Peer-to-Peer (P2P) electricity trading and Power Purchasing Agreements (PPAs)

Part 2 of the GJETC Study on Digitalization and the Energy Transition

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Content

1 Introduction and objectives of the study

Digitalization is one of the major megatrends of the 21st century, which is increasingly radiating into more and more areas of life, creating new business models, but also bringing with it previously unknown challenges. The health sector, politics and administration, urban development and communication are just a few examples of this trend.

The energy sector, too, is seeing rapid development of uses of digitalization. The potential of digital solutions for a major transformation of the energy system may be high, especially with regard to a comprehensive energy transition. Overall, there is hope that digitalization can play a key role in increasing the efficiency of the energy system and opening up the energy market to new technologies and business models. In the electricity market, digitalization enables high transaction speeds and micro-transactions; parts of the electricity market could be organized decentrally and automatically between producers and consumers, including energy storage and demand response, and certification and trading of green electricity can be simplified and made more transparent (see Agentur für Erneuerbare Energie 2018).

Of course, this is also associated with challenges: The constant increase of digital processes causes an enormous computing effort and the corresponding energy and materials consumption. The market roles and responsibilities of new players in electricity trading have not yet been clarified. In addition, there is a conflict of interest between data protection and “hunger for data” of an intelligent energy system, which is also a question of social acceptance of digital technologies.

In the following, the possibilities, opportunities and potential positive and negative effects of digital technologies for a transformation of the energy system will be examined in more detail for the example of peer-to-peer electricity trading (P2P) and power purchasing agreements (PPAs), by reviewing and evaluating existing research work and performing own analysis.

P2P trading is of particular interest because, within the framework of the energy sector, it creates the opportunity to network different market players directly with each other and thus establish direct electricity trading without previously usual instances such as electricity exchanges or energy suppliers. P2P can affect both the interaction between companies and that between companies and consumers (in the sense of traditional supply relationships); on the other hand, innovation such as blockchain technology also enables P2P trading of energy between consumers or from consumers to companies. Nationwide electricity trading via such a P2P network would have massive effects on the existing energy market and its established market players, as there is technically the possibility of a fully decentralized and autonomous energy supply (cf. Kreuzburg 2018). This will depend on who is allowed or able to participate in such P2P trading, for which purpose, and what will be the consequences for the markets and particularly for those not allowed or able to participate in P2P trading.

The questions this paper seeks to analyze are, therefore:

- What are purposes and objectives of P2P trading and PPAs proposed or already tested today (chapter 2.1)? For example, enabling continued operation of RES-E plants after the end of Feed-in Tariff (FIT) payments; meeting corporate green electricity purchase or decarbonization goals; regional decentralized power markets; grid stabilization via targeted P2P trading; financing new RES-E plants without FIT- or FIP/MP-type payments (FIP = Feed-in Price; MP = Market Premium[1]); or other purposes or objectives? And what is the relevance of each of the identified purposes/objectives for Germany and Japan today or in the future?

- Which models of P2P trading and PPAs (e.g. single bilateral PPAs; decentralized autonomous network of producers and customers; supplier-facilitated market) are possible or do already exist? What are the roles and interests of market actors? And which contractual arrangements are possible in the different models? Are these appropriate for the purposes and objectives identified? How relevant are the respective models for both Japan and Germany today and in the future? (Chapter 2.2)
- In chapter 2.3 we will ask for the preconditions for each model, especially for the digital technology needed for P2P trading and PPAs (e.g. smart or other data-storing load meter, blockchain or other technology for tracking supply and implementing contracts and payments, EVs and smart chargers, legal/regulatory preconditions, necessity of assuming balancing group responsibility). What is the status of preconditions in both countries?
- Which experiences to date and current development/trends, with whatever model, exist in Germany and Japan (chapter 3)?
- Based on the previous chapters, chapter 4 will ask what the potential positive and negative impacts are and for the opportunities and threats for each type of market actor; on the on hand for markets and the energy system in total, on the other hand for non-participating generators and consumers for each model.
- Derived from the analysis of the preceding chapter, recommendations for both countries on models that would be useful in their respective markets are formulated in Chapter 5.1.
- Which policies and regulations are needed for a successful introduction of the models recommended (chapter 5.2)?

The report ends with conclusions and recommendations in chapter 6.

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[1] Under the German Renewable Energy Law, grid access and payments for new medium to large renewable energy generators are granted only by succeeding in an auction. The generators will receive the Feed-in Price (FIP) they bid or the wholesale market price at the time of feed-in, whatever is higher. If the wholesale market price for the same type of generator (e.g. Solar PV, on-shore wind), averaged over the month, is lower than the FIP, the generator will receive the Market Premium (MP) covering the difference to the accepted FIP of the generator. Japan currently considers to newly introduce the FIP/MP scheme similar to German in place of the existing FIT scheme for large scale solar PV and onshore/offsore wind.

2 Peer-to-Peer electricity trading (P2P) and Power Purchasing Agreements (PPAs): purposes, models, and preconditions

2.1 Purposes and objectives of P2P electricity trading and PPAs

To discuss purposes, preconditions and objectives of P2P trading and PPAs, first the question arises what is the definition of P2P trading and PPAs?

2.1.1 P2P trading

There is no internationally standardized definition of P2P trading, peer-to-peer electricity trading. In fact, P2P trading is a new concept whose functional possibility has not been fully explored yet. As an example specifically addressing P2P trading of electricity (or gas) from renewable energy, the EU RES Directive (EU 2018/2001, Article 2 Definition (18)) states that "peer-to-peer trading of renewable energy means the sale of renewable energy between market participants by means of a contract with predetermined conditions governing the automated execution and settlement of the transaction, either directly between market participants or indirectly through a certified third-party market participant, such as an aggregator." In this paper, P2P trading can be defined as "a contractual model that will enable short-term electricity exchange on a regional or national scale between multiple peers such as 'prosumers' or/and small to medium power generators or/and electricity appliances located at the end of distribution networks, i.e. distributed energy resources". The P2P trading will normally be based on contractual rules and electricity prices determined by the market or the contract, as well as predetermined conditions governing the automated execution and settlement of the transaction.

Especially the last element, the automated execution and settlement, will require extensive use of digitalization. In most pilot or full business schemes existing to date, blockchain is used for this automated execution and settlement, but there may also be other software solutions for implementing it.

As a rule today, electricity, including from renewable energy sources, is supplied to final consumers by electricity suppliers, who procure the electricity they supply from wholesale markets or, in some cases, directly from generators, including green electricity producers. Increasingly, however, the direct supply of green electricity from producers to final consumers is also being discussed and in some cases already practiced.

Peer-to-peer (P2P) electricity supply models may become particularly interesting against the background of the increasing number of "prosumers", i.e. electricity consumers who have an electricity generation plant for their own supply and sell any surpluses to other consumers, i.e., their peers (instead of selling surpluses to the electricity network operator, combined with a claim to the feed-in tariff, as for example in Germany under § 21 EEG 2017) (here and in the following Buchmüller 2018: 117). Such a massive increase in distributed renewable generation plants, particularly rooftop solar PV, associated with an enormous increase in excess electricity after self-consumption calls for exploring the strengths and weaknesses of P2P trading as one of means of effective use of these resources.

P2P models can also be an option for connecting small-scale and decentralized generation with corresponding consumers and thus reacting to the increasing decentralization of energy generation, which is ongoing in Germany as a result of nuclear and coal phase-out and the increasing expansion of renewable energies. An additional driver may be the end of the FIT support period for the FIT certified plants, which will apply to an increasing number of wind and solar plants from 2021 in Germany and already applies to a large number of residential roof-top solar plants even from 2019 in Japan. P2P models are discussed as an approach for enabling the continued economic operation of the FIT certified plants after the end of the funding period. In addition, supporters of peer-to-peer trading also see this as a contribution to increasing social acceptance of the energy transition, as electricity can be advertised with the attributes “directly from the producer” and “from the region”.

2.1.2 PPAs

An internationally standardized definition is also not yet available for PPA, Power Purchasing Agreement. At the EU level, the above-mentioned RES Directive (EU 2018/2001 Article 2 Definition (17)) defines that “renewables power purchase agreement means a contract under which a natural or legal person agrees to purchase renewable electricity directly from an electricity producer.” The definition given by IRENA (2018) is more specific that is “an arrangement under which a company enters into a long-term contract with an independent power producer or a utility and commits to purchasing a specific amount of renewable electricity or the output from a specific asset (sleeved or virtual), at an agreed price”. Having these, this paper defines PPA as “a medium-to-long-term electricity supply agreement concluded between a seller (plant operator) and a buyer, e.g. an energy supplier or final electricity consumers, such as large industrial consumers, data centres, and large buildings”.

In principle, PPAs have a very wide scope of application, which can include a wide variety of design forms. This makes the scientific discussion more difficult because PPAs are a collective term for various different types of contracts, which do not necessarily have a novelty value, compared to the current status of known energy contracts. Classic direct marketing or electricity trading contracts, for example, also fall under this term according to their wording.

The only defining feature of any PPA seems to be that it is a civil law contract in the electricity sector with certain individually designed conditions to the contract contents which are to be regulated compellingly. This concerns, for example, a remuneration agreed for the purchase of electricity. In the current discussion, however, it is also regularly a question of certain additional elements of an electricity purchase or purchase that can qualify a PPA: This concerns, for example, the negotiation of a comparatively long contract term, if a PPA is intended to secure the refinancing of an investment in renewable energy plants, the passing on of guarantees of origin as proof of the green electricity property or the proof of further characteristics of the electricity to be supplied, such as a certain regional purchase. PPAs are often, but not necessarily, regarded as a counter-model to FIT or FIP/MP support. In addition, the focus is particularly on forms in which electricity is sold and supplied directly from a producer or direct marketer to a final consumer -

such as a large company (cf. Hilpert 2018). This last point is also reflected in European law (see above).

2.1.3 Differences between P2P trading and PPAs

As already seen above, P2P trading is a bilateral electricity trade between prosumers. In contrast, by the definition of PPA, PPA is a unilateral electricity trade contract in a one-way from renewable power producer (seller) to final consumer or an intermediary, such as a supplier (buyer). A distinct cast of either generator or consumer is defined under a PPA, i.e. the contractors under a PPA must be either generator or consumer, which is completely different from the P2P case: in P2P trading, each contacting party can be both generator and consumer, although this does not always have to be the case.

Besides this, there are a number of differences between P2P trading and PPAs. First, the capacity of renewable power plants under a PPA is likely to be much larger, for instance a few MWs capacities are commonly seen, compared to that of under P2P which can include small-scale plant less than 10 kW capacity. Though small-scale plants like less than 10 kW can be a contractor of PPA in theory, an actual application of such case is rarely seen unless these small plants are aggregated by an aggregator, typically large private companies. Similarly, the consumer side of a PPA is most likely to be a large organization and not an individual household. Once again, this is a highly distinct feature compared to the P2P trading case, which theoretically can accommodate any type of consumers from individual household to a large organization. However, this may change in the future, with PPAs offered also to smaller consumers. On the other hand, some P2P trading pilot schemes also include more medium-sized renewable energy plants that reached the past-FIT age.

Second, the duration of contracts for electricity trading is significantly different between P2P trading and PPAs, i.e. the duration of a PPA is normally on a yearly-basis, which can last 10 years or more. In contrast, the duration of a P2P trading contract execution can vary from few seconds to few hours, days, weeks depending upon the situation, but very unlikely to be on a yearly-basis. However, the P2P 'framework' contract between the participating generators, prosumers, and consumers to sell and buy electricity at a certain price and conditions can be concluded for several months, a year or two, and can be automatically renewing.

The purpose of PPAs is obviously to provide private/public organizations with a means to procure renewable electricity over the longer period at an agreed price without capital investment in physical installation of the plant by themselves. For the seller, the purpose is to provide security for the investment and operation in the renewable energy plant. An engagement of private/public organizations to acquire renewable electricity is a key driver of PPAs. Those organizations are likely to commit to SDGs related initiatives such as RE100 and may also consider hedging against the rising costs of conventional energy. As seen from the renewable power plant's viewpoint, the purpose also includes securing operation of renewable power plants over the longer period without explicit financial support like FIT and subsidy. Both of the purposes are applicable to the cases of newly built plants in a "post-FIT/FIP era" and "FIT-expired" plants. This point is particularly relevant to policy makers who make a balance between promotion of renewables and fiscal expenditure or energy prices that would otherwise carry the cost to support the renewables.

Therefore, promotion of renewable energy without public or legally based financial support should be a purpose of PPAs.

Based upon these purposes, the primary objective of PPAs can be summarized as either 1) the promotion of newly built renewable power plants over the long period in “post-FIT/FIP era” or 2) supporting continuous operation of “FIT-expired” renewable energy plants without explicit financial support from the public sector or energy consumers (via a FIT levy).

2.2 Models of P2P trading and relevance of each model for Germany and Japan today and in the future

This section discusses existing or possible models of P2P trading, the role and interests of market actors and the contractual arrangements in each model, and their appropriateness for the purposes and objectives identified, in both countries. In this way, the relevance of each model for Germany and Japan today and in the future is analyzed.

2.2.1 Germany

Kreuzburg (2018: 8 et seqq.) identifies **three market models** as possible uses of P2P energy trading. Although this source implies the use of blockchain technology, these market models could also be performed with other technical solutions for the P2P trading:

1. **The wholesale power market model**: The aim of P2P trading in this model is to achieve market-based P2P sales revenues by using wholesale power market prices to determine a marketable price from the relationship between supply and demand. This means that the wholesale prices are used as a reference to determine the prices on P2P trading, but the latter are not necessary the same as the former. Similar to conventional electricity trading, the transport and distribution of electricity to the final consumer would be based on the concept of a so-called “copper plate”, which in principle allows any producer to trade electricity with any consumer and disregards network constraints. A P2P trade according to such logic would come closest to the current electricity market design; consequently, electricity will continue to be understood here as a pure commodity and differentiated by price. Providers of P2P electricity are in the direct competition with traditional suppliers, so the expected P2P trading revenue should not exceed the price of conventional generation and marketing. However, the difference between the costs of the P2P trading platform and the combined margin of traditional traders and suppliers could be shared between the P2P platform provider, the sellers, and the buyers.
2. **Regional/Local electricity procurement, or regional decentralized power markets**: The consumer purchases electricity here in close proximity to the producer. This and the ‘green’ attribute of renewable power may induce consumers to pay a small price premium for the regional electricity, while they may be able to save on the traditional supplier margin, as in the first model, and in addition on transmission grid fees, if regulation allows. If there are shorter distances of transport, line and transformation losses and even needs to enhance the transmission grid could be reduced in such a

model. However, this model too will not automatically take network constraints and system stability into account.

