P2P energy markets are designed with Blockchain where all transactions will be validated by every node of the network and stored permanently without the involvement of a central authority. Smart energy contracts are available through the integration of Blockchain with energy trading. The Blockchain can conduct transactions automatically and immediately once an implementation agreement is triggered. Under the Blockchain framework, if one prosumer expresses an interest of purchasing electricity and the demand matches with another prosumer's supply, they can contract directly without the need of a central utility or a regulatory body.

The role of distribution system operators (DSOs) will change with increasing digital capabilities to potentially become DSPs. Based on the new business models of P2P energy trading platforms, an integrated energy market ecosystem can be proposed. To achieve a high-level of flexibility in the energy market, P2P energy trading can be promoted by various market mechanisms such as:

- Innovative tariffs: flexible and innovative tariff designed to suit the new patterns of the energy market;
- Smart home devices: using the Internet of Things (IoT) to connect the online flexibility market with flexible energy equipment;
- Energy storage technologies: saving electricity to bridge the gap between demand peaks and valleys, as well as increasing flexibility and liquidity;

- Consumer data collection and forecasting using machine learning: applying digital technology to analyse consumer data and better match available supply and demand.
- Mobile energy hubs: providing energy to rural communities via access to electrification.

Figure 2 summarises this new flexible energy market ecosystem.

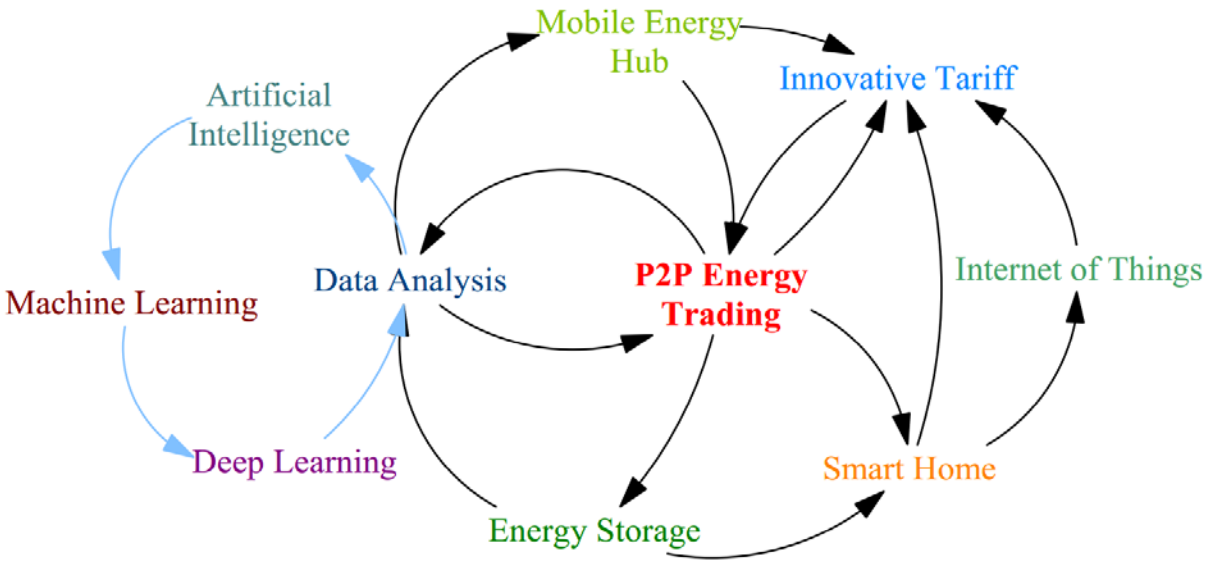

Figure 2. New flexible energy market ecosystem

5. New Business Models

We now turn to consider a number of new business models that we observe in practice, that have arisen the context of the digitalisation opportunities that we discussed in the previous sections.

We started our research by reviewing firms whose business models are based on Blockchain technology. Later on, we extended our research and included other start-ups that rely on ICT more broadly rather than just Blockchain. As a result, reviewed more than one hundred start-ups in the energy sector worldwide. In this section, we compile 40 interesting cases and summarise their business models. We included not only the companies offering services in energy trade but also other services such as electric mobility, energy efficiency and savings, grid state monitoring, CO2 credit trading and others. The companies are compiled from Ofgem' regulatory sandbox (Upgrading Our Energy System, 2017), Free Electrons World's Best Energy Startup 2018 competition (Free Electrons, 2018) and Blockchain2Business (Blockchain2Energy, 2018), Event Horizon summit (Event Horizon, 2018), and through a comprehensive market scanning. In the selection process, we paid extra attention to geographic diversity of the origination of companies. The geographical location of our companies are: 8 UK, 6 Germany, 6 US, 3 China, 3 France, 3 Netherlands, 3 Switzerland, 2 Australia, 1 Austria, 1 Bangladesh,1 Ireland, 1 Norway, 1 Portugal and 1 Turkey. We have prepared two separate tables: Table 1 summarises the business models which do not utilise Blockchain, whereas Table 2 compiles the ones with Blockchain technology.

The descriptions of their business models are compiled from official websites of the companies[9]. In line with business model theory we identify four business model theory dimensions (see Gassmann et al., 2014). These start with the value proposition, where we look at what the business model involves and who it is aimed at. We then look at how value will be created (the nature of the technological solution). And finally, we examine how the company plans to capture revenue (i.e. make money).

[9] For reference, you may click on the hyperlinks on the company names.
https://adaptricity.com/en/; https://beebryte.com/; https://crowd-charge.com/; http://equotaenergy.com/en/; https://www.getfresh.energy/; https://www.greenbird.com/; https://www.gridcure.com/; http://www.mac.ie/; https://www.jungle.ai/; https://www.chargepoint.com; https://www.origamienergy.com/; https://orison.com/; https://piclo.energy/; https://www.powerpeers.nl/; https://www.relectrify.com/; http://www.sensgreen.com/; https://www.me-solshare.com/; https://www.sterblue.com/.

Table 1.