3. **P2P trading serving grid stabilization**: If the aim is to stabilize the electricity network through P2P trading, incentives for targeted electricity consumption, demand response, and load shifting will have to be created. For example, network providers could be allowed to make their network charges more flexible and provide consumers with price signals via smart metering systems, so that financial incentives to shift loads (demand side management) could be created depending on the feed-in situation. This approach could anticipate grid bottlenecks but also imbalances in the electricity market and counteract them through coordinated P2P trading, e.g. using storage facilities.

An essential challenge that would arise through the establishment of a P2P electricity trading, by means of blockchain or other technology, would be the change on the previous role models of the energy sector. Compatibility with the regulatory framework and the influence of the distribution of roles will depend on the concrete design of the P2P trading. On the one hand, a P2P network is conceivable, which is still operated and controlled by a single company or a consortium taking a role similar to traditional suppliers or to VPP operators. On the other hand, there may be a decentralized autonomous network of peer consumers, prosumers, and producers, characterized by maximum independence from public or private energy supply companies.

(1) Approach of a controlled P2P network (cf. Kreuzburg 2018: 23f): In this approach, decision-making power and responsibility for security of supply and for contracts and payments, as well as balancing group responsibility will be concentrated in a single P2P network operator or a consortium of cooperating operators (e.g. the provider of the P2P trading platform and an energy company acting as the balancing group responsibility and possibly as a supplier of missing power and buyer of excess power, as in the enyway example presented in chapter 3). As a service provider, this operator, like the operator of a virtual power plant, would aggregate the decentralized generation capacities and loads and at the same time bundle various administrative processes. But instead of reselling the capacities on the wholesale market, as is the case with the capacities of a virtual power plant, the P2P service provider would enable its participants to trade electricity directly with each other. By commissioning a service provider with the purchase and supply of P2P electricity and the transfer of the associated obligations, P2P participants would transfer the role of supplier and deployment manager to the service provider. The same applies to balancing group responsibility, which would also be transferred to the service provider in this context. Finally, this approach would enable the usual access to electricity procurement by means of an all-inclusive contract between the final customers and the P2P network operator, whereby the operator of the P2P network acts as a supplier vis-a-vis the distribution network and transmission system operators, assumes balancing group responsibility, transmits schedules accordingly, and compensates for overcapacities or undercapacities of the P2P network on the wholesale markets.

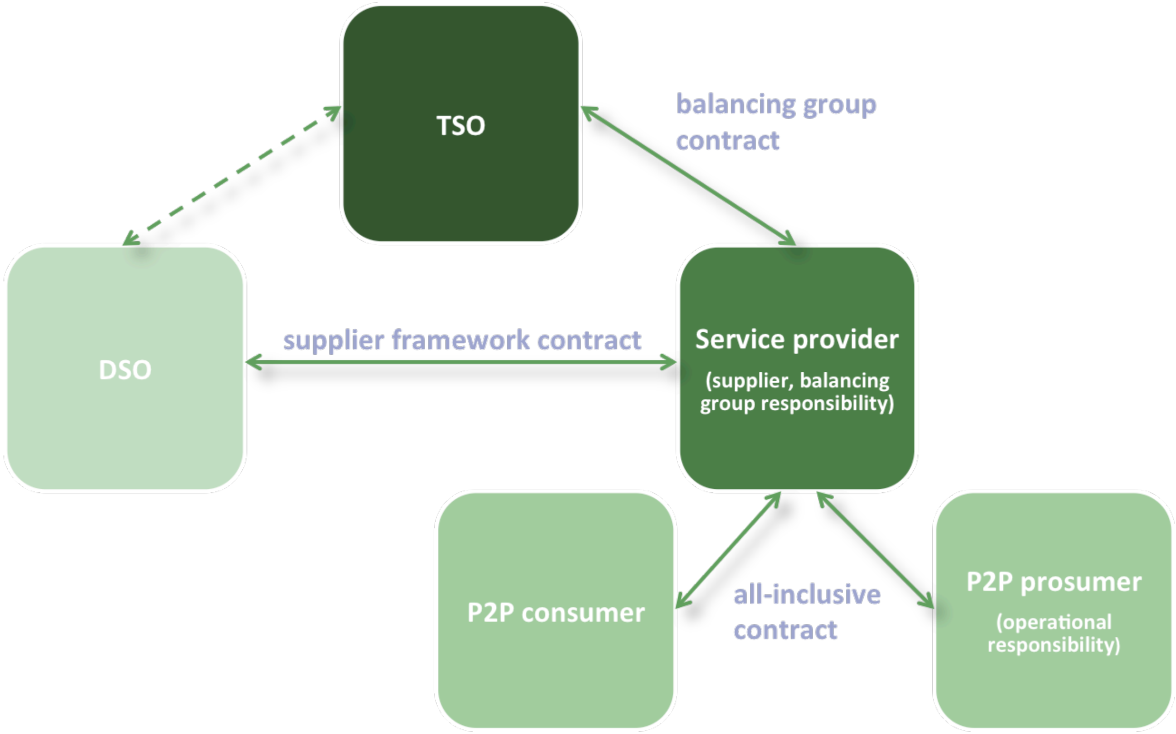

Figure 1: Approach of a controlled P2P network

Source: own graphics based on Kreutzburg (2018)

In the event that the quantities of electricity traded on P2P basis within the network are not sufficient for full supply of all consumers, the service provider would also sell residual quantities of electricity to P2P participants. For example, the service provider could offer a "P2P tariff", which would enable the final customer to trade electricity directly between neighbors and friends, but would oblige all network participants to cover the demand not covered by P2P trading with an electricity purchase in the conventional way. If supply in the P2P network exceeded demand, the P2P network operator would sell the excess electricity to other customers or in the wholesale market. In addition to operating the P2P network, the service provider thus provides all the services that modern energy suppliers already offer today. It can thus be stated that the established energy suppliers, be they traditional suppliers or recent market entrants including VPP operators, would actually be predestined for this role of P2P service providers.

(2) The decentralized autonomous approach (cf. Kreuzburg 2018: 21f): This approach is an organizational model, which completely dispenses with a central power and control instance. Instead, all network and transactional decisions are taken by consensus, giving each network participant a voice and the opportunity to participate. This approach is in any case based on the blockchain technology. With regard to the distribution of roles, such a model would mean that the network participants, i.e. producers, consumers, and prosumers, would have to assume essential areas of responsibility. If the aim is to achieve complete independence of final customers from the established electricity suppliers and autonomy among final customers, the distribution of roles and the associated obligations and responsibilities will shift in the direction of final customers. Accordingly, the P2P producer will have to assume the role of a supplier, which will require contracts to be concluded with each individual electricity customer and with the transmission and distribution system operator. The obligations arising from these contracts, in particular the balancing group responsibility, will have to be borne accordingly by a P2P producer in the role of supplier and person responsible for operations. On the consumer side, the final customer will also have to reckon with significantly more responsibility, since according to this model, the final customer will have to conclude a grid connection contract as well as a grid usage contract with the responsible distribution grid operator. In addition, an all-inclusive contract with a supplier will no longer be possible, which is why P2P consumers will either have to join the balancing group of a service provider or independently register and settle their withdrawals, i.e., become their own balancing group responsible. In reality, it is unlikely that both small producers and consumers will be able to take such responsibilities (see below). However, this requirement could be avoided if the P2P electricity trading is performed in a microgrid (cf. Model J1 - J3, which are the "off-grid P2P transaction" models in the Japanese definition).

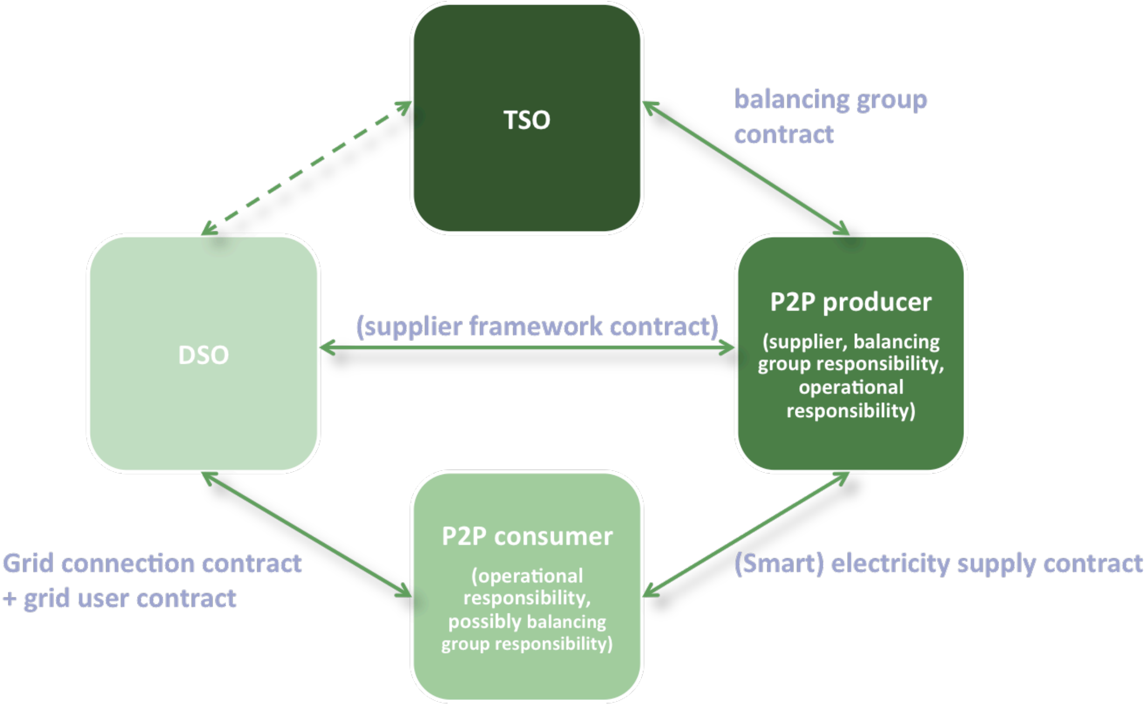

Figure 2: The decentralized autonomous approach

Source: own graphics based on Kreutzburg (2018)

Since non-discriminatory network access must be guaranteed in Germany, in principle any private or commercial producer can also become an electricity supplier. More than 700 energy suppliers of various sizes are already officially registered with the Federal Energy Regulator (Bundesnetzagentur). In this regard, however, it should be noted that any natural or legal person who supplies energy to others via the public network is an energy supply company in the meaning of §3 no. 18 EnWG and must notify the Bundesnetzagentur immediately of the commencement of energy supply pursuant to §5 EnWG. However, if the regulatory authority comes to the conclusion that the notified energy supplier cannot provide the necessary personnel, technical or economic capacity and therefore cannot guarantee a reliable supply, the authority shall be entitled to prohibit the performance of the activity pursuant to §5 sentence 4 EnWG.

For the electricity supplier in an open P2P network, this would not only mean that he or she would have to set up a corresponding company to handle his or her trading transactions, but also that (s)he would have to register with the regulatory authorities and, if necessary, prove his or her efficiency and reliability.

Furthermore, it should be noted that the role of the person responsible for the operation schedules has so far only been important for large power plants and industrial consumers, but not for small PV systems and household customers, since feeds are forecast by the grid operator and load profiles by the electricity supplier. However, if in future the members of a P2P network disengage themselves from their conventional electricity suppliers and no longer feed the electricity they generate into the grid within the framework of the EEG feed-in tariff, it is conceivable that P2P participants would become responsible for the schedules and would have to meet the associated requirements. Again, this would not be needed in a microgrid.

One possibility of implementing both the above approaches of P2P energy trading that may develop is through the platform economy, in which digital platforms act as intermediaries between suppliers and consumers of services. “The disruptive potential of platforms lies in the fact that, in extreme cases, they can make a large part or even all of the intermediaries previously active in the business field superfluous. Platforms technically form a central communication interface, they simplify the search for information and trading partners for all market participants and consequently reduce the costs for market participants considerably.” (Buchmüller 2018: 118; translation by the authors of this paper) Instead of a large number of electricity suppliers that have so far mediated between electricity producers and consumers in Germany, only a single or at most a few platforms would be needed.

In this context, the possibility of promoting P2P delivery models through the use of blockchain technology is currently being discussed even more strongly (for the technical functioning of blockchain see Chapter 2.3).

To sum up, the P2P models identified in Germany can be summarized as follows.

Centralized or Decentralized	**Sub-category**	**Model name**
Controlled P2P network model	Wholesale market model	Model G1
	Regional/local electricity procurement model	Model G2
	P2P trading serving grid stabilization model	Model G3
Decentralized autonomous P2P network model	on-grid trading	Model G4
	local microgrid trading (off-grid)	Model G5

Table 1: Classification of P2P models in Germany

2.2.2 Japan

In Japan, model classification of P2P electricity trading has been considered mainly by the policy side from the viewpoint of legal perspective, which legal/regulatory framework is required for the implementation of P2P. In this respect, METI (2019) identifies theoretically possible models of P2P, which are broadly divided into two categories. The first category is (1) P2P transactions taking place only limited to within a particular micro-grid without using the existing power grid. Hence, this category can be called “off-grid P2P transaction” in this paper. The second category is (2) P2P transactions through the existing grid including both distribution and transmission, which can be called “on-grid P2P transaction” in this paper.

(1) **Off-grid P2P transaction** can be further divided into the following 3 models according to the way of electricity transactions as follows:
- ✓ Model J1: P2P transaction is exclusively occurring within a limited building/flat/apartment.
- ✓ Model J2: P2P transaction is exclusively occurring using charged electricity in EV, i.e. the electricity charged in an EV is supplied to a building/facility at different location.
- ✓ Model J3: P2P transaction is exclusively occurring via a private line within a limited community.

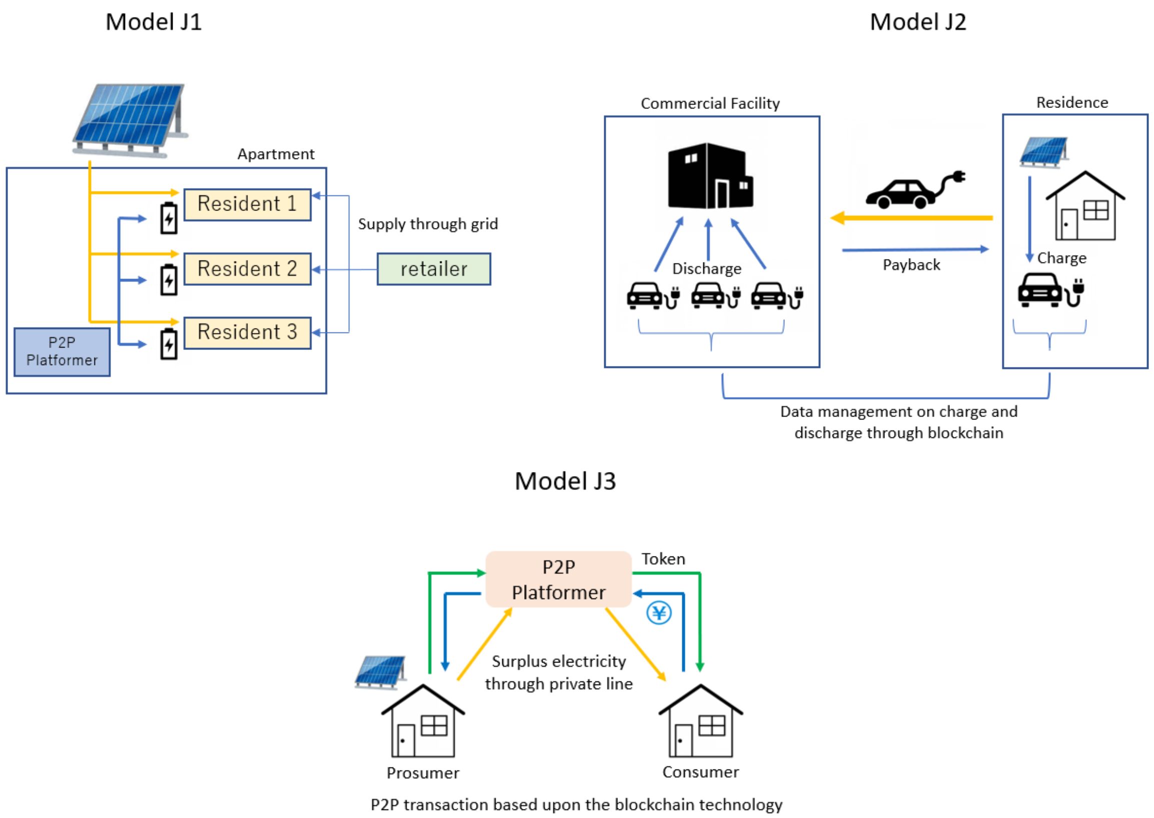

Figure 3: Examples of P2P transaction models (Model J1 - J3)

Source: Cited from METI (2019) with modification.

Under current laws and regulations, P2P transactions occurring within a specific building in Model J1 and via EVs without using electricity grid in Model J2 are not regulated and, therefore, can be implemented with a minor revision of the measurement act. This act currently obliges to use the accurate specified measuring instruments certified by JEMIC (Japan Electric Meters Inspection Corporation) under METI or a designated verification body in order to execute the proper measurement for any electricity trading, which are however rarely installed in the household sector in the country. If such obligation were required for individual prosumers and consumers, the cost borne would be enormous; therefore, a minor correction of the law to introduce differential weighting measurement or permitting the usage of other measuring instruments above a certain standard of accuracy is currently under consideration. Regarding Model J3, the platform provider (also called platformer in the graphs and the following text) is required to register as an electricity retailer under the Electricity Business Act to manage the transactions between prosumer and consumer. This is because in Model J3, the P2P transaction is not considered as a direct trading between the prosumers in the legal basis, but is considered as an electricity supply to a prosumer by the platformer who procures the electricity from other prosumers, irrespective of using a private line (as in this case) or grid network.

(2) **On-grid P2P transaction** can be further divided into the following 4 models focusing on the role of the platform provider.

- ✓ Model J4: An electricity retailer acts as a P2P platformer as well. P2P transaction is provided by the retailer using existing grid who is also responsible for balancing the demand and supply within the balancing group. This model can be seen as equivalent to Model G1 (controlled P2P network model) in Germany (See 2.2.1). Although the existing grid charge can be considered as too expensive for individual P2P transaction, this model can be implemented under the current legal framework.
- ✓ Model J5: In this model, a P2P platformer is not necessarily the same as the existing electricity retailer like implicitly expected in Model J4. A P2P transaction is separately provided by another independent P2P platformer who is also registered as an electricity retailer, but balancing responsibility is still on the existing retailer. This is the case of so-called “low-voltage partial power supply by multiple suppliers”, for which the current electricity regulation guideline states that the existing retailer could refuse to offer such partial electricity supply due to high inefficiency caused by the service for a small-scale user. Therefore, Model J5 is not possible to be implemented under the current regulatory framework in Japan. However, if the regulation on low-voltage partial power supply by multiple suppliers is revised, the model can be implemented at least on a legal basis.
- ✓ Model J6: A P2P transaction occurs between several factories at different locations owned by the same company through self-consignment, provided by a P2P specialized platformer without a retail license. Since such a P2P transaction is considered as a kind of self-consumption by the company, an electricity retailer does not appear in this model, and it is legally allowed. The P2P platformer has a balancing group responsibility in this model and also pays grid fees as well as taxes and levies to the DSO and TSO.
- ✓ Model J7: The P2P transaction occurs between consumers or prosumers forming a specialized partnership without financial ties, meaning that they are financially independent from each other, and provided by the P2P specialized operator without a retail license. This model is quite similar to Model J6 (the P2P transaction is aiming to be defined as a kind of self-consumption between association members, not supplied by a retailer, but provided by a P2P platformer who has a balancing responsibility and pays grid fee to DSO/TSO), but the only difference is that, in Model J6, the factories are owned by the same company whereas, in Model J7, each residence is owned by different individuals. This difference of the ownership between the two models makes an obvious distinction

under the Japanese law, so that Model J6 can be implemented under the current law, whilst Model J7 cannot; the law does *not* consider this model as self-consumption, due to the different ownership. Currently, Model J7 can only be implemented if it is not using the existing power grid, but using their own private line. Then, Model J7 is in effect converted into Model J3 of off-grid P2P transaction.

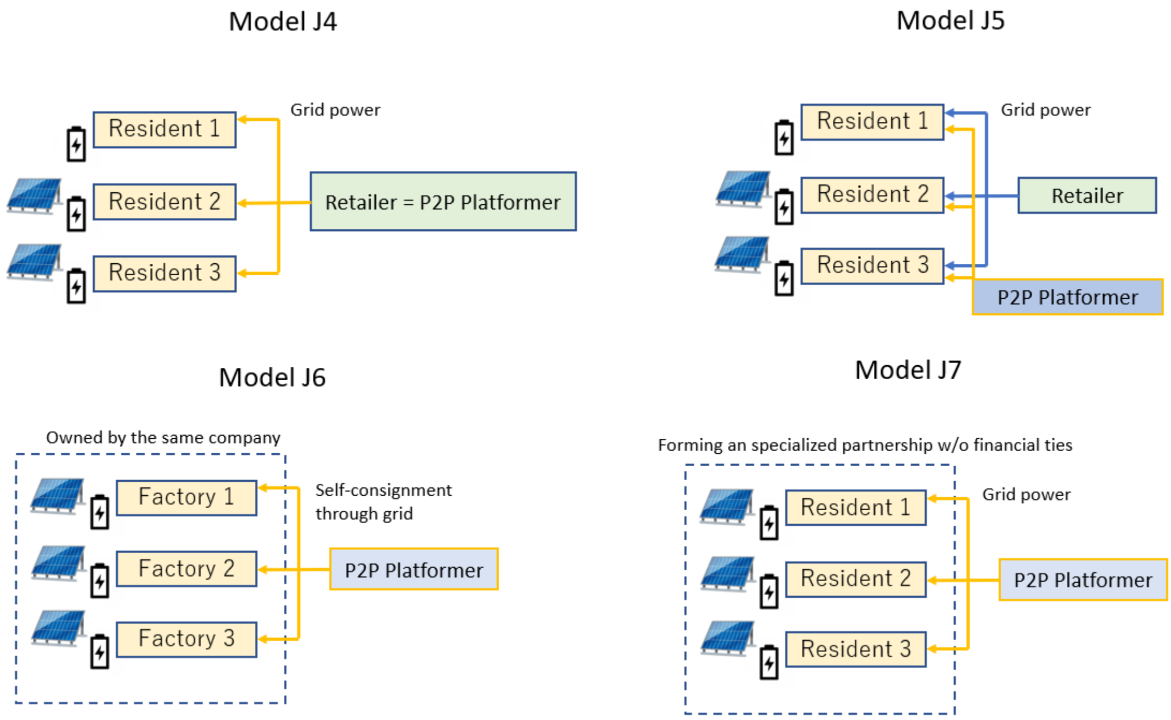

Figure 4: Examples of P2P transaction models (Model J4-J7)

Source: Cited from METI (2019) with modification.

Regarding the on-grid P2P transaction, as the grid operator in charge is required to be involved in balancing group responsibility, the operation of P2P transaction is complicated compared with off-grid P2P transaction. In order to realize Model J5 and J7, it will be necessary to make further discussion on the burden of the grid fee (e.g. grid fee is too high for individual P2P transaction) and who will take responsibility for managing the demand and supply in the balancing group where the P2P platform is established. Then, the law would have to be adapted to allow these models.

The following table summarizes the Japanese P2P models considered above corresponding to those of Germany in the previous section.

Peer-to-Peer (P2P) electricity trading and Power Purchasing Agreements (PPAs)

Centralized or Decentralized	**Sub-category**	**German model name**	**Japanese model name**
Controlled P2P network model	Wholesale market model	Model G1	Model ・ J4: Existing electricity retailer acts as P2P platformer ・ J5: P2P platformer is independent of the electricity retailer ・ J6: P2P transaction b/w factories/buildings owned by the same company ・ J7: P2P transaction b/w prosumers/ consumers forming a partnership
	Regional/local electricity procurement model	Model G2	
	P2P trade serving grid stabilization model	Model G3	
Decentralized autonomous P2P network model	on-grid trading	Model G4	
	local microgrid trading (off-grid)	Model G5	Model ・ J1: P2P transaction within a limited building/flat/apartment ・ J2: P2P transaction using charged electricity in EV ・ J3: P2P transaction via private line within a limited community

Table 2: Classification of P2P models in Germany and Japan

2.3 Preconditions, especially digital technology for P2P trading; status of preconditions in both countries

This section focuses on preconditions required for an implementation of P2P trading, in particular digital technology. Since PPAs are less prerequisite on the technological level, they are negligible here.

2.3.1 Connected load meters, e.g. smart meters

In addition to digital value transmission e.g. via blockchain, P2P electricity trading also requires the physical supply of electricity. This means that in addition to the digital networking of the respective producers and consumers via the Internet, a physical connection must also be created. Access to the existing public power grid is the most obvious option for feeding and supplying P2P trading.

In order to link the physical flow of electricity and the digital processing of trading transactions, an intelligent measurement system, also known as a smart meter, consisting of a measuring device for recording electrical energy and a smart meter gateway for integration into the communication network, is the best solution. The traditional connected load meters, which have been required for generators and customers above 100 MWh/year in Germany, could of course also meet these criteria. The smart meter measures the exact generation and consumption data of each individual network participant at defined time intervals, which are then documented and shared in the P2P network using the smart meter gateway. In addition, the smart meter gateway receives information (e.g. price signals) from the network and can adapt delivery options and market forms based on user preferences (cf. Kreuzburg 2018: 3f).

However, due to the delay in smart meter roll-out, some of the P2P pilot projects in Germany presented in chapter 3 now also enable participation for standard load profile customers.

Status of smart meter roll-out in Germany

The entry into force of the Metering Act (MsbG) in Germany in September 2016 triggered significant changes in metering. The Act requires the comprehensive rollout of modern metering equipment and smart metering systems. Whereas in the past household customers were mainly equipped with analogue Ferraris meters, 'modern metering systems' are digital meters. However, modern metering systems do not transmit any data. They will be called 'intelligent metering systems', i.e. smart meters, only if they are connected to a communication unit (smart meter gateway) via an interface, enabling them to transmit the data recorded by the meter.

Since the beginning of 2017, the first modern metering systems have been available in the market and have been installed by the first metering operators on a large scale. It has still not been possible to start the rollout of smart metering systems in 2017, since no BSI-certified smart meter gateways that had been certified by the competent authority BSI were yet available in the market. However, in light of the statutory requirements set out in the Act and advances in metering technology, a large-scale roll-out of modern metering equipment and smart metering systems is expected in the coming years (cf. Bundesnetzagentur/ Bundeskartellamt 2019). In the end of 2019, the third smart meter gateway meeting the strict data safety requirements was certified by the BSI. The legally defined precondition for the smart meter roll-out has therefore now been met. During the spring of 2020, the authority officially stated this fact. Since that date, the conversion to of smart meters has now been mandatory for consumers using more than 6,000 kWh/yr and for PV of CHP power plants between 7 and 100 kW of capacity (generators above 100 kW have been required to use a tradtional load meter with a communication gateway before). These thresholds will be reduced based on regular analysis of cost-effectiveness. The aim is to finalize the smart meter roll-out by 2032.

Status of smart meter roll-out in Japan

The 5th Strategic Energy Plan, which consists of the principal national energy policies, decided by the cabinet on June 2018, states that smart meter will be installed in every household and office throughout the country by the mid-2020s as a basis of implementation of demand response in domestic and building sectors with dynamic electricity retail pricing. The strategic plan also urges the establishment of a technical foundation to transfer information collected by smart meters into EMS (energy management systems) equipped in households and office buildings, and to connect between EMS and individual electricity appliances.

In fact, an installation of smart meter began long before the 5th strategic energy plan, around the early 2010s, by the traditional 10 electricity utilities, called General Electric Unities (hereafter, GEUs). As a result, by the end of 2016, all of electricity consumers with a contracted power of more than 50 kW, which are factories and large buildings representing 2/3 of electricity demand of the country, have been equipped with smart meters. For the rest of electricity consumers contracted with a power of less than 50 kW, who are a very large number of households and small buildings representing 1/3 of the national electricity demand, roll-out of smart meters is planned to be completed during 2020 in the Tokyo area, and by 2022/23 in the rest of the whole nation. As of the end of 2019, the total number of smart meters actually installed was around 51.82 million which covers 63.7% of the number of planned smart meters installed in the country. Once again, this value is expected to be 100% by 2024.