Companies with Digital solutions which do not utilise Blockchain

Company/Project (Field) [10]	Country	Value Proposition (What?)	Targeted Customers (Who?)	Value Creation/Value Delivery (How?)	Value Capture/Revenue Model
Adaptricity (Smart Grids)	Switzerland	"It helps utilities make their power grids smarter and reduce costs. It enables grid operators to automate repetitive tasks such as connection requests, perform in-depth, time-series based analyses of grid behaviour across all voltage levels and evaluate effects of demand response."	Business (Commercial)	"It provides a software, Adaptricity.Mon, to enable real-time data and simulation driven grid transparency across all grid levels. This software is used for grid planning, operation and asset management."	More efficient grid operation. Data analysis and sales of the Adaptricity.Mon software.
BeeBryte (End-user & Digitisation)	France & Singapore	Software-as-a-Service to reduce energy consumption in commercial buildings, factories and EV charging stations.	Business (Commercial) and End-user (Residential)	"Via AI they minimise utility bills with automatic control of heating-cooling equipment (e.g. HVAC), pumps, EV charging points and/or batteries. If solar generation is present, it is used for maximising self-consumption. The concept is 'Internet of Energy'."	Revenue stream through savings. Based on weather forecast, occupancy, usage and energy price signals, the company claims up to 40% savings is possible via maintaining processes & temperature within an operating range set by the customer. 43 buildings are already using this service.

[10] Information collected from official websites of respective companies.

Company/Project (Field)	Country	Value Proposition (What?)	Targeted Customers (Who?)	Value Creation/Value Delivery (How?)	Value Capture/Revenue Model
Crowd Charge (End-user & Digitisation)	UK	Vehicle-to-Grid charging	End-users	"Machine learning and artificial intelligence are used to provide optimised charging sessions. Grid balancing, and real-time reporting services provided via Vehicle-to-Grid scheme."	Revenue creation through providing energy stored in EV batteries at peak times to be used in provision of grid services.
EQuota Energy (End-user & Digitisation)	China	"An energy intelligent management service provider. It provides energy savings and carbon management. Based on AI and Big Data, it provides energy efficiency optimization, operation and maintenance monitoring, carbon emission management, energy planning, electricity sales services, micro-grid services and other industrial chain technology solutions."	Business (Commercial) and End-user (Residential)	"Software solutions are InsightTM & InsightLite. InsightTM is an energy management tool which is used for power monitoring, energy efficiency optimization, equipment management, and predictive operation and maintenance through AI and big data. InsightLite is used for energy reporting, real-time alarms, optimization suggestions and analysis tools."	Revenue through optimised energy consumption, energy savings and carbon emissions management. It is already successfully used for some commercial scenarios. A steel plant in East China saves $1 million USD on energy-related costs and realized an equivalent reduction of 5,000 tons of coal in six months by using EQuota service.

Company/Project (Field)	Country	Value Proposition (What?)	Targeted Customers (Who?)	Value Creation/Value Delivery (How?)	Value Capture/Revenue Model
Fresh Energy (End-user & Digitisation)	Germany	It analyses data collected from smart meters.	End-user (Residential)	"It analyses the data from customer's Smart Meter using complex algorithms, pattern recognition and machine learning, to identify how much power your equipment consumes, and how much that will cost you each month."	Savings through monitoring the energy consumption of household appliances. They will install or replace the existing meter with their own Smart Meter. Revenue through sales of this intelligent power meter.
Greenbird (Smart Grids)	Norway	A digital utility hub managing data	Utilities (Commercial)	"It provides a smart utility hub Metercloud. Metercloud promises managing the data flow faster and more smoothly. The product delivers configurable integration applications for smart metering, smart billing and smart grids."	More efficient grid operation. Utilities can transform into digital platform operators. Revenue through sales of Metercloud.
Gridcure (Smart Grids)	USA	A Software-as-a-Service predictive analytics for electric utilities.	Utilities (Commercial)	"It provides Grid Health Monitoring Platform product. Based on Machine Learning and AI, the platform has module options of which utilities are free to choose with respect to their needs. These modules are used for diagnosing grid issues faster with more	Revenue creation through faster fault management and improved reliability. Sales of Grid Health Monitoring Platform and their optional modules. The platform promises saving costs, recovering lost revenue, and creating new revenue streams with predictive analytics for the utilities.

				sophisticated analysis, saving engineering operations time by optimizing queries & maintenance schedules and increasing customer satisfaction through improved reliability."	
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
GridWatch MAC (Smart Grids)	Ireland	A digital platform for monitoring underground cable networks, overhead line networks and sub-station assets on the medium and low voltage distribution networks. The company, MAC, also provides real-time environmental monitoring.	Utilities (Commercial)	"GridWatch is a digital platform for smart grid monitoring. It has two product solutions: Earth Fault Monitoring Solutions and Load Current Monitoring. These are used for smart sensor and real-time monitoring purposes. "	Revenue creation through faster fault management and improved reliability. Sales of GridWatch and Environmental Monitoring solutions products.
Jungle AI (Smart Grids)	Portugal	Based on AI and Machine Learning, it is a platform for renewable energy generation, and it promises to reduce unplanned downtime, react quickly by detecting faults early on and assuring that	Business (Commercial)	"The Dashboard monitors by using the existing data streams of the assets, uncovers the value of the data using our mix of domain knowledge and machine learning skills and acts based on real-time insights and recommendations delivered	Revenue creation through faster fault and outage detection for the generation companies. Sales of the app Jungle.

		customers' assets are performing at their maximum capacity.		through the web app."	
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
Kisensum (ChargePoint) (End-user & Digitisation)	US	A fleet management software platform.	End-users	"Energy Management storage platform is through smarter charging, grid edge connections and fleet scheduling connection."	Revenue through fleet management, storage and smart charging.
Origami Energy (Smart Grids)	UK	A platform where suppliers and traders meet with flexible generation and energy storage.	Business (Commercial)	"It connects customers' distributed energy assets – generation, demand and battery storage to the technology platform by using its purposed-built energy router. The energy router is capable of continuously streaming sub-second metrology data to its centralised technology platform, which processes and stores it in Big Data system. By using advanced analytics and machine learning, Origami technology platform is able to solve various operational optimisation problems and	Potential revenue stream from ancillary services, billing and settlement.

				derive new insights for medium and long-term strategy."	
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
Orison (End-user & Digitisation)	US	Domestic battery storage system.	End-user (Residential)	"An all-in-one, self-installable home battery system. Orison units include battery storage, power conversion electronics and a smart networking control system."	Storing your own energy for the residential customers. Sales of domestic battery system with an in-home display panel and a smartphone application.
Piclo – Open Utility (Smart Grids)	UK	A top-down approach marketplace platform for flexibility services.	Business (Commercial)	"Piclo Flex is the platform for flexibility buyers and sellers. Together with Good Energy, Piclo introduced Selectricity, a platform for P2P energy trade. Through this platform, businesses and communities can reach renewable energy. Piclo also provides its customers data visualisation and analytics."	Working with big partners and large businesses, a high revenue capture potential through flexibility services.
PowerPeers (Smart Grids)	Netherlands	P2P renewable energy trading platform where users can choose their energy mix.	Business (Industry) and End-user (Residential)	"A P2P energy trade platform for residential customers as well as Dutch This not only includes trading between residential homes but also for the Dutch wind, solar and hydropower suppliers."	Consumers will easily access 100% renewable electricity. Large generators and prosumers will be able to sell their excess energy.