The basic specifications of smart meters were standardized in 2011 by the government. The standard includes granularity of monitoring data such as every 30 minutes of minimum 0.1 kWh of electricity two-way flows with high precision and real time two-way connection, conforming IEC DLMS/COSEM standards, and remote switching control. A connectivity with EMS, conforming Echonet-Lite communication standard, is also required for effective utilization of the information collected by a smart meter to control individual electricity appliances, EV, battery and solar PV as a function of demand response.

Overall, in Japan, the roll-out of smart meter has progressed right along with the national plan. Therefore, a digital measurement system, which is the minimum infrastructure required for P2P trading is expected to be completed, at least in a physical basis, within the next 5 years. The remaining key issue is an establishment of an appropriate legal framework how to keep privacy of specific information and data collected from individual households and offices, which is still under discussion.

2.3.2 Data transmission and handling, and economic transaction system, such as blockchain

The second function to be performed for P2P trading is that of a digital system for data transmission and handling, and implementing the economic transactions associated with the P2P trading. Blockchain technologies are often used in P2P trading schemes, but other systems using central database and data processing technologies and software would also be feasible, particularly for the approach of a controlled P2P network discussed in chapter 2.2. The decentralized autonomous approach may only be feasible with blockchain technologies.

The Research Centre for Energy Economics (Forschungsstelle für Energiewirtschaft e.V.) (FfE 2018b: 118 et seqq.) identifies **three basic applications** of **blockchain** technology in connection with energy trading:

1. Mapping of electricity exchange processes on a blockchain (B2B)
2. OTC trading via blockchain (B2B)
3. Decentralized P2P trading via blockchain (C2C)

Here, we focus on the third application, i.e. P2P trading.

Blockchain technologies consist of decentrally distributed database structures. Transactions are combined in discrete time steps (blocks) and attached to preceding blocks (see here and in the following FfE 2018a: 8ff). Due to the consensus mechanism used, there is agreement on the validity and sequence of transactions. Manipulation and misuse can thus be prevented.

While today in many cases central parties (e.g. energy suppliers) carry out transactions and store the records on central servers, the blockchain technology offers the possibility to carry out decentralized transactions directly between equal users ("peers") without intermediaries. The information about transactions carried out is distributed and stored in a so-called "Distributed Ledger" at a large number of participating parties instead of being saved in central databases. The core of the blockchain technology consists of collecting transactions that have taken place within a certain period of time and combining them into so-called blocks that represent the network's consensus on the correctness of the transactions and their sequence. In order to confirm the correctness and authenticity of transactions in the blocks and to prevent transactions of the same transaction object from taking place several times ("double spending"), each block chain requires a so-called consensus mechanism. This confirms the correctness of the transaction processes in the block using standardized procedures (decentralized) and "chains" the confirmed block to the previous block. In this way, a constantly growing chain of blocks ("blockchain") is created over time. The blockchain can be viewed by any participant in the network at any time and enables transparent monitoring of interactions taking place.

A further component of the blockchain technology is the option to store programs on the blockchain and to let them perform activities automatically. These so-called Smart Contracts enable a high degree of automation because, for example, business processes can be mapped through them.

In combination with the decentralized autonomous approach, blockchain technology potentially leads to a radical change in the existing transaction system in the energy market. Instead of an intermediary, a blockchain protocol and the consensus mechanism inscribed in it take over the validation and logging of the transaction. For P2P trading in the energy sector, this means that in the simplest case each network participant can be uniquely identified via an individual, public key, whereas authentication takes place via the signing of transactions using the private key. So-called tokens are then used for value transfer, which assign a defined value to their owner within the network and can ideally be exchanged for crypto currencies or central bank money. Before a consumer can obtain electricity via the P2P network, he or she must first exchange central bank money for tokens via a platform. The smart contract can then be used to define that a P2P delivery of electricity is remunerated with a corresponding number of tokens. Depending on the transaction amount, the tokens are transferred from the consumer to the P2P supplier, who can then either use the tokens itself to purchase electricity from the P2P network or exchange them for central bank money (cf. Kreuzburg 2018: 5f).

3 Experiences to date and current developments/trends with P2P trading and PPAs in Germany and Japan

3.1 Examples of P2P energy trading services in Germany

A study by the German Federal Network Agency (Bundesnetzagentur 2019) on the potential and challenges of blockchain technology analyses various conceptual approaches for the use of this technology in the various stages of the energy industry's value chain. Based on data from the sector association EDNA Bundesverband Energiemarkt & Kommunikation e.V., 35 concrete blockchain pilot projects were being tested in Germany's energy industry in June 2019. The majority of these can be allocated to the value chain stages of generation and sales. These include, above all, P2P neighborhood models and microgrids as well as various projects in the field of certification of "green" and "regional electricity"; also tradable emission and CO2 products. The remaining projects are mainly in the areas of electricity wholesale, e-mobility and grid congestion management.

A selection of the existing P2P trading projects and full-scale business models in Germany is presented below.

3.1.1 Enyway

The first and largest commercial peer-to-peer energy platform in Germany by its own account is the online marketplace **enyway** (enyway.com). As a part of its business model, enyway currently offers two products: *Change* and *Power*. *Change* is to serve the realization of large-scale solar power plants beyond government subsidies. *Power* makes it possible to purchase green electricity directly from producers in the region.

The basis for this is a blockchain system consisting of a multitoken model and a digital identity register (cf. here and in the following enyway 2019). The multitoken model enables the redesign of common exchange relationships and value storage, while the register for digital identities ensures the authenticity and integrity of actors and assets within the blockchain system.

Implementation of the Power *product*

In early 2020, around 35 electricity producers with a total of around 20 MW used the enyway platform to sell their generated electricity directly to electricity customers, i.e. the electricity producers thus become electricity suppliers. The need to convert every generator-supplier into a balancing group responsible is avoided by organizing these services from another suppliers. enyway or a partner company assumes responsibility for the balancing group, the preparation of forecasts for feed-in and customer demand as well as marketing surplus power for the producers. The customers of the individual energy suppliers are standard load profile customers (households, trade, agriculture, etc.). This is, hence, a controlled and a decentralized autonomous P2P trading model (model G1), focused on renewable energy, but with a few elements of the G4 model: the generators act as suppliers on their own account. However, it is not really P2P trading, as the generators have at least 100 kW, since the Smart Meter roll-out in Germany was still pending until very recently. Once smaller generators or prosumers have Smart Meters, it could be expanded to these as well.

The electricity prices are determined by the sellers themselves. Whether this price is higher or lower than the monthly market value, to which they would be entitled in classic direct marketing via the power exchange, is therefore determined by the fixed price and the result of the monthly market value; as a rule, however, the price achievable via enyway is higher. The prices are calculated with postcode precision in order to take local network charges into account. The average prices that the producers can achieve are higher than those of the EEX because the fees that enyway and the balancing group manager receive are below the distribution margin of traditional suppliers. As a rule, electricity prices are comparable/equal to those from the green electricity segment, but there are regional differences in the pricing of competition (postal code sharpness vs. uniform tariff etc.). All taxes, charges and levies correspond to those of a traditional electricity supply.

New electricity sellers who are admitted to the marketplace do not necessarily have to have participated in direct marketing beforehand, but it is advantageous in so far as the technical preconditions for the enyway trading (remote control, power meters recording consumption data, etc.) are already in place, and therefore no technical conversion of the system is necessary.

Implementation of the Change *product: Asset Sharing*

The product *Change* is designed to make asset sharing possible. *Change* (1) offers the opportunity to participate in the construction of a renewable energy system; starting from a small two-digit investment sum for a piece of a solar system, e.g. the size of a pizza box, and (2) to purchase the participant's entire electricity demand at the purchase price. By fractionation of the plant into different package sizes, a participation for different needs and budgets should be possible.

As much as possible of the own electricity demand is covered directly from the own solar plant, the rest is filled up by certified green electricity. Together with the other investor-consumers, large-scale solar plants are to be set up and operated in this way at low cost, independent of large companies. The jointly erected solar plant is made possible by all participants and without EEG subsidies.

The blockchain technology helps to clearly allocate the system shares to the customers and prevents shares from being distributed twice. This way, forgery-proof and transparent documentation is provided of who is entitled to which solar yield.

Based on the multitoken model presented below and the register for digital identities, this is the first productive application on enyway's blockchain system: the tokenization of a real-world asset. In the first project under this product line, a solar PV plant will be built. On an area of 7308.12 m^2, a solar plant with a capacity of 1282.38 kWp and an expected yield of 1003 kWh/kWp is planned; without taking advantage of financial support through FIP from the EEG. In addition, the asset sharing application can potentially be used for different assets.

Contracts and transactions: The multitoken model

The multitoken model of enyway consists of five tokens, which represent different characteristics of values and should enable the clear documentation of the value transfer and thus the value chain. The tokens can be divided into the two categories: *Security Token* and *Utility Token*. The *security tokens* are only relevant for the *Change* product and comprise the tokens *Ownership*, *Use* and *Invest* and are the digital image of an existing asset in the real world. They represent different rights associated with the asset (usage rights, ownership rights, right to profit sharing). *Utility tokens* serve as a means of operating the platform's processes; in concrete terms, these are *currency* and *power utility tokens*, which represent the flows of currency and energy quantities.

Blockchain				
Security Token			**Utility Token**	
Asset Smart Contract			*Currency Smart Contract*	*Power Smart Contract*
Ownership Token →Deed of Ownership; Right of co-determination	Invest Token →generate returns for investments	Use Token →Right to use the product	Currency Token →Credit note for purchase of products	Power Utility Token →Proof of electricity origin and quantity

Table 3: Levels of the Multitoken-Modell (Source: enyway 2019: 9)

The financing of an asset does not have to be done via a certain type of token, a combination of the different models is also possible. For example, part of the asset can be financed via ownership tokens and another part via crowd financing via a loan, i.e. an invest token.

The *ownership tokens* defined by enyway empower the holders to take advantage of the asset in the real world, but also contain obligations. The token serves as the basis for a clear allocation, e.g. which co-owner is entitled to which income from a renewable asset or in which proportion the maintenance of that asset must be carried out. The Ownership Token allows an individual and comprehensible assignability, as well as the storage of further possession-relevant information.

The second token introduced by enyway is the *Use Token*. This allows the holders to participate in the proceeds of an asset from the real world. Holders therefore do not own the asset and can therefore at most transfer the claim to the proceeds of the asset to third parties. There are no obligations for the holder of the token. Due to its structure, important information on use is contained directly in the Use Token. This includes, for example, data such as the useful life, terms of use and output already generated.

Another component of the platform is the *Invest Token*. The purchase of these tokens enables the financing of an investment through a loan. In return, the owner of the token is entitled to pre-determined returns. The owner of this token does not own the asset and can therefore transfer the claim to the fixed return to a third party. A flexible participation in the proceeds of the asset does not exist due to the fixed definition of the return. On the one hand, this offers greater security for the owner of the token, on the other hand it limits the chance of participating in higher profits. The invest token forms exchangeable absolute shares, while the maximum number of tokens per asset is either fixed or variable. The latter also makes it possible to represent subsequent capital increases.

enyway has introduced the *currency token* to map payment flows on the platform. Together with classical payment methods, this forms the economic basis for the enyway marketplace. The currency token is implemented as a stable coin. As a stable coin, the token is linked to the value of a fiat currency, the euro, and is thus stable in value at all times. The fact that the currency is a token on the blockchain does not involve any additional effort for the end user of the platform. All payments on the platform are displayed as if they were made directly in euros. Only in the background, the respective transaction is fixed in the blockchain with the help of the currency token and thus remains transparent and tamper-proof. Any form of revenue from the various products is credited to the users as credit on the platform. This credit is displayed in the blockchain as currency token credit, but is displayed to the user as euro on the user interface. The platform credit can be used e.g. for the own electricity contract, new investments and the purchase of articles on a perspective enyway marketplace. In addition, there is the option to withdraw the accumulated credit. The credit is not transferable between single participants without consideration like the purchase of a product or a service.

The *Power Utility Token* was defined as a virtual unit of electricity quantities on the platform, which represents the exchange of electricity on the blockchain. A token represents a fixed power unit, e.g. a watt second (Ws). The tokens are generated for power generation and devalued for power consumption. The creation of the tokens is based on the input of real data from a generation plant, which passes the data on to the blockchain via a direct communication unit of the intelligent electricity meter. Each Power Utility Token carries a signature of the generation plant, which can be used to prove the origin of the electricity in a counterfeit-proof manner. In combination with the register for digital identities, the power utility tokens can be assigned at any time and provide information on items such as energy source, plant type, place of generation and the age of the plant. This data basis enables the implementation of many application cases, such as proof of origin, the power community and the P2P market. In regular time units, tokens of the generated energy quantity are generated by the generation plant. These tokens are then transferred to the respective electricity consumer in order to map the electricity supply.

Digital Identities

How can actors on the blockchain be unambiguously identified and their authenticity ensured, so that their anonymity can be maintained, while there is still unambiguity?

enyway's solution is based on a hybrid master data register for identity management, consisting of different levels of data management. The first level is publicly visible and contains, e.g. for a generation plant, metadata of the plant as well as the approximate location (postal code). On the second level, additional personal data is stored, which can be used for the execution of applications, e.g. the corresponding Smart Contract. The last level contains sensitive personal data, which is exclusively managed by enyway. They are necessary to handle value-added services, market communication and other processes.

In connection with an individual, public key on the blockchain, the identity register forms the basis for the unambiguous identification of actors (e.g. persons, production plants, etc.). In order to guarantee data security and anonymity, the public keys of the actors keep changing. Thus it is not possible for uninvolved parties to draw conclusions about the identity of a person and their activity in the enyway ecosystem.

Access to the various levels of the identity register is organized via a read-only system. For the execution of some applications, the access to specific information of the individual levels is necessary. An authorized Smart Contract, which triggers the creation of a plant specific proof of origin, for example, is fed by the relevant data from the register.

Data protection

In order to file data in accordance with the EU's General Data Protection Regulation (GDPR), two different methods are used for storing documents. Public documents, such as general terms and conditions, are stored for everyone to access on an IPFS (InterPlanetary File System), a decentralized file system. Documents with personal information, on the other hand, are securely stored at a central location. Only a hash value is publicly stored in IPFS. This ensures that the contract cannot be changed and prevents private information from being publicly viewed. The assignment to an identifiable person takes place in secured systems of enyway, where it can be deleted without leaving a trace.