Company/Project (Field)	Country	Value Proposition (What?)	Targeted Customers (Who?)	Value Creation/Value Delivery (How?)	Value Capture/Revenue Model
Relectrify (End-user & Digitisation)	Australia	Battery storage with used electric vehicle batteries.	Business (Commercial) and End-user (Residential)	"Uses retired electric vehicle batteries with advanced control technology and converts those to second-life batteries."	Cheaper second-life batteries can be used in residential solar storage, commercial peak-shaving and grid support purposes.
Sensgreen (End-user & Digitisation)	Turkey	"Sensgreen provides energy saving solutions for commercial real estates by utilising AI models with plug-and-play sensors. The company offers reduction in heating, ventilation and air-conditioning (HVAC) related energy expenses."	Business (Commercial)	"By using IoT and deep learning, the company learns about building occupancy patterns, energy consumption behaviour and user comfort ranges. Then they dynamically control HVAC units to adapt operations into building utilisation and comfort pattern of occupants."	Reduced energy consumption and hence reduced energy bills by smart HVAC service. The company charges the customers 2 USD per square meter of building. Primarily offices, large scale healthcare facilities and hotels are targeted customers.
SOLshare (Smart Grids)	Bangladesh	ICT based P2P energy sharing platform for solar energy generation.	Business (Commercial) and End-users (Residential)	"SOLbox is installed as a direct-current (DC) bi-directional power meter, solar charge controller and machine-to-machine (M2M) communications. Then, SOLweb and SOLapp facilitate secure peer-to-peer electricity trading between users; integrating mobile money payment, data	Monetising excess microgrid solar generation in households and businesses. Sales of SOLshare products.

				analytics and grid management services.”	
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
Sterblue (Smart Grids)	France	Drone inspection for wind energy, electricity distribution, electricity transmission and solar energy.	Business (Commercial & Industry)	“Planning, scheduling and managing flights over industrial facilities or power grid and then uploading and analysing the collected data. The data is collected and analysed at Sterblue Cloud with AI algorithms. Finally, the results are reported to customers.”	Revenue through improved asset management. The customers will be able to take the right decisions for the future of their assets by using detailed Sterblue reports.

Table 2.

Companies with Digital solutions which utilise Blockchain

Company/Project (Field)[11]	Country	Value Proposition (What?)	Targeted Customers (Who?)	Value Creation/Value Delivery (How?)	Value Capture/Revenue Model
Conjoule (P2P)	Germany	A P2P market place for producers and consumers of renewable energy (photovoltaic), as well as owners of batteries and other sources of flexibility, to transact with each other.	Business (Commercial) and End-user (Residential)	"The generators, prosumers and consumers can trade power with Conjoule's platform without the need for traditional intermediaries. Consumers include non-self-powered neighbours, local businesses, supermarkets and schools. A smart meter will be installed with each producer and consumer to ensure that the flow of energy used is measured and billed in real-time. A large energy generation company Innogy assures that it will supply the green energy in case the local generation is insufficient."	Revenue creating through trade of excess local solar energy trade.
Dajie (P2P)	UK	A P2P energy trading platform that combines IoT with Blockchain.	Business (Commercial) and End-user (Residential)	"In a micro-grid, IoT device, Dajie Box, is installed at prosumers. Then the transactions are made and recorded in the platform through Blockchain."	In addition to reaching local energy surplus, the prosumers will be able to redeem their carbon credits by reducing their CO2 emissions. Each kWh traded

[11] Information collected from official websites of respective companies. http://www.conjoule.com/; https://www.dajie.eu/; https://www.energolabs.com/; https://www.energy21.com/; https://lo3energy.com/; https://www.omegagrid.com/; https://ponton.de/; https://www.powerledger.io/; https://verv.energy/; https://www.daisee.com/; https://www.joindrift.com/; http://www.electron.org.uk/; https://energyweb.org/; https://www.enledger.io/; https://gridsingularity.com/; https://www.ibm.com/case-studies/energy-blockchain-labs-inc; https://prosume.io/; https://spectral.energy/; https://wepower.network/; https://slock.it/; https://car-ewallet.de/; https://motionwerk.com/;

					over the Blockchain is represented by 1 Energy Coin, which can be stored in a wallet.
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
Energo Labs (P2P)	China	A P2P platform for a distributed energy system and P2P EV charging using Blockchain technology.	End-users	"With Blockchain, it integrates real-time flow of power, information, and value as energy transactions. The company also provides a smart meter and a smart app. The app is used to connect to the smart meter and to the Energy trading platform."	Excess energy trade between prosumers. Additional revenue stream through smart EV charging.
Energy21 & Stedin (P2P)	Netherlands	A market model for P2P energy trade at local level and in addition, exchange with wholesale markets.	Business (Commercial)	"It provides energy data management solutions through EBASE platform. The platform is open for industrial energy users, traders and suppliers and balancing and flexibility service providers. Layered Energy System (LES) provides solutions to problems resulting from the energy transition, including grid congestion, system imbalance, energy poverty and grid defection."	Revenue stream through lowering grid and balancing costs, accelerating distributed energy transition.
LO3 Energy (P2P)	US	Provides Blockchain based innovations to revolutionize how energy	End-users	"The Smart Meter measures a building's energy production and communicates with the network to collectively	Revenue through energy generation, storage and trade locally. P2P and trustless

		can be generated, stored, bought, sold and used, all at the local level. In collaboration with Siemens, the company is behind the Brooklyn Microgrid Project.		manage energy. Then, Blockchain is used in a decentralized digital ledger in which private computers verify transactions automatically. The application programming interface (API) enables the collaboration. It creates an open path that encourages participation and innovation from members across the network. Finally, the grid connection is done to achieve a community of buildings that generate, store, and trade energy locally.”	cooperation of local community of buildings achieved without the need for intermediaries. Prosumers will be able to sell their excess solar energy directly to their neighbours.
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
OmegaGrid (P2P)	US	A P2P energy platform for grid balancing and market settlement of electric utilities. It is a Blockchain based platform that helps utilities calculate, deliver and redeem rewards for clean energy.	Business (Commercial)	“The software, Ameren accelerator, is used for removing revenue risks of distributed generation of utilities, encourages energy investment by property owners, and enables access to lower rates.”	Reduced revenue risks and compensation for clean energy for utilities.