3.1.2 Lition Energy

Lition (cf. www.lithion.de) is a P2P energy trading platform that connects, as an example for Model G1 and similar to enyway's product *Power*, clean energy producers and suppliers directly with end users on the blockchain. Lition launched an energy exchange dApp in April 2018, and serve a customer base spanning over 100 cities in Germany. Once a user finds the energy they want to buy, they make a payment in Euros to Lition. The blockchain technology takes over, simplifying the process of buying energy directly from green producers of any scale by employing transparent smart contracts that allow consumers to circumvent the complexity of traditional utility companies. The customer then automatically gets their energy. According to their own information, Lition is saving customers an average of 20 percent on their utility bills, and power plants are seeing increased revenues of up to 30 percent (cf. https://www.disruptordaily.com/blockchain-energy-use-case-lition/). These numbers should probably be taken with caution. Customers get to choose their green energy from wind, solar and biomass, and their preferred provider. The energy is delivered automatically once processed and billed in Euros.

As a licensed electricity supplier, the business model is simple: Lition earns money by selling electricity and offering customers fair prices through process efficiencies. Through the direct connection to the consumers, renewable energy providers can be strengthened and they can achieve higher margins than in the traditional market context. Consumers, on the other hand, have the option of choosing their own regional electricity provider.

Producers make sales offers and customers can choose from these offers and, for example, choose the nearest regional supplier. Lition will handle the entire process. It takes care of market partner communication, billing and management of supplier switching, and the call center.

Lition provides the Blockchain technology and enables transactions directly between customers and producers via smart contracts. Lition is currently still running on the open source Ethereum blockchain, but is currently developing its own blockchain software together with SAP.

3.1.3 WSW Tal.Markt

Since January 2018, Wuppertal's municipal utilities (WSW) have been offering P2P energy trading with their "Tal.Markt" (“valley market”) platform (cf. https://talmarkt.wsw-online.de as well as GJETC 2019). Here, too, customers can compile their own electricity mix and purchase it directly from the producer. Wuppertaler Stadtwerke act as the operator of the trading platform and as the balancing group responsible, and are thus responsible for the formal aspects. In addition, they ensure energy supply in the event of supply not matching demand. This is therefore an example of the controlled regional P2P trading approach, as it is characterized in Model G2. In order to optimally cover individual electricity consumption with the green electricity offered, in the first phase intelligent electricity meters were planned to be installed at all customers.

For the virtual infrastructure, Wuppertaler Stadtwerke cooperates with the Swiss company Axpo, which developed the P2P platform Elblox.

Tal.Markt 2.0

Since 2019, the Blockchain platform has been further differentiated and extended to neighboring districts. There are also efforts to roll out the concept nationwide: Together with the municipal utilities from Bremen, Halle and Trier, the Wuppertal municipal utilities have founded the trading platform "Blockwerke". Each partner can build their own business models on the basis of the platform developed in Wuppertal, or use the Tal.Markt platform for their own market as a ‘white label’ product with local green electricity producers. In addition, the platform represents a central marketplace for producers. In practical terms, this means that any producer registered on "Blockwerke" can supply all connected markets.

Tal.Markt 2.0 is therefore planned in two variants: A basic variant, which can be invoiced using traditional meters and nationwide by comparing the individual green electricity order with the standard load profile; and within a radius of around 50 km of Wuppertal, the "Tal.Markt.Live" variant, which provides for real-time invoicing, once a smart meter has been installed. The blockchain capacities were also improved to 20,000 transactions per second (ea.nrw 2020). As of early 2020, more than a dozen electricity generators were offering power on Tal.Markt (WSW 2020).

3.1.4 RegHEE – Regional trading of electricity from renewable energy sources and power labeling on a blockchain platform

Another example for a controlled regional P2P network and the G2 model is the RegHEE project. The energy supply company Thüga and the Technical University of Munich started the RegHEE project together with regional energy suppliers in March 2019 (https://www.thuega.de/pressemitteilungen/blockchain-forschung-ermoeglicht-regionalen-energiehandel-bayerisches-wirtschaftsministerium-foerdert-forschungsprojekt/). The aim of this project is to research, develop and establish a peer-to-peer energy market for decentralized generation and storage units based on a blockchain that at the same time clearly identifies the electricity traded. For this purpose, available blockchain approaches are first analyzed and evaluated and a concept for the architecture of the system is developed. Smart Contracts are then developed, which represent an automated marketplace for direct exchange between prosumers and final consumers and comply with energy industry and regulatory requirements. A centralized trading system for comparison will also be designed and implemented. Both systems will be operated within the scope of a field test and then subjected to a comparative evaluation, from which recommendations for action will be derived.

The trading platform to be developed, in which all participants can be both producers and consumers of energy, is in principle open to all conceivable producers, such as photovoltaic systems, combined heat and power plants or even wind turbines of citizen energy cooperatives. The price for the electricity is made up of the production price plus a trading margin. The amount of electricity produced is fed into the local grid, while intelligent metering systems record the electricity quantities and post them on the platform. Anyone wishing to purchase electricity via this platform specifies a maximum price as the upper limit. If the electricity price offered by the connected generators is above this personal limit, supra-regional electricity is purchased from the general electricity grid instead.

3.1.5 Allgäu Microgrid

Since 2015, Siemens has been cooperating with the U.S. company LO3. The cooperation focuses on the development of ‘virtual microgrids’, i.e. local virtually self-sufficient communities of generators and prosumers in a power grid, in order to promote local energy trading on a blockchain basis. One pilot project in this cooperation is the Allgäu Microgrid (https://www.auew.de/privatkunden/allgaeu-microgrid/). This controlled regional P2P network model is very similar to the two previous examples presented above (Model G2). Although it calls itself a virtual microgrid, it is in fact an on-grid model.

The community microgrid project in the Allgäu region in Bavaria, being executed in partnership with the local energy supplier Allgäuer Überlandwerk GmbH, will initially be a short-run proof of concept, with some prosumers selected to participate in a virtual microgrid. The project is designed to demonstrate how seamlessly distributed energy and virtual microgrid solutions can fit into existing networks—letting prosumers and consumers realize the benefits of a localized energy marketplace—and to establish the level of interest regional consumers have in knowing the origins of their energy, and paying for clean local energy. LO3 Energy and Allgäuer Überlandwerk are collaborating on the project with the aim of gathering valuable information on the viability of a virtual local community microgrid, then refining an effective model based on that information and ultimately deploying a permanent virtual microgrid in the Allgäu region.

3.2 Examples for P2P in Japan

In this section, several examples for P2P in Japan are introduced by referring to the categorization shown in the section 2.2. All of the examples presented here are demonstration projects. Therefore, tangible results are not yet available.

3.2.1 Urawamisono Project[2]

As an example of Model J3 of P2P transaction, it is worth noting that the trial project in collaboration with the University of Tokyo and the Digital Grid Corporation, the start-up company established in 2017, was launched in the Urawamisono district.

In this district, the municipality established a private line to connect several households and has demonstrated the real time P2P transaction using the blockchain technology. The type of the blockchain platform applied in this project is Ethereum, which enables to establish the smart contract. In the smart contract, the matching mechanism of the project is embedded, so the actors in charge of the P2P transaction register their sell or buy order accordingly. The actual electricity transaction is realized in case the registered orders are matched. The way to match orders is discriminatory pricing method.

The consensus algorithm for this project is Proof of Authority (PoA), in which transactions are validated only by the approved participants. The biggest characteristic of PoA is that the consensus is realized in a speedy manner compared with other algorithms. Since the real time P2P transaction requires the speedy consensus, PoA was select for this project.

For each household participating in this trial project, 5.3kW of solar PV, 12 kWh of storage battery, a Digital Grid Controller (DGC) and a Digital Grid Router (DGR) are mounted. The DGC is a smart controller developed by the Digital Grid Corporation, which estimates the electricity demand of households based on the past records and automatically conducts the buy and sell order. The DGR performs power control necessary for power interchange, which is also developed by the Digital Grid Corporation.

Combining the DGC and DGR with solar PV and storage battery, the Urawamisono project has been demonstrating real time P2P transactions using the blockchain technology.

3.2.2 KEPCO (Kansai Electric Power Co.)

Regarding the Model J4 of P2P transactions, the trial project by KEPCO and Power Ledger, an Australian energy technology company established in 2016, is a good example.

At the site of KEPCO in Osaka, the surplus electricity generated by the prosumers is sent to other consumers, and the P2P transaction between them is demonstrated based on the platform developed by the Power Ledger.

Power Ledger uses blockchain technology to enable energy trading, renewable asset financing and efficient carbon and renewable energy credit markets (Power Ledger, 2019). It provides a market trading mechanism for residential and commercial businesses to decide whom they want to sell their surplus energy to and at what price (Pimentel, 2018). Under this platform, KEPCO shares meter data from participants, and Power Ledger provides KEPCO access to its trading platform to facilitate and monitor energy trading between prosumers and consumers.

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[2] This sub-section largely refers to Tanaka (2019).

The aim of this project is to provide the community with cheap power and create the mechanism to sell and buy the electricity among the actors of the community. In the future, KEPCO intends to build a virtual power plant to support the local energy demands.

Since KEPCO plays the role of platform provider, this scheme is already possible under the Japanese Electricity Business Act; however, there are still some issues to be considered, such as the grid charges and the requirement under the measurement law.

3.2.3 Minna Denryoku

Another example of Model J4 of P2P transaction is the project demonstrated by Minna Denryoku Corporation. In contrast to the above KEPCO project, this project focuses more on an accurate tracking of the electricity generated from renewable power plants to final consumers for providing GoO (Guarantee of Origin) employing blockchain technology, while an aspect of P2P, which is bilateral two-way trading between prosumers and prosumers, is not much emphasized at present. The renewable power producers who participate are mainly medium to large size, specifically 300 kW to 10 MW, of solar PV, onshore wind and solid biomass, and the final consumers are large commercial buildings/factories who are seeking direct procurement of renewable electricity to meet the RE100 targets for instance.

Minna Denryoku[3] Corporation is an energy innovation venture company established in 2011 who has developed an electricity tracking system with blockchain called ELECTION2.0. In the system, tokens are allocated corresponding to the electricity generated from renewables, which are re-allocated to the consumers corresponding to the amount of the renewable electricity consumed within the balancing group of Minna Denryoku who also acts as an electricity retailer. The blockchain-based system uses a platform of NEM cryptocurrency, which is open to public.

The system makes it possible to identify the producers of renewable energy and trace the origin of the electricity. This is intended to attract companies with a strong awareness of ESG investment and RE100 as well as individuals and small-scale consumers who are motivated to purchase renewable energy.

On September 2018, several producers and consumers in the same balancing group of Minna Denryoku participated in the project to demonstrate the matching between demand and supply in 30 minutes unit (Minna Denryoku, 2018). The execution results are recorded on the blockchain-based system, which enables to certificate the origin and the amount of the electricity.

Having gained the positive outcome from the demonstration project, Minna Denryoku has opened the power pool platform called “ENECT Power Pool” based on the ELECTION2.0 on a commercial scale. Approximately 300MW renewable energy has already been participated in this platform as of July 2019, and an additional 200MW were expected to join until March 2020 (Miyake, 2019).

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[3] “Denryoku” means “electricity” in Japanese.

3.3 Examples for PPAs in Germany

3.3.1 Innogy and various customers

One supplier of PPAs on the German market is Innogy. As part of its business model, Innogy offers corporate PPAs, i.e. long-term supply contracts between companies and Innogy as the electricity generator (cf. here and in the following https://iam.innogy.com/ueber-innogy/innogy-innovation-technik/erneuerbare-energien/power-purchase-agreements/ppa-detail). During the term, Innogy supplies customers with green energy at a fixed price and invests in renewable energy power plants to generate that power. These plants will usually be built at a site of low generation cost, but could also be on the customer's premises.

Potential customers can choose between physical and virtual/financial PPAs. For physical PPAs, the contract term is fixed at five or more years. This is implemented either as a direct PPA or as a sleeved PPA. With the direct PPA, the company obtains its electricity physically directly from the generator (Innogy), who produces the energy specifically for this purpose. In this case, the generator not only invests in new plants, but also covers the entire supply chain, thus becoming a full-service provider and taking over the supply. With a sleeved PPA, the generator produces electricity at a fixed price and feeds it into the grid. In this constellation, another company takes over the supply and tasks such as making load forecasts or providing balancing energy.

Virtual PPAs are purely financial products that do not include the physical supply of energy. Innogy distinguishes between a price-guaranteed agreement, in which a base price is agreed for a certain period and the deviation from the market price is compensated either by the electricity supplier or by the electricity customer; and the certificate purchase agreement, in which only the certificates of origin of the electricity are sold at a certain price over the long term and are not linked to the electricity price.

3.3.2 Mercedes-Benz and Statkraft

Since 2018, the Norwegian energy supplier Statkraft has been supplying Mercedes Benz with renewable electricity from a total of six citizen wind farms; this is also stipulated by a PPA (https://www.statkraft.de/presse/News/news-archiv/2018/daimler-und-statkraft/ and https://www.statkraft.de/presse/Pressemitteilungen/Pressemitteilungen-archiv/2018/daimler/). Statkraft is contributing experience from all over Europe in the field of PPA.

In September 2018, Statkraft concluded the first wind PPA in Germany with six citizen wind farms in Lower Saxony. The individual contracts have terms of three to five years and the electricity generated there is intended to supply industrial companies. The project comprises 31 wind turbines with a total installed capacity of 46 MW and generates approx. 74 GWh per year.

From 2021 Mercedes-Benz Cars will purchase this electricity to supply its production site for the EQC electric car in Bremen and the German battery sites in Kamenz and Stuttgart. The supply of electricity from the wind farms will be integrated into the existing power supply to Mercedes-Benz Cars by Enovos Energie Deutschland GmbH. Enovos is responsible for billing, grid usage and the integration of the green electricity volumes into the power supply portfolio of the car manufacturer's plants.

The green electricity generated in the wind farms will be fed into the grid after the contract comes into force and simultaneously removed from the grid by the Mercedes-Benz plants. The power supply is staggered according to the different end of the EEG (FIT law) support for the individual plants: 33.1 GWh are planned for 2021, 74 GWh for 2022 to 2024 and 21.8 GWh for 2025.

3.3.3 Statkraft and Enerparc

In addition to the PPA with Mercedes-Benz, Statkraft announced in December 2019 that it had entered into a long-term power purchase agreement with Enerparc to implement five subsidy-free solar projects in Bavaria (cf. https://www.statkraft.de/presse/Pressemitteilungen/2019/statkraft-und-enerparc-schlieben-langfristigen-stromabnahmevertrag-zur-realisierung-von-funf-forderungsfreien-solarparkprojekten-in-bayern/).

The contract with Enerparc as a specialist for the development, construction and operation of large-scale solar power plants provides for a term of 12 years. The solar parks have an installed capacity of approx. 52 MWp and Statkraft intends to draw a total of around 600 GWh of electricity from them from May 2020 to December 2031. Commissioning is planned for spring 2020. Enerparc is responsible for development, construction and operation. Sunnic, the direct marketing subsidiary of Enerparc, is responsible for short-term marketing on the spot market. Statkraft plans to use the electricity for the structured supply of industrial companies.

3.3.4 Greenpeace Energy

Greenpeace Energy, a green power supplier, has concluded a PPA with Windpark Ellhöft GmbH und Co. KG to enable the continued economic operation of the Ellhöft wind farm in northern Germany after the end of EEG funding and sell the green power to its retail customers. The contract for the supply of electricity from six wind turbines with a capacity of 1.3 megawatts each will come into force in 2021 and is set to run for five years. The agreed fixed price per kilowatt hour can be adjusted during the term of the contract if wholesale power market prices rise above or fall below certain thresholds. Risks and benefits are shared between Greenpeace Energy and the wind farm operator.

3.3.5 EnBW and Energiekontor

EnBw Energie Baden-Württemberg AG and Energiekontor AG have concluded a PPA for a new solar park east of Rostock in North-Eastern Germany; installed capacity will be approximately 85 MW and is expected to produce 88GWh of electricity annually (cf. https://www.enbw.com/unternehmen/investoren/news-und-publikationen/investorennachrichten/presse-detailseite_203904.html). The agreement stipulates that EnBW will purchase 100 percent of the electricity at a fixed price. Within the agreed contract period of 15 years, the two companies assume that the total amount of electricity produced will be around 1.3 terawatt hours.

Energiekontor will implement the project on 120 hectares of agricultural land in the city of Marlow and the municipality of Dettmannsdorf. The commissioning of the solar park is scheduled for the end of 2020.

3.3.6 Overall PPA market development

Overall, it can be stated that PPA is still a niche phenomenon in Germany and that there are only a few practical examples on the German market; especially in comparison to the global or European market (see figure 1 and table 3). However, this may soon change dramatically with 1) the end of the FIT payments for an increasing number of wind and PV power plants from January 2021; and 2) due to the fact that it is currently already economically attractive to build large-scale PV power plants without FIP/MP remuneration, i.e. without participating in auctions.

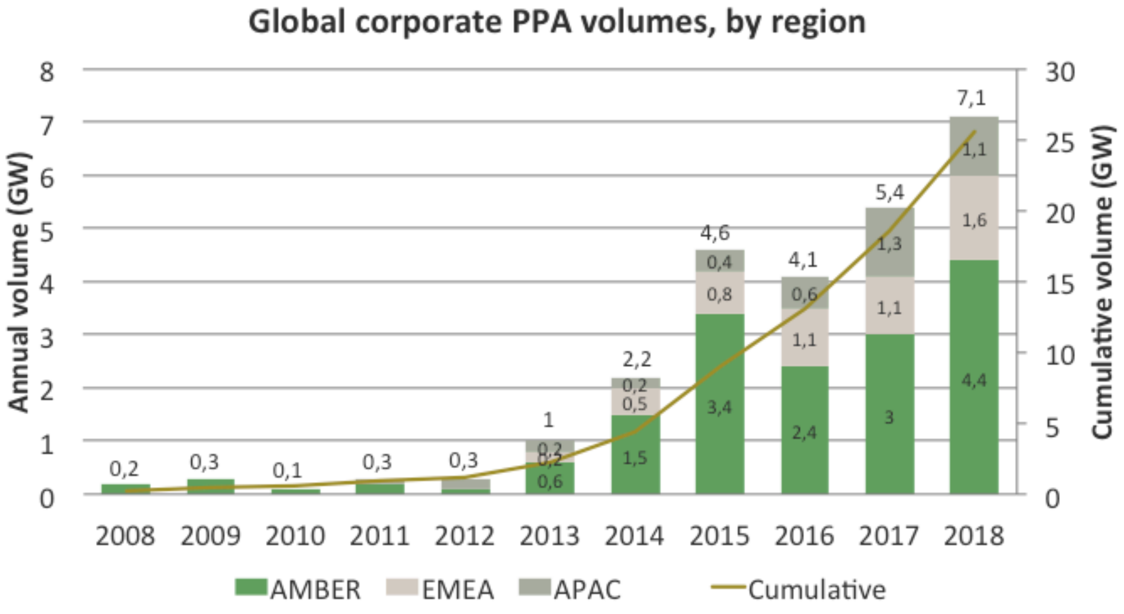

Figure 5: Global corporate PPA volumes, by region (Source: own presentation based on Bloomberg NEF 2019)

	Wind Onshore	Wind Offshore	Solar
Great Britain	333	860	367
Scandinavia	4.095	600	
Poland	45		
Germany	65		
Netherlands	548		68
Ireland	78		
Spain			1.661
France	41		
Italy	693		

Table 4: PPA in Europe (End 2018), cumulated in MW
(Source: own presentation based on Energy Brainpool 2019)

In view of developments and Europe and the rest of the world, it is therefore likely that PPAs will also become increasingly important in Germany in the future, especially against the background of the phasing out of EEG funding. This assessment is also confirmed by the PPA Barometer from Energie&Management; 31 companies from the fields of energy supply, direct marketing, project development and plant operation took part in the survey:

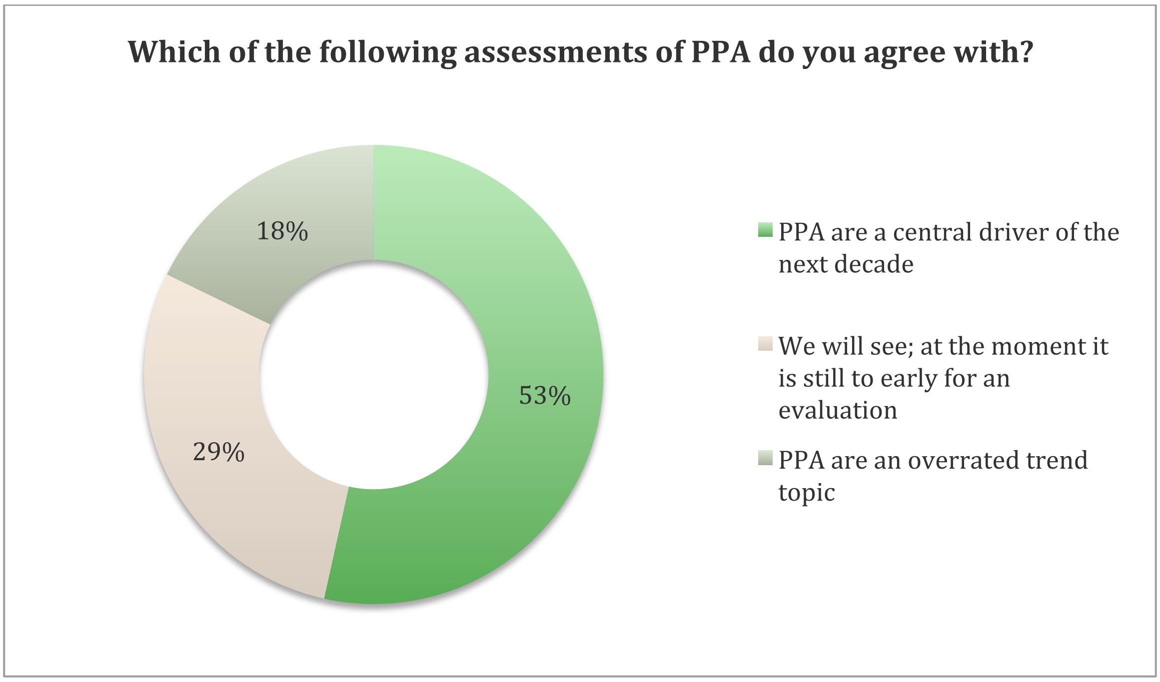

Figure 6: Assessments of PPA in Germany (own graphic; Source: E&M 2019)

3.4 Examples of PPAs in Japan

3.4.1 General situation

The situation surrounding PPAs in Japan has been rather different from the case of Germany. In short, PPAs have not been widely employed as much as Germany. A primary reason of this difference is the generous FIT prices given for solar PV so that until very recently, the FIT scheme was too attractive for renewable electricity producers to consider PPAs.

Before 2018, FIT was applied to all of solar PV projects of less than 2 MW[4] which currently occupy 98% of the total number and 46% of the total capacity of solar PV projects implemented in the country, with FIT prices of JPY 18 (USD 0.16)/kWh for 2018, JPY 21 (USD 0.19)/kWh for 2017 and JPY 24 (USD 0.22)/kWh for 2016. The FIT prices were set at a more inflated level for residential solar PV projects of less than 10 kW and were JPY 26 (USD 0.24)/kWh for 2018, JPY 28 (USD

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[4] Before 2017, even this threshold did not exist i.e. FIT could be applicable to any of solar PV projects including more than 2 MW.

0.25)/kWh for 2017 and JPY 31 (USD 0.28)/kWh for 2016. Even higher FIT prices have applied to other renewables than those for solar PV.

These FIT prices were much higher than the retail electricity prices which are around JPY 16 (USD 0.15)/kWh for the industrial sector and JPY 25 (USD 0.23)/kWh for the residential sector. Under such a generous FIT scheme, renewable electricity producers were given little incentive to sell the electricity directly to final users via PPAs or use it for their own consumption, but an enormous incentive to sell it to the grid as much as possible they can to maximize their profit. As a result, few examples of PPA have been found in Japan where, in converse, PPA options were unavailable for final consumers who seriously seek renewable electricity, like RE100 partnership organizations, for many years.

This rather peculiar circumstance in Japan, however, has gradually changed recently. The FIP for any solar PV plants of more than 500 kW are now set by competitive auction after mid-2019 and the threshold of 500 kW will be even lower down to 100 kW after 2020. The latest auction for solar PV more than 500 KW, taken place in August 2019, brought about an average contract price of JPY 12.98 (USD 0.12)/kWh with the lowest ever solar PV price of JPY 10.50 (USD 0.095)/kWh. These recent contract prices revealed by the auction imply that solar PV can produce electricity at a cost far less than the retail price for the industrial sector of JPY 16 (USD 0.15)/kWh.

In addition, after 2021, a Feed-in Premium (FIP) is likely to be newly introduced for solar PV of more than a few hundred kW and onshore wind in place of the generous FIT or FIP. The FIT prices will continue to apply only for excess electricity from small-scale solar PV of less than 50 kW after self-consumption, which must be a large part of the generated electricity. Unless otherwise such the conditions are met, FIT will be no longer available for solar PV more than 10 kW. Even in the case that FIT is still applicable, the FIT price will be set less than the current price of JPY14 (USD 13)/kWh for 2019, which is already lower than, once again, the retail electricity price for the industrial sector.

Furthermore, over the past years, an increasingly large number of Japanese companies and organizations have begun to participate in RE100 and similar initiatives to commit to sourcing 100% renewable electricity. This has newly created a substantial volume of demand for electricity from renewables.

The end of the generous FIT and the cost reduction of solar PV generation with the increasing demand for renewable electricity are likely to create a new environment in Japan. Renewables producers are now likely to consider selling the electricity directly to the final user via PPAs, if the selling prices are higher than the auction contract price of around JPY 12.98 (USD 0.12)/kWh. At the same time, final consumers who seek renewable electricity are likely to consider purchasing it directly from renewable producers via PPAs instead of the existing electricity retailers if the prices of PPAs are fairly competitive. A continuously increasing FIT surcharge on the retail electricity price, JPY 2.95 (USD 0.027) /kWh at present, which is more than 4 times compared to 2014 and expected to further increase up to 2032, also boosts the cost competitiveness of PPAs against the grid supply of electricity through existing retailers. Therefore, the employment of PPAs is expected to grow substantially over the next decades in a post-FIT era in Japan.

To date, there are several, if not many, examples of PPAs in Japan as shown in the next sub-section. Most of PPAs observed so far are so-called “on-site PPA” or “Third-party ownership (TPO) model”, which is a sort of “direct PPAs” mentioned in the above section on Germany, however without using the grid in any case. In this PPA model, renewable developers (sellers) build solar PV plants directly on-site on the final consumers’ (buyers’) properties, mainly factories and buildings, to inject the generated electricity into consumption facilities within the site according to the contracts under PPAs. The final consumers purchase renewable electricity from solar PV plants on the site, but they do not need to care about installation, operation and maintenance of the plants.

This bias toward on-site PPA is also a distinct feature of Japan in comparison to the European countries. As mentioned in the above sections for Germany, there are many PPAs, in which renewable producers feed electricity into grid and through which final consumers (buyers) purchase renewable electricity according to the contract under PPAs (see 3.3.1 Innogy and various customers). Such bias can be explained by several reasons.

Firstly, the Japanese electricity market has just been deregulated and not been fully competitive yet. The market environment as well as the current regulatory framework are not yet well suited for wide application of on-grid PPAs. In addition, the share of renewables in the total generated electricity was around 18% in 2019, which contrasted to 43% in Germany in the same year. This implies that the availability of renewables in the Japanese electricity market is simply far less in Japan than Germany. Thirdly, almost all renewable electricity in Japan comes from the FIT certified plants. Since the current FIT scheme does not have any functions neither to identify nor to guarantee the origins of renewable sources, FIT electricity is difficult to be used to comply to RE100 unless otherwise an appropriate GoO (Guarantee of Origin) system is in place within the scheme. Having these circumstances, if someone seriously needs to acquire renewable electricity, the most reliable way is generating it by themselves, which is usually on-site generation within their own property. Under these circumstances, on-site PPAs are preferred to sleeve PPAs in Japan.