Company/Project (Field)	Country	Value Proposition (What?)	Targeted Customers (Who?)	Value Creation/Value Delivery (How?)	Value Capture/Revenue Model
PONTON (P2P)	Germany	A Business-to-Business (B2B) IT company with a focus on energy trading, grid management and customer-related processes. The company provides solutions for energy trade (power, gas and CO2 certificates) and grid operation.	Business (Commercial)	"PONTON is a part of the Enerchain project. It is a decentralized energy trading platform for the over the counter wholesale energy market. Within this platform. prosumers, DSOs, and aggregators can exchange energy that is locally produced. Gridchain is a Blockchain-based project with a focus on TSO/DSO process integration. It simplifies and standardises the way how market participants (TSOs, DOSs, aggregators, suppliers and generators) collaborate and communication in the grid management process."	Main revenue source will be the P2P trading tool which is used as the platform for the first European energy trade over the Blockchain. Charging mechanism for the participants is not publicly announced yet.
Power Ledger (P2P)	Australia	It provides software solutions including peer-to-peer trading (xGrid), microgrid trading (μGrid), carbon product trading (C6 and C6+), electric vehicle settlement (Power Port), Asset	Business (Commercial) and End-user (Residential)	"Electricity consumers within an energy microgrid or embedded network are empowered through complete visibility of their electricity usage and transactions; simply, securely, transparently and available to be viewed in real-time. xGrid is a P2P electricity trading across the regulated	Residential customers can make an income from their excess generation and receive a better return on renewable energy investments. Other potential customers are residential strata complexes, such as apartment buildings or units, shopping centres, retirement

		Germination and virtual power plants (VPP 2.0) to access cleaner, cheaper and more reliable electricity.		electricity network. It allows neighbours to trade low-carbon energy. µGrid enables electricity metering, big data acquisition, rapid micro-transactions and microgrid management at an unprecedentedly granular scale.”	villages, caravan/holiday parks and industrial parks.
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
Verv Energy ((End-user & Digitisation)	UK	A smart household service provider based on IoT and AI.	End-user (Residential)	“It is a home energy assistant that gives you intelligent information about key appliances and electricity usage in your home, helping you to tackle your bills, reduce your carbon footprint and keep your home safe. It uses AI to tell the real-time energy consumption of the appliances in the household.”	With Machine Learning it lets the customer know about the energy consumption behaviour of new appliances and gives an alert if an appliance is left turned on too long. Energy savings through monitoring of the appliances and through warnings.
Daisee (Platform)	France	An open and decentralised data platform that collects information from producers, consumers and physical data.	Business (Commercial & Industry) and End-user (Residential)	“The do supply and demand monitoring and collect physical infrastructure data to enable the prosumers decide how they share their energy. Electricity, network and market data are combined.”	The company provides an extra value added by monitoring the physical structure of the electric power system assets.
Drift (Platform)	US	A Renewable energy utility platform that uses Blockchain, AI and machine learning.	Business (Commercial) and End-user (Residential)	“The users, both consumers and suppliers, sign up the platform to buy and sell renewable energy. The platform switches the user’s supplier. It	By eliminating intermediaries, the platform promises between 10% and 20% cheaper electricity to its customers.

				predicts the energy consumption and provides cheaper wholesale energy prices. The residential customer can pick their power mix. It serves local renewable energy and bills the customer monthly.”	
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
Electron (Platform)	UK	A top-down approach company which provides; a registration platform for electricity and gas meters, flexibility trading program and smart meter data privacy.	Business (Commercial) and End-user (Residential)	“Meter Registration Platform, which is a shared registration platform for all UK gas and electricity supply points, reduces the supplier switching from 17 days to minutes. The Flexibility Trading Platform is a common trading venue for all demand-side response actions, P2P energy trade and micro-grid trading.”	Revenue stream through maximising the overall value and liquidity of the flexibility market, at the same time by enabling individual purchasers of flexibility to share costs.
Energy Web Foundation (Platform)	Switzerland	It is an open-source platform designed for the energy sector’s regulatory, operational, and market needs. The company aims to minimise the barriers to enter or exit the energy markets and minimise	Business (Commercial & Industry) and End-user (Residential)	“The platform D3A will use smart contracts and it will provide a market model that will include spot and balancing markets, automating the core technical processes of grid balancing and operation, trading flexible capacity from distributed energy resources, including renewable energy generation, energy	Revenue generation through more competitive futures, spot, and balancing markets. The D3A promises eliminating or diminishing wholesale capacity markets, energy-only markets, primary reserves, secondary markets, and ancillary

		transaction costs.		storage and demand response. The Energy Web Blockchain, on the other hand, will manage the electricity grid's transactions, customers and devices in an open-source and secure environment."	products. As an alternative, it will provide necessary grid services through recursive energy and balancing markets that operate from the bottom up.
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
EnLedger (Platform)	US	A platform for grid optimisation and P2P energy trade.	Business (Commercial) and End-user (Residential)	"EnLedger EnergyChain Project has two services: Automated Power Exchange and Energy Credit Tracking. The project is a platform for automated tracking of energy production, usage, availability, share ownership, dividend and profit-sharing pay-outs from grid-attached devices and appliances, including tracking generation and retirement of renewable resource credits and device audit/registrations."	It provides real-time markets for true pricing of energy and renewable resource credits tokenized into Blockchains in the EnergyChain Project.
Grid Singularity (Platform)	Austria	An open and decentralised energy data exchange platform.	Business (Commercial & Industry)	"It will use The Energy Web Blockchain of Energy Web Foundation. A data exchange platform and a grid management agent for grid balancing, investment facilities, certificate trading	Revenue sources through D3A model and other P2P energy trading platform pilot projects.

				and energy trading and validation. They are in the D3A market model building team.”	
Company/Project (Field)	**Country**	**Value Proposition (What?)**	**Targeted Customers (Who?)**	**Value Creation/Value Delivery (How?)**	**Value Capture/Revenue Model**
IBM Energy Blockchain Labs Inc. (Platform)	China	A climate change focused platform for green energy marketplace to monitor and buy carbon credits.	Business (Commercial & Industry)	“Energy Blockchain Labs Inc. uses IBM technology to introduce more efficient ways for organizations to meet government-mandated carbon emissions reduction quotas. High-emission participants will be able to monitor their carbon footprints and meet quotas by buying carbon credits from low-emission participants.”	The company resembles a small-scale, decentralised and Blockchain based application of European Emissions Trading Scheme. Revenue stream through carbon purchase.
PROSUME (Platform)	Switzerland	A platform that will serve multi purposes such as P2P energy trading, Electric Vehicle management and smart metering.	Business (Commercial) and End-user (Residential)	“In addition to P2P energy trade and smart metering and billing, Crypto-Equity for Renewable Energy Projects is used for co-ownership of renewable energy plants and storage assets. Moreover, Smart Community Energy Aggregator Development is for participating to specific aggregator requests of energy demands, where the consumers choose different energy sources like green, local, fossil.”	Selling excess local energy, easy smart metering and billing services. Easing the financing of renewable plants through co-ownership scheme.