3.4.2 Examples of on-site PPAs in Japan

Car manufacturer SUBARU has committed to reduce by 30% their CO_2 emissions, which were 680,000 t-CO_2 in total in 2018, by 2030. As a part of a series of actions to meet this target, they have contracted “on-site PPA” with NTT facilities to lend them 52,000 m^2 of idle area in their main factory for installation of a 5 MW solar PV plant. The electricity generated from the plant is directly sold to SUBARU to be consumed by the facilities within the factory over 20 years. This is one of the largest PPA projects so far in Japan. Moreover, on the rooftop of the warehouse located nearby the main factory, 1 WM of solar PV plants are installed as on-site PPA project (NTT Facilities, 2019a). In a similar fashion, the pharmaceutical company, Dai-ichi Sankyo Chemical Pharma, has concluded a contract for on-site PPA with NTT facilities to lend idle area in their factory for installation of 3.3 MW solar PV plants. The generated electricity is sold to their facilities over 20 years (NTT Facilities, 2019b).

Other examples of on-site PPAs are found mainly in retail stores/supermarkets. Most of the cases have similar business models of on-site PPAs. Renewable developers typically install 100 kW-500 kW of solar PV plants, with batteries in some cases, on the rooftop of stores/car parks/buildings. All of the generated electricity is sold to the retail stores/supermarkets to be directly consumed by them over 10 years.

Peer-to-Peer (P2P) electricity trading and Power Purchasing Agreements (PPAs)

4 Potential positive and negative impacts for each P2P trading model and for PPAs in general

This chapter will analyze positive and negative impacts, opportunities and threats for each type of market actor, for markets and the energy system in total, and for non-participating generators and consumers for each P2P trading model described in chapter 2. The same is done for PPAs in chapter 4.2. No distinction by model is made here, since differences are not so big.

4.1 P2P energy trading

4.1.1 Overview of incentives and barriers for market actors in each model

Possible incentives/opportunities and barriers/threats for market actors can be summarized in the following tables for each model in Germany and Japan.

Germany and Japan: Model G1 and J4 - J7: controlled P2P network: The wholesale market model		
Type of market actor	**Incentives and opportunities**	**Barriers and threats**
Small to medium generator or prosumer	· If the P2P trading cost is lower than the cost/price of the traditional supply chain, the difference could be shared between the generator and the customer, leading to higher revenues for the generator (cf. Lition claims in Germany, KEPCO in Japan) · In this way, P2P trading could create new Incentives for continuous selling of renewable electricity from post-FIT plants and for investment for a new renewable plant without FIP/MP payment in a post-FIT era	· Providers of P2P electricity are in the direct competition with traditional suppliers, so expected P2P revenue may not exceed the price of conventional generation and marketing. · A further price premium for the producer would probably only possible for green electricity but not for 'grey' electricity, since neither a rational nor an emotional added value for the electricity customer can be expected from P2P trading itself. · There is an uncertainty, if the prices obtained from customers will be higher than from the wholesale power market, particularly if the smart contracts are made using fixed or other predetermined prices.
Wholesale trade company, e.g. VPP operator	· VPP operators may organize P2P trading through an aggregation of a large number of prosumers, which would create a new business opportunity	· The direct P2P trading will reduce their business, unless they can aggregate prosumers for the P2P trading.
TSO	· In this model as in any other model of electricity trading, the TSO has a financial incentive to shift feed-in and loads (via demand side management) to avoid grid bottlenecks: it can support this through flexible network charges, if the law allows. However, this is not a feature of the P2P trading in this model.	· Utilization of transmission lines may decrease when P2P trading exclusively or more strongly occurs within DSO or even lower local areas, implying revenue from the grid fee would reduce. However, this is not an effect of the P2P trading per se in this model (cf. chapter 4.2). In Germany, it will also be partly compensated for by the revenue regulation (through the "regulation account" mechanism) · A grid stabilization effect would not be expected with a nationwide exchange model, since the P2P market price only

		reflects the nationwide relationship between P2P supply and P2P demand, but not the distances between the respective market locations of the producers and consumers and the associated transmission and distribution through the public networks. There is even a certain risk that P2P trading aggravates grid bottlenecks if trading occurs across the borders of TSOs.
DSO	• In this model as in any other model of electricity trading, the DSO has a financial incentive to shift feed-in and loads (via demand side management) to avoid grid bottlenecks: it can support this through flexible network charges, if the law allows. However, this is not a feature of the P2P trading in this model.	same as for TSO
Electricity supplier incl. traditional and new electricity retailer, VPP aggregator; *also could be a P2P platform provider at the same time, but this line only analyses the retail supply function)*	• P2P trading could be its core business or create new business and retain customers. • In addition, a supplier could offer variable prices for the remaining electricity needs / selling surpluses and earn an additional margin for this service, plus enhance the supply-demand balance in its balancing group and save on balancing energy	• For a traditional or new supplier in the classical electricity market, there is the risk of losing margin, when customers move from traditional supply to P2P trading, even if organized by the same supplier.
P2P Platform provider / platformer	• P2P trading could be its core business	• Privacy risk of consumers/prosumers might be a barrier for the business
P2P Platform technology provider	• P2P trading technology could be its core business	• None
Consumer or prosumer	• Wider Options of power purchase, for example specific preference on particular renewable resources and areas/regions, are available for consumer/prosumer • Added value is only created for the consumer when he or she can purchase P2P electricity at a lower price than electricity via a conventional electricity supply contract. • If the P2P trading cost is lower than the cost/price of the traditional supply chain, the difference could be shared between the generator and the customer, leading to lower prices (cf. Lition claims)	• There may be costs associated with new smart meters and devices required for P2P trading by the law • There is an uncertainty, if the prices to be paid will be lower than in traditional supply, particularly if the smart contracts are made using variable (market-oriented) prices • Privacy risk may be caused by individual data collected via smart meters and cyber security • In models J5 and J7, a prosumer is required to be registered as an electricity retailer with legal obligations when she/he sells electricity independently, implying a direct P2P trading is almost impossible in reality (in Japan, except for Model J1, J2, J4 and J6)

Table 5: Incentive/opportunities and barrier/threats of wholesale market P2P model in Germany and Japan

Germany Model G2: controlled P2P network: Regional/local electricity procurement		
Type of market actor	**Incentives and opportunities**	**Barriers and threats**
Small to medium generator or prosumer	· Possible price premium by regionality; in particular, the law on the electricity tax allows to waive the tax (2,44 ct/kWh incl. VAT), if single or aggregated generators that are smaller than 2 MW and do not receive the FIT or FIP sell electricity to consumers not farther away than 4.5 km ("regional direct marketing") (FfE 2018b)	same as for model G1
Wholesale trade company, e.g. VPP operator	same as for model G1	same as for model G1
TSO	· Line and transformation losses and even needs to enhance the transmission grid could be reduced if regional electricity trading reduces grid bottlenecks; however, this effect is uncertain in this model (see below in chapter 4.2). · The TSO would probably need to incentivize this through flexible network charges, if the law allows, same as in model G1.	· If the P2P trading does not change physical electricity flows: same as for model G1. Otherwise, will depend on the (presumably positive) effect on grid stabilization and the direction of changes in kWh transported via the grid
DSO	· Line and transformation losses and even needs to enhance the transmission grid could be reduced; however, this effect is uncertain in this model (see below in chapter 4.2). · The DSO would probably need to incentivize this through flexible network charges, if the law allows, same as in model G1.	· If the P2P trading does not change physical electricity flows: same as for model G1. Otherwise, will depend on the (presumably positive) effect on grid stabilization and the direction of changes in kWh transported via the grid
Electricity supplier incl. traditional and new electricity retailer, VPP aggregator; *also could be a P2P platform provider at the same time, but this line only analyses the retail supply function)*	· same as for model G1; however, higher potential margin for organizing "regional direct marketing" (see explanation above in generator line)	same as for model G1
P2P Platform provider / platformer	same as for model G1	Same as for model G1
P2P Platform technology provider	· P2P trading technology could be its core business	· none
Consumer or prosumer	same as for model G1; however, higher potential margin for saving on the electricity price in case of buying from a local generator via "regional direct marketing" (see explanation above in generator line)	same as for model G1

Table 6: Incentive/opportunities and barrier/threats of regional/local electricity P2P model in Germany

Germany: Model G3: controlled P2P network: P2P trade serving grid stabilization		
Type of market actor	**Incentives and opportunities**	**Barriers and threats**
Small to medium generator or prosumer	· For prosumer: More flexible network charges	same as for model G1
Wholesale trade company, e.g. VPP operator	same as for model G1	same as for model G1
TSO	· Has financial incentive to shift feed-in and loads (via demand side management and targeted use of storage) to avoid bottleneck: either TSO or DSO or both will support this in this model through flexible network charges or incentive payments if law allows	· Utilization of transmission line may decrease when P2P trading exclusively or more strongly occurs within DSO or even lower local area, implying revenue from grid fee would reduce to some extent (in Germany, this will be partly compensated by the revenue regulation)
DSO	· Has financial incentive to shift feed-in and loads (demand side management and targeted use of storage) to avoid bottleneck: either TSO or DSO or both will support this in this model through flexible network charges or incentive payments, if law allows	· If the P2P trading does not change physical electricity flows: same as for model G1. Otherwise, will depend on the (presumably positive) effect on grid stabilization and the direction of changes in kWh transported via the grid
Electricity supplier incl. traditional and new electricity retailer, VPP aggregator; *also could be a P2P platform provider at the same time, but this line only analyses the retail supply function)*	· same as for model G1; revenue could be a little higher due to extra transaction feature of flexible network charges	same as for model G1
P2P Platform provider / platformer	same as for model G1; revenue could be higher due to extra transaction feature of flexible network charges	same as for model G1
P2P Platform technology provider	· P2P trading technology could be its core business	· none
Consumer or prosumer	· More flexible and possibly reduced network charges · Price signals via smart metering to shift loads	same as for model G1

Table 7: Incentive/opportunities and barrier/threats of decentralised autonomous P2P network model in Germany and Japan

Germany: Model G4: decentralized autonomous P2P network with on-grid trading		
Type of market actor	**Incentives and opportunities**	**Barriers and threats**
Small to medium generator or prosumer	· Higher revenues without a supplier as intermediary	· Have to assume key responsibilities in the energy market, i.e. supplier (i.e. Contracts with Consumers, TSO and DSO); balancing group manager
Wholesale trade company, e.g. VPP operator	same as for model G1; VPP operators could take over the key responsibilities in the energy market for the generators, prosumers, and consumers for a fee, bringing this model closer to model G1	same as for model G1
TSO	same as for model G1 or G2	same as for model G1 or G2
DSO	same as for model G1 or G2	same as for model G1 or G2
Electricity supplier incl. traditional and new electricity	· not relevant; however, electricity retailers or VPP operators could	same as for model G1

retailer, VPP aggregator; *also could be a P2P platform provider at the same time, but this line only analyses the retail supply function)*	take over the key responsibilities in the energy market for the generators, prosumers, and consumers for a fee, bringing this model closer to model G1	
P2P Platform provider / platformer	same as for model G1; share of the avoided traditional supplier margin could be higher	same as for model G1
P2P Platform technology provider	• P2P trading technology could be its core business	• none
Consumer or prosumer	• Reduction in transaction costs due to elimination of intermediaries. • Lower electricity prices without intermediaries. • Independence from energy supply companies	• Have to assume key responsibilities in the energy market, i.e. network connection contract and network usage contract with DSO; no all-inclusive contract with supplier (i.e. Consumer has to join the balancing group of a service provider or register and balance electricity purchases independently)

Table 8: Incentive/opportunities and barrier/threats of decentralized autonomous P2P network with on-grid trading

Germany and Japan: Model G5 and Model J1 - J3: decentralized autonomous P2P network in off-grid		
Type of market actor	**Incentives and opportunities**	**Barriers and threats**
Small to medium generator or prosumer	• Higher revenues without a supplier as intermediary; • No legal requirement for generator or prosumer to register as an electricity retailer	
Wholesale trade company, e.g. VPP operator	not relevant	same as for model G1; "self-consumption" within the P2P network will reduce trade volume further
TSO	same as for model G1 or G2	same as for model G1 or G2; "self-consumption" within the P2P network will reduce grid fees
DSO	same as for model G1 or G2	same as for model G1 or G2; "self-consumption" within the P2P network will reduce grid fees
Electricity supplier incl. traditional and new electricity retailer, VPP aggregator; *also could be a P2P platform provider at the same time, but this line only analyses the retail supply function)*	not relevant	same as for model G1; "self-consumption" within the P2P network will reduce retail volume further
P2P Platform provider / platformer	same as for model G4	same as for model G1
P2P Platform technology provider	• P2P trading technology could be its core business	• None
Consumer or prosumer	• Reduction in transaction costs due to elimination of intermediaries. • Lower electricity prices without intermediaries and saving on grid fees (models G5, J1, J2). • Independence from energy supply companies • No legal requirement for prosumer to register as an electricity retailer (for Model J1 and J2)	

Peer-to-Peer (P2P) electricity trading and Power Purchasing Agreements (PPAs)

Table 9: Incentive/opportunities and barrier/threats of decentralized autonomous P2P network in off-grid in Germany and Japan

As the above tables show, when P2P trading expands at a large scale, the most heavily impacted area would be the business opportunities of traditional electricity retailers. There would be the significant risk of losing their business margin as customers move from their traditional electricity supply to P2P trading. Even when the same electricity retailer serves the P2P platform, its business model and revenue stream would be substantially altered. Wholesale trade companies, including VPP operators, would also be affected since the direct P2P trading will reduce their business opportunity. In any case, the traditional electricity retailers and the wholesale trade companies would have a strong incentive to become P2P platformers themselves to avoid losing their business margin. In fact, electricity retailers are in a good position to do so since they already have a connection with the final electricity users. In addition, they also have registered as a retailer under the current legal/regulatory framework with a responsibility of balancing with experience/knowledge on operation of balancing group. It is no wonder that the traditional electricity retailers have begun to work on P2P pilot projects like the KEPCO project observed in Japan or the WSW Tal.Markt and others in Germany.

In contrast, small to medium renewable generators, prosumers and consumers would have more positive opportunities to enter a P2P trading with lower cost than the cost/price offered by the traditional electricity supply chain. Such cost/price differences could be shared between the stakeholders leading to higher revenue or lower prices for them. A P2P trading could bring a significant incentive to sell renewable electricity and to invest in new renewable plants in a post FIT era. Nevertheless, the cost/price are not necessary to be lower than the traditional supply chain. It could highly depend upon the cost of IT tools, such as smart meters and monitoring devices, P2P platform operation and billing costs and others, which creates a huge uncertainty. In all on-grid models (G1 to G4; J4 to J7), the grid fees, taxes, and levies cannot be avoided. In addition, privacy risk and cyber security associated with individual data collected by smart meters and other IT devices may also bring uncertainty. However, if the cost and other risk issues are effectively addressed, P2P trading could bring a large positive impact on both renewable electricity producers and prosumers/consumers, which would lead to a further increase in renewables without financial support, like FIT or FIP schemes, from the public sector or the community of electricity consumers.

P2P platformers and P2P platform technology providers would have enormous business opportunities in the field of P2P trading, which could be their core business in the newly emerging market. An increase in demand side management with P2P trading, which may financially be led by TSOs to shift feed-in and loads, would further expand their business opportunities.

The impacts on TSOs and DSOs would be a mixture of positive opportunities and threats depending upon whether or not P2P trading occurs across the borders of TSOs and between TSO and DSO. When P2P trading occurs exclusively within a particular TSO or DSO or even smaller area and is combined with flexible network charges or other incentives for grid-stabilizing generation, demand, and use of storage capacities (see chapter 4.2 below), then P2P trading could relieve bottlenecks of distribution and transmission lines by matching supply and demand of renewable electricity generated within a closer area. On the other hand, if such P2P trading is growing in a large volume, the utilization rate of transmission lines is likely to decrease, which would be an economic threat to TSOs and maybe DSOs as well, depending on regulation (in the revenue regulation in Germany, losses in revenue due to a reduced volume of electricity transported in a TSO or DSO system will be at least partly compensated for by the "regulation account" mechanism). However, overall, a P2P trading would generate the positive incentive and opportunity for enhancing grid stability for TSOs and DSOs by the possibility of adding incentives for flexibility for the generators and consumers in the P2P trading scheme.

4.1.2 Potential positive and negative impacts for markets and the energy system in total

Having the above discussion on types of market actors, this section considers the positive and negative impacts for markets and the energy system in total.

1. On the one hand, there could be positive impacts by allowing the continued use of post-FIT renewable power plants as well as new investments in renewable energy plants without a FIT or FIP payment. In comparison to the traditional market model, this will depend on a) willingness to pay a price premium for electricity from renewable and/or regional generation assets, b) regulation aspects (such as the possibility to save grid fees, taxes, and levies through off-grid P2P trading models or to save the electricity tax in Germany for generators smaller than 2 MW and less than 4.5 km away from consumers, "regional direct marketing"), c) particularly on cost savings in electricity sale and supply, and d) if or not the electricity prices provided by a P2P trading are lower than those given by the traditional model by an amount sufficient to compensate for the costs of IT devices and others needed for the P2P trading.
2. Such cost savings in electricity trading and retail supply will also mean an economic benefit for the country.
3. Finally, a potential benefit from improved grid integration of variable renewable energies will depend on the difference in the effect for matching regional supply and demand between the classical model and the P2P model.

1) Regarding the first potential impact, the first pilot projects in Germany and Japan indeed target the trading of electricity from renewable energies, and hence a group of customers interested in green and/or regional electricity; sometimes also customers who like to be part of a community of like-minded energy transition pioneers, such as in the enyway or Sonnen businesses. Some may just be interested in lower electricity prices too. The numbers of customers using the existing offers is, however, unknown to us. Lition claims to have customers in over 100 cities in Germany. Enyway has linked 20 MW of generation assets to customers. So there seems to be some potential for the continued use of post-FIT renewable energies as well as new investments in renewable energy plants without a FIT or FIP payment, but the future development is difficult to estimate.

2) As regards cost savings in electricity trading and retail supply, evidence from pilot projects presented in chapter 3 seems to indicate that such cost savings do exist. Although the margins in traditional supply chains are relatively small (a few JPY or cents/kWh for residential customers, e.g. 12 % of the retail price or ca. 3.5 cent/kWh in Germany (FfE 2018b), and less than 1 JPY or 1 cent/kWh for larger customers), it seems they are large enough to make P2P trading attractive,

especially if combined with higher willingness to pay a price premium for electricity from renewable and/or regional generation assets.

3) For assessing the potential for improved grid integration of variable renewable energies and grid stabilization, we need to analyze whether there is a difference in the effect for matching regional supply and demand between the classical model and the P2P models.

In the **classical model**, in Germany renewable power is sold to the DSO (in a DSO area), then via the TSO to the wholesale market (outside), or sold directly to the wholesale market. There, it will be sold to a supplier (in or outside the DSO area) and from the supplier to the customer in the DSO area (or outside). In Japan, most of RE in Japan is under FIT entitlement. Therefore, such FIT electricity is purchased by a DTSO at the fixed FIT prices. Then, a lot of this electricity is sold to the retailers within the DTSO area at the contracted price and the rest of it is sold at the wholesale market at the DTSO area (some of them goes to different DTSOs through inter-connection lines, which are typically weaker in Japan compared to the Europe).

The physical flow, however, is first of all within the DSO area from generator to consumer. Excess power is flowing outside (the overlaying transmission system), deficit power is flowing into the DSO area from the outside. This is shown in figure #7.

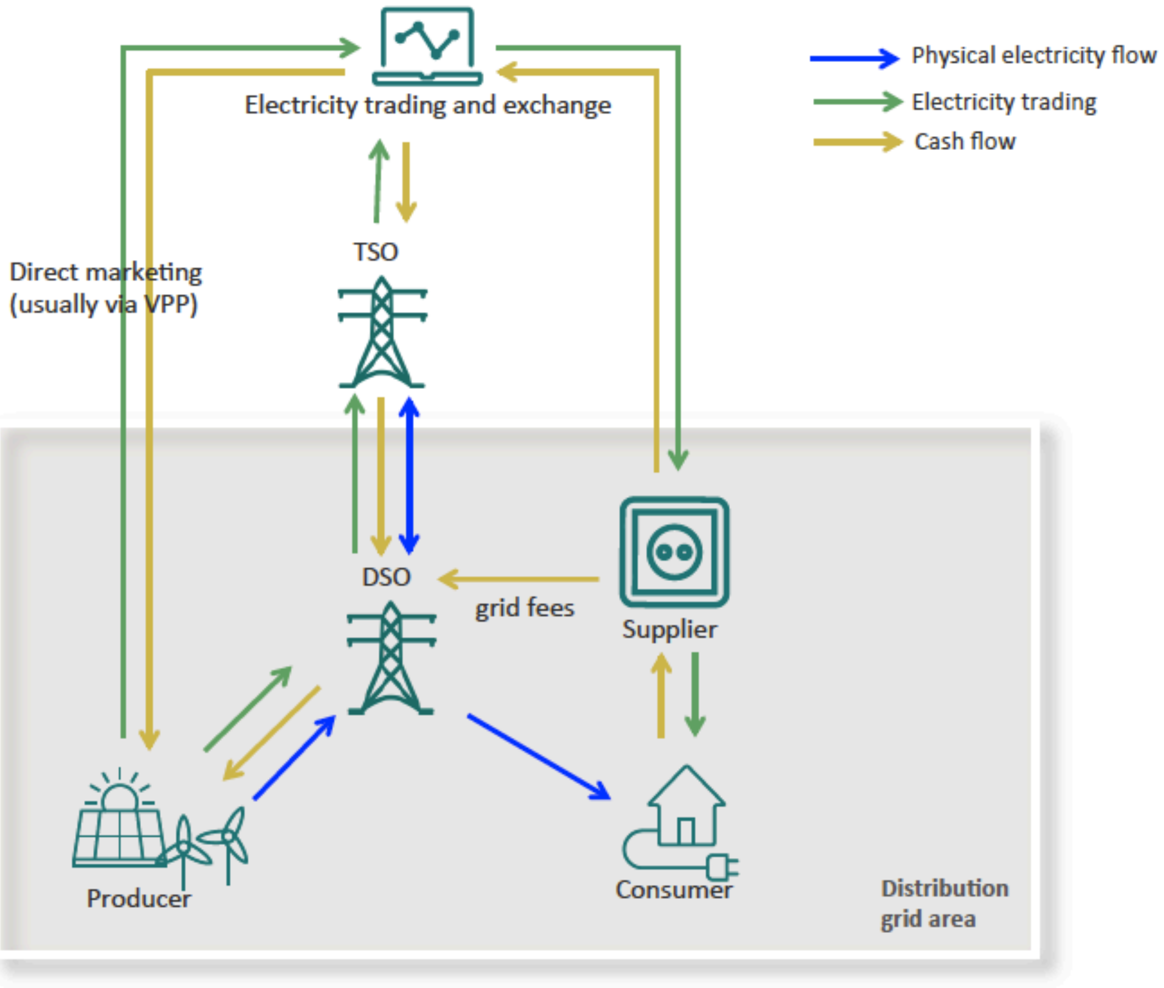

Figure 7: Physical, contractual, and monetary flows in the classical electricity trading model

Peer-to-Peer (P2P) electricity trading and Power Purchasing Agreements (PPAs)

In the **on-grid P2P models**, economic flow is primarily within the P2P platform and can be directly from generator to a customer within the same DSO area (then it usually equals the physical flow), but also to customers in other areas. And for surplus or deficit power, the flows in or out of the DSO area are the same as in the classical model (Figure #8).

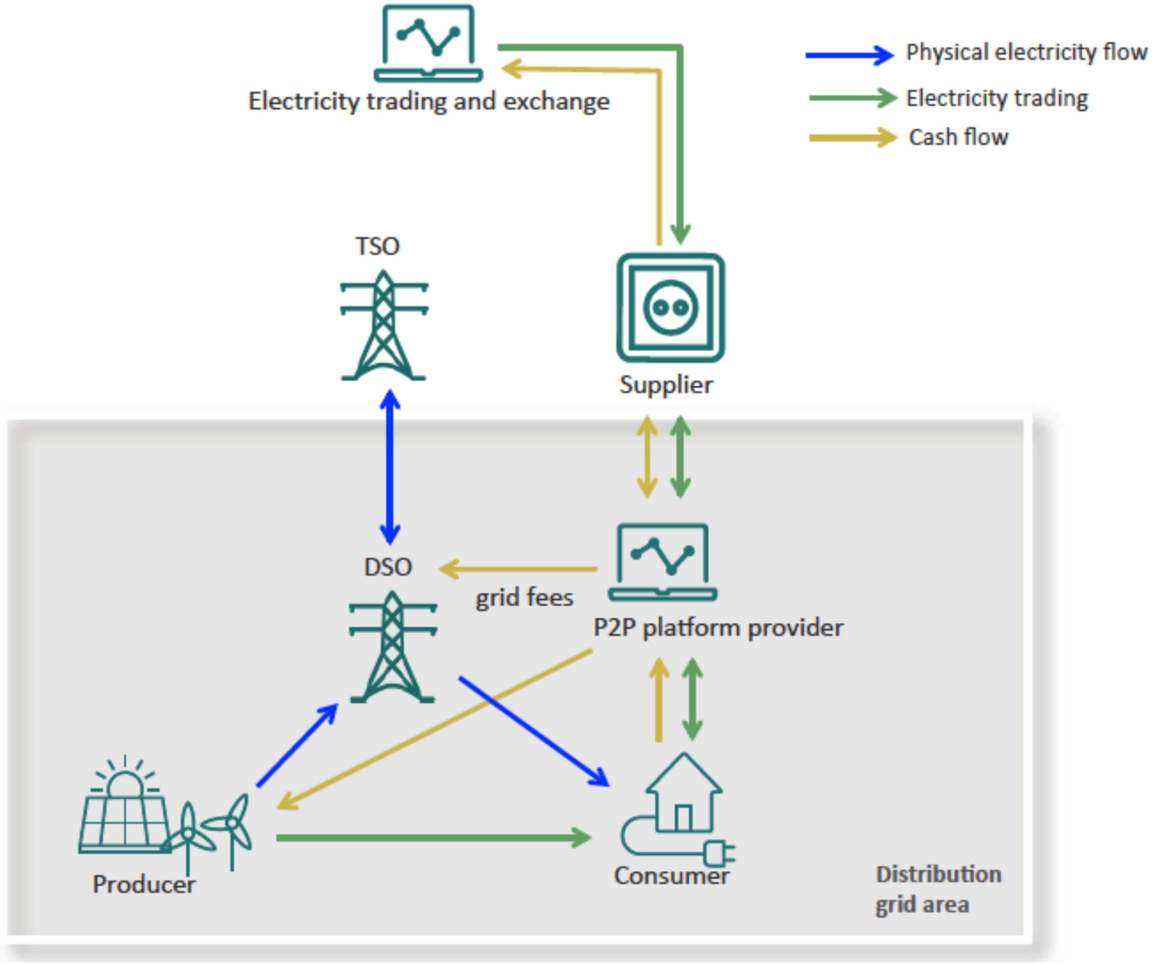

Figure 8: Physical, contractual, and monetary flows in the P2P electricity trading model at regional level

Note: the P2P platform provider may be paying the grid fee to the DSO on behalf of the producer, if the latter formally acts as a supplier in the model (e.g. enyway). If the P2P platform provider concludes the grid use contract for the consumer, i.e. the platform provider is the supplier, the platform provider will pay it on behalf of the consumer.

As these graphs show, on-grid P2P trading per se is unlikely to change anything in physical flows of electricity, unless either the P2P trading explicitly includes or induces additional demand/supply changes through DSM, flexible generation, system-driven use of batteries/BEV, or they are induced otherwise by grid operators or government policies. It would, therefore, per se not provide any additional benefits for the alleviation of grid bottlenecks and the *grid integration* of renewable energy without additional measures to changes in demand/supply.

This may be explained as follows: With on-grid P2P trading in a region or DSO area, the customer now has a regional supplier, and the generator has a regional customer. But if the customer does not change his/her load curve (i.e., does not use DSM or storage), and if the generator were to generate also in the traditional market model as the sun shines and the wind blows, nothing will change in the physical supply-load balance in the DSO area. It is just that the electricity fed into the grid by the generator is now *sold* directly to this customer and not to others via the market; these other consumers will now *buy* electricity from other generators via the market. And the P2P customer is now *buying* the electricity directly from the generator instead of from the market. This is all about *economic* flows of electricity in figures #7 and #8. But *physically*, the same amount of electricity will be fed into the DSO grid by the generator; and the same amount of electricity will be taken from the grid by the consumer.

This holds for the case, that there is no difference in the capacities of generation or the loads in a DSO area. Then, there will also be no change in the total power generated in a DSO area, and no change in total electricity consumption in this area either. In contrast to this case, there will be an effect on physical electricity flows, if *the existence* of the P2P model induces and enables