Company/Project (Field)	Country	Value Proposition (What?)	Targeted Customers (Who?)	Value Creation/Value Delivery (How?)	Value Capture/Revenue Model
Spectral (Platform) SPECTRAL	Netherlands	A data analytics platform for of energy storage, demand flexibility, and locally produced renewable energy, propelling the evolution of smart energy networks.	Business (Commercial)	"Spectral Energy Management Systems is an energy management platform which enables deployment and control of a single battery system or aggregate an entire neighbourhood. Furthermore, Spectral Energy Xchange provides a transaction system for automated negotiation and settlement of energy and flexibility trading. It integrates with existing smart-metering infrastructure, real-time energy visualizations and billing."	Revenue stream through flexibility solutions and optimisation of user behaviour.
WePower (Platform) we power	UK	A platform for the renewable energy generators to raise capital by selling their energy production upfront in the form of tradeable Smart Energy Contracts.	Business (Industry) and End-user (Residential)	"The platform gathers the renewable energy producers who own solar, wind and hydropower plants. It is used for fundraising for future renewable energy projects. The smart contracts represent the amount of energy that a powerplant is planning to produce in the future and how that energy is distributed between the investors."	The smart contracts are tradeable and can also be liquidated into the local energy wholesale market.

Company/Project (Field)	Country	Value Proposition (What?)	Targeted Customers (Who?)	Value Creation/Value Delivery (How?)	Value Capture/Revenue Model
Slock.it (Platform & EV)	Germany	A Blockchain based platform for sharing economy where Sharing Economy where customers can rent, sell or share any smart object including EVs.	Business (Commercial) and End-user (Residential)	"IoT enables smart objects to be a part of the platform or the 'Economy of Things'. Human to Machine, Machine to Machine, and Machine to Human options are available. The interoperability is achieved securely via smart contracts or application programming (API). Transactions are done over Blockchain."	The company targets a large customer segment by promising renting, selling and sharing anything with IoT capability. Extra revenue will be created via faster and easier transactions and by eliminating third-party participants.
Car eWallet (EV)	Germany	A platform that makes the car a business entity which can autonomously pay for services like parking or charging on its own.	End-users	"Based on Blockchain, it provides a platform with low transaction costs, no creditor risk and full security. All transactions are done with smart contracts, which are stored as a chain of data blocks."	Revenue capture through eliminating intermediaries and trusted third-party participants when the user wants to charge the car or park it. The service allows customer to use all charging stations.
MotionWerk (EV)	Germany	A Blockchain based e-mobility platform to support an open, secure and decentralized mobility infrastructure.	Business (Commercial) and End-user (Residential)	"Share&Charge is a decentralized protocol for EV charging, transactions, and data sharing – enabling companies to offer a smart and secure charging experience. Oslo2Rome project offers Roaming Solution where the customers can use charging infrastructure across Europe by connecting public and private	Smart charging and cheaper transactions. A larger charging infrastructure network. Revenue through increased number of EV users by promising a wider European charging landscape.

				charging infrastructure which are included in the platform."	

We summarise the number, service areas and the technologies used by these companies in Table 3. We should highlight that one company can engage with numerous services at the same time (and may be counted more than once).

Table 3.

Number, service areas and digital technologies used by start-ups in Tables 1 and 2

Service area / *Digital technology*	*Carbon management, carbon credits*	*Data management*	*Energy efficiency, energy savings, domestic applications*	*EVs, grid services, EV sharing, fleet management, smart charging and parking*	*Grid services, grid performance and monitoring*	*Platforms, P2P energy trade, flexibility, storage*	*Smart metering, billing and switching*
AI, ML, DL[12]	1		5	3	3	2	1
Blockchain	4	3		6	1	17	4
Big Data	2		1	1		1	1
IoT			2	1		2	
Other ICT		1	1	2	2	3	1

An important issue for many of these firms is whether they are dependent on existing market players for their success, in particular, whether they can ever successfully capture revenue without partnering with an existing utility.

At least 14 of our 40 companies explicitly report having utility partners on their websites. Energy Web Foundation (Switzerland), Power Ledger (Australia) and Spectral (Netherlands) are good examples.

Energy Web Foundation has affiliations with GL (AU), Duke Energy (US), Enedis (BE), Exelon (US), Eneco (NL), E.ON (GE), Innogy (DE), PG&E (US), PTT (TH), SB Energy Corp (JP), Swisspower (CH) and Wipro (IN). The 10 founding ones are Centrica, Elia, Engie, Sempra Energy, Shell, SP Group, Statoil, STEDIN, TEPCO, and TWL. The company has numerous pilot projects in the US, Netherlands and Denmark. Power Ledger is partnered with BCPG (renewable energy firm) (TH), Vector ltd

[12] ML stands for Machine Learning and DL stands for Deep Learning.

(power utility), (NZ), Origin Energy (retailer & power generation), (AUS) and KEPCO (JP) in various projects in Thailand, Australia and California. Spectral is partnered with Alliander (a Dutch DSO) and Greenchoice (a Dutch green energy supplier) in multiple projects in the Netherlands. Obviously, we observe that partnering with a utility or a corporate is the best way of reducing regulatory obstacles and having a better financial support.

A key final observation is whether any of our companies actually have a sustainable revenue stream? Unfortunately, it is not easy to access whether these companies currently generate revenues or not. However, among the ones we accessed, we saw that quite few of those do currently earn revenue from their services. For example, Piclo is one of these few in the UK. Nonetheless, the funding information is more accessible. Power Ledger has had two funding rounds (as of mid-2019): Nov 17, 2017, money raised: $8M and Sep 4, 2017, money raised: A$34M with a total of $35M (Crunchbase, 2019a). The company has 4 investors. Similarly, Energy Web Foundation had two funding rounds: May 10, 2017, money raised: $2.5M (from Tokyo Electric Power) and Aug 2017, money raised: $14M (from 37 Affiliates) (Crunchbase, 2019b; Energy Web Foundation, 2018).

6. How the Regulators Should Support New Business Models

In 2017, venture capitalists invested over $1 billion in 215 Blockchain based company deals (CBINSIGHTS, 2018). The technology is quite promising in terms of providing a secure and trustless transaction and data storage medium. By 2027, it is expected that around 10% of global gross domestic product will be stored on Blockchain (World Economic Forum, 2015). We do not know the precise share of this technology in energy sector yet. However, the number of start-ups is booming, and appropriate regulation will be crucial to its success.

An important question that these new companies and their associated energy regulators need to ask of their business models is: how do they depend on the current regulatory framework? This can be in terms of depending on the current regulatory arrangements remaining in place *or* on the current regulatory arrangements being changed to be more supportive of the business model. For instance, regulators need to be wary of business models that exploit loopholes in existing regulation which did not foresee the rise of distributed generation or electric vehicles. And similarly, regulators may need to change market rules that arbitrarily exclude new players simply by not imagining that they could play a role in the system, e.g. rules on minimum sizes for market parties or on excluding parties from offering multiple services simultaneously.

Such regulatory obstacles are a key concern for many of our companies. In UK, Ofgem provides a regulatory sandbox "*to allow businesses to trial new ideas, subject to conditions, without incurring all the usual regulatory requirements*" (Upgrading Our Energy System, 2017, p.16). Electron, Origami Energy and Piclo (reported in the previous section) are among the 'regulatory sandbox' companies in UK. Some companies from the US and Netherlands that we contacted mentioned that they are hoping to have a similar platform to alleviate regulatory barriers in their country of operations.

Policy support is vital in the flourishing of new business in energy sector. In 1789, Benjamin Franklin states in one of his letters "…in this world nothing can be said to be certain, except death and taxes." (The Works of Benjamin Franklin, 1817). Today, we might update this statement as "in this world nothing can be said to be certain, except death, taxes *and regulations*." The future regulatory framework in Europe is quite promising in this sense (and in line with the New York REV developments noted above). Article 15 & 16 of EU Clean Energy Package will be highly beneficial for the start-ups especially the ones which provide digital platforms for energy trade (EC, 2019):

"Article 15, Active customers:

1.Member States shall ensure that final customers:

1.1 The energy installation required for the activities of the active customer may be managed by a third party for installation, operation, including metering and maintenance."

"Article 16, Local energy communities:

(a)are entitled to own, establish, or lease community networks and to autonomously manage them;

(b)can access all organised markets either directly or through aggregators[13] or suppliers in a non-discriminatory manner;".

To achieve democratisation via enhancing prosumers and local energy communities, similar regulatory support will be helpful for the start-ups in other parts of the world.

Nevertheless, even though the idea of P2P trade seems attractive in terms of the democratisation of the energy system, we should stress that thanks to the digitalisation the scattered small prosumers might easily connect together and become large players in the markets as aggregators or as a part of the suppliers. On the other hand, in some countries demand is falling partly due to the increasing energy efficiency. European Union has ambitious energy efficiency targets for 2020 and 2030. In the UK typical annual domestic consumption value of Profile Class 1 customers is 3,100 kWh, whilst it was 3,300 kWh in 2010 (Ofgem, 2019). Falling demand and 'utilities' death spiral' pose a challenge to conventional businesses. Therefore, we might conclude that partnerships among utilities and start-ups might be the answer to this threat via creating novel services and generating new revenue streams.

7. Conclusions

Decentralised generation and increasing numbers of prosumers pose new challenges and as well as new business opportunities in the energy sector. Traditional centralised markets have their shortcomings in enabling the participation of small parties. Aggregators could be a way of integrating prosumers to the electricity markets. Nevertheless, aggregators require access to markets and market instruments, and they might need to acquire access rights via agreements with existing retail suppliers (Ofgem, 2016). However, this might mean confining the freedom and flexibility of the prosumers. The development of digital technologies promises to have significant impacts in the energy industry. Advanced algorithms such as artificial intelligence, machine learning and deep learning are frequently used in electricity trading projects to promote digitalisation in energy markets. Numerous P2P energy trading systems utilise Blockchain technology. P2P trading through smart contracts is one application of Blockchain technology that will impact all commodity market

[13] An aggregator is an agent that operates multiple small-scale decentralised sources and acts as if it is a larger-scale centralised generation asset. Australia, Belgium, France, Germany, Netherlands, UK, US have already established regulatory frameworks for aggregators (IRENA, 2019).

participants in the near future. However, we should underline that the application of Blockchain technology in energy trading is a supplementary practice and Blockchain will support, rather than replace the existing energy market.

This paper analyses the new trends towards digitalisation driven by the rise of distributed generation; the application of artificial intelligence, machine learning, deep learning and Blockchain in energy sector. These trends enable entrepreneurs and start-ups to propose new business models to take part in the large existing energy markets. We have tried to compile 40 business models from around the world which represent interesting cases. Even though these companies offer novel and exciting solutions and services, due to the weaknesses in value capture and revenue creation models, we believe many of these companies – as with all start-ups - will not survive in the long run.

As a disruptive technological innovation, P2P energy models promote renewable resources by offering customers more options, increasing trading efficiency and optimising resource utilisation, reducing unnecessary financial burdens, introducing more market participants, building trust among prosumers, and making the transaction procedure simpler. Nevertheless, these models involve a series of drawbacks such as consuming more energy, illegal information that might be contained in a Blockchain, current policy limitations, a lack of previous experience and conflicts of interest between P2P platform providers and the established culture of traditional energy firms.

References

Allen, D., 2017. Blockchain innovation commons. SSRN Electronic Journal, pp. 20. http://dx.doi.org/10.2139/ssrn.2919170

Alvaro-Hermana, R., Fraile-Ardanuy, J., Zufiria, P.J., Knapen, L., Janssens, D., 2016. Peer to peer energy trading with electric vehicles. IEEE Intell. Transp. Syst. Mag. 8, pp. 33–44.

Barreno, M., Nelson, B., Sears, R., Joseph, A.D., Tygar, J.D., 2006. Can machine learning be secure?, in: Proceedings of the 2006 ACM Symposium on Information, Computer and Communications Security. ACM, pp. 16–25.

Berriel, R.F., Lopes, A.T., Rodrigues, A., Varejão, F.M., Oliveira-Santos, T., 2017. Monthly energy consumption forecast: A deep learning approach, in: 2017 International Joint Conference on Neural Networks (IJCNN). Presented at the 2017 International Joint Conference on Neural Networks (IJCNN), pp. 4283–4290. https://doi.org/10.1109/IJCNN.2017.7966398

Blockchain2Energy, 2018. [WWW Document]. Blockchain2Business, 5-6 February 2018, Amsterdam. URL https://europe.Blockchain2energy.com/Blockchain-content/2019/1/8/Blockchain-amp-energy-in-europe#Blockchainoverview (accessed 8.6.18).

BNEF, 2017. Digitalisation of Energy Systems [WWW Document]. Bloom. NEF. URL https://about.bnef.com/blog/digitalisation-energy-systems/ (accessed 8.6.18).

Bose, R., 2009. Advanced analytics: opportunities and challenges. Ind. Manag. Data Syst. 109, 155–172.
BrooklynMicrogrid, 2018. Brooklyn Microgrid [WWW Document]. Future Energy Local. URL https://www.brooklyn.energy/ (accessed 8.28.18).

Burger, C., Weinmann, J., 2016. European utilities: Strategic choices and cultural prerequisites for the future, in: Future of Utilities Utilities of the Future. Elsevier, pp. 303–322.

California Distributed Generation Statistics, 2019. Statistics and Charts [WWW Document]. URL https://www.californiadgstats.ca.gov/charts/ (accessed 12.5.19).

CBINSIGHTS, 2018. Blockchain Startups Absorbed 5X More Capital Via ICOs Than Equity Financings In 2017. industry [WWW Document]. URL https://www.cbinsights.com/research/blockchain-vc-ico-funding/ (accessed 20.6.19).

Con Edison, 2016. Distributed System Implementation Plan (DSIP). Consolidated Edison, Jun. 2016.

Con Edison, 2018. 2017 Annual Report. Consolidated Edison, Feb. 2018.

ConsultancyUK, 2018. Artificial Intelligence set to revolutionise energy & utilities industry [WWW Document]. URL https://www.consultancy.uk/news/16767/artificial-intelligence-set-to-revolutionise-energy-utilities-industry (accessed 8.7.18).

Copel, M., 2016. The Difference Between AI, Machine Learning, and Deep Learning? | NVIDIA Blog [WWW Document]. Off. NVIDIA Blog. URL https://blogs.nvidia.com/blog/2016/07/29/whats-difference-artificial-intelligence-machine-learning-deep-learning-ai/ (accessed 8.7.18).

Crunchbase, 2019a. Power Ledger. [WWW Document]. URL https://www.crunchbase.com/organization/power-ledger#section-overview (accessed 12.5.19).

Crunchbase, 2019b. Energy Web Foundation. [WWW Document]. URL https://www.crunchbase.com/organization/energy-web-foundation (accessed 12.5.19).

Cuofano, 2019. Cuofano, G. FourWeek MBA. [WWW Document]. What Is a Business Model? 30 Successful Types of Business Models You Need to Know. URL https://fourweekmba.com/what-is-a-business-model/ (accessed 12.5.19).

DECC, 2019. Solar photovoltaics deployment. [WWW Document]. Solar photovoltaics deployment. URL https://www.gov.uk/government/statistics/solar-photovoltaics-deployment (accessed 12.5.19).

De Martini, P. and Kristov, L. 2015. Distribution Systems in a High Distributed Energy Resources Future. Planning, Market Design, Operation and Oversight. Future Electric Utility Regulation, Report No. 2, Oct. 2015.

Dena, 2019. Deutsche Energie-Agentur GmbH (dena), German Energy Agency. dena Multi-Stakeholder Study, Blockchain in the integrated energy transition, Study findings. Dena, Berlin, Germany, Feb. 2019.

Deng, L., Yu, D., 2014. Deep Learning: Methods and Applications. Found. Trends® Signal Process. 7, 197–387. https://doi.org/10.1561/2000000039

EC, 2019. The European Commission, Clean energy Package, Chapter III, Consumer Empowerment and Protection. 2009/72/EC Annex I.1 (adapted).

E-ISAC, 2016. Analysis of the Cyber Attack on the Ukrainian Power Grid. SANS, Washington D.C.

Engerati, 2018. Utilities and machine learning – the use cases [WWW Document]. Engerati - Smart Energy Netw. URL https://www.engerati.com/energy-management/article/machine-learning/utilities-and-machine-learning-%E2%80%93-use-cases (accessed 8.7.18).

Energy Web Foundation, 2018. [WWW Document]. Newsletter. URL https://energyweb.org/news/ewf-february-5-2018/ (accessed 12.5.19).

Essl, A., Ortner, A., Haas, R., Hettegger, P., 2017. Machine learning analysis for a flexibility energy approach towards renewable energy integration with dynamic forecasting of electricity balancing power, in: 2017 14th International Conference on the European Energy Market (EEM). Presented at the 2017 14th International Conference on the European Energy Market (EEM), pp. 1–6. https://doi.org/10.1109/EEM.2017.7981877

Evans, G., 2016. DeepMind AI Reduces Google Data Centre Cooling Bill by 40% | DeepMind [WWW Document]. Deep. AI Reduces Google Data Cent. Cool. Bill 40. URL https://deepmind.com/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-40/ (accessed 8.27.18).

Event Horizon, 2018. [WWW Document]. EventHorizon Summit, Berlin. URL https://eventhorizonsummit.com/ (accessed 8.27.18).

Fehrenbacher, 2016. How Data and Machine Learning Are Changing The Solar Industry | Fortune [WWW Document]. URL http://fortune.com/2016/09/14/data-machine-learning-solar/ (accessed 8.27.18).

Forbes, 2018. The 5 Big Problems with Blockchain Everyone Should Be Aware of. [WWW Document]. URL https://www.forbes.com/sites/bernardmarr/2018/02/19/the-5-big-problems-with-blockchain-everyone-should-be-aware-of/ (accessed 6.3.19).

Free Electrons, 2018. Free Electrons World's Best Energy Startup. [WWW Document]. URL http://www.freetheelectron.com/news/and-the-30-startups-chosen-for-the-free-electrons-bootcamp-are%E2%80%A6 (accessed 8.27.18).

Gao, G., Lo, K., Lu, J., 2017. Risk assessment due to electricity price forecast uncertainty in UK electricity market, in: Universities Power Engineering Conference (UPEC), 2017 52nd International. IEEE, pp. 1–6.

Gassmann, O., Frankenberger, K., Csik, M. (2014), The St Gallen Business Model Navigator, Working Paper University of St Gallen.

Giotitsas, C., Pazaitis, A., Kostakis, V., 2015. A peer-to-peer approach to energy production. Technol. Soc. 42, pp. 28–38.

Inam, W., Strawser, D., Afridi, K.K., Ram, R.J., Perreault, D.J., 2015. Architecture and system analysis of microgrids with peer-to-peer electricity sharing to create a marketplace which enables energy access, in: Power Electronics and ECCE Asia (ICPE-ECCE Asia), 2015 9th International Conference On. IEEE, pp. 464–469.

IRENA, 2019. Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables. International Renewable Energy Agency (IRENA), Abu Dhabi.

Joint Utilities, 2016. Supplemental Distributed System Implementation Plan. CASE 14-M-0101. In the Matter of Distributed System Implementation Plans. Joint Utilities, Nov. 2016.

Jucikas, T., 2017. Artificial Intelligence and the future of energy. WePower.

Khan, A.S.M., Verzijlbergh, R.A., Sakinci, O.C., De Vries, L.J., 2018. How do demand response and electrical energy storage affect (the need for) a capacity market? Appl. Energy 214, pp. 39–62.

Kim, M., Song, S., Jun, M.S., 2016. A Study of Block Chain-Based Peer-to-Peer Energy Loan Service in Smart Grid Environments. Journal of Computational and Theoretical Nanoscience 22(9), pp. 2543-2546.

Kingma, D.P., Mohamed, S., Rezende, D.J., Welling, M., 2014. Semi-supervised learning with deep generative models, in: Advances in Neural Information Processing Systems. pp. 3581–3589.

Küfeoğlu, S., 2015. Economic impacts of electric power outages and evaluation of customer interruption costs. Espoo, Finland.

Küfeoğlu, S. and Özkuran, M., 2019. Energy Consumption of Bitcoin Mining. Cambridge Working Papers in Economics, 1948.

Lima, C.A.F., Navas, J.R.P., 2012. Smart metering and systems to support a conscious use of water and electricity. Energy 45, pp. 528–540.

Munger, M.C., 2018. Tomorrow 3.0: Transaction Costs and the Sharing Economy. Cambridge University Press.

NY DPS, 2014a. Reforming the Energy Vision. Staff Report and Proposal. CASE 14-M-0101 - Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision. State of New York Department of Public Service Apr. 2014.

NY DPS, 2014b. Developing the REV Market in New York: DPS Staff Straw Proposal on Track one Issues. CASE 14-M-0101 – Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision. State of New York Department of Public Service, Aug. 2014.

NY DPS, 2014c. Memorandum and Resolution on Demonstration Projects. CASE 14-M-0101 – Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision. State of New York Department of Public Service, Dec. 2014.

NY DPS, 2015. Order Adopting Regulatory Policy Framework and Implementation Plan. CASE 14-M-0101 – Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision. State of New York Department of Public Service, Feb. 2015.

NY DPS, 2016a. Order Adopting a Ratemaking and Utility Revenue Model Policy Framework. CASE 14-M-0101 – Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision. State of New York Department of Public Service, May 2016.

Ofgem, 2016. Aggregators - Barriers and External Impacts. Ofgem, UK.

Ofgem, 2018a. State of the energy market Report. Ofgem, UK.

Ofgem, 2018b. Office of Gas and Electricity Markets, Feed-In Tariff (FIT) rates. Ofgem, UK.

Ofgem, 2019. Default tariff price cap level: 1 January 2019 to 31 March 2019. [WWW Document]. URL https://www.ofgem.gov.uk/publications-and-updates/default-tariff-price-cap-level-1-january-2019-31-march-2019 (accessed 12.5.19).

Pouttu, A., Haapola, J., Ahokangas, P., Xu, Y., Kopsakangas-Savolainen, M., Porras, E., Matamoros, J., Kalalas, C., Alonso-Zarate, J., Gallego, F.D., 2017. P2P model for distributed energy trading, grid control and ICT for local smart grids, in: Networks and Communications (EuCNC), 2017 European Conference On. IEEE, pp. 1–6.

PV Status Report, 2018. Jäger-Waldau, A. Joint Research Centre (JRC) Science for Policy Report. Ispra, Italy.

Ramos, C., Liu, C., 2011. AI in Power Systems and Energy Markets. IEEE Intell. Syst. 26, pp. 5–8. https://doi.org/10.1109/MIS.2011.26

REN21, 2018. Renewables 2018 Global Status Report. REN21 Renewable Energy Policy Network for the 21st Century. REN21 Secretariat, Paris, France, 2018.

Roy, A., Bruce, A., MacGill, I., 2016. The Potential Value of Peer-to-Peer Energy Trading in the Australian National Electricity Market, in: Asia-Pacific Solar Research Conference.

Samad, T., Kiliccote, S., 2012. Smart grid technologies and applications for the industrial sector. Comput. Chem. Eng. 47, pp. 76–84.

Schoklitsch, H., 2018. Digitalisation Is Revolutionizing the Renewable Energy Sector - Renewable Energy World [WWW Document]. URL https://www.renewableenergyworld.com/articles/2018/02/digitalisation-is-revolutionizing-the-renewable-energy-sector.html (accessed 8.6.18).

Shead, 2016. Google DeepMind AI to be in all of Google's data centres by end of 2016 - Business Insider [WWW Document]. Deep. AI Will Be Every Google Data Cent. End 2016. URL https://www.businessinsider.com/google-deepmind-ai-in-every-company-data-centre-end-of-year-2016-7 (accessed 8.27.18).

Swan, M., 2015. Blockchain: Blueprint for a new economy. O'Reilly Media, Inc.

The Works of Benjamin Franklin, 1817. Letter to M. Le Roy. Philadelphia, 13 November, 1789. [WWW Document]. URL https://oll.libertyfund.org/titles/franklin-the-works-of-benjamin-franklin-vol-xii-letters-and-misc-writings-1788-1790-supplement-indexes (accessed 29.4.19).

Tien, J.M., 2013. Big data: Unleashing information. J. Syst. Sci. Syst. Eng. 22, pp. 127–151.

Upgrading Our Energy System, 2017. Ofgem, Smart Systems and Flexibility Plan. London, UK.

World Economic Forum, 2015. Global Agenda Council on the Future of Software & Society [WWW Document]. Deep Shift Technology Tipping Points and Societal Impact, Survey Report. URL http://www3.weforum.org/docs/WEF_GAC15_Technological_Tipping_Points_report_2015.pdf (accessed 20.6.19).

Zhou, Y., Han, M., Liu, L., He, J.S., Wang, Y., 2018. Deep learning approach for cyberattack detection, in: IEEE INFOCOM 2018-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS). IEEE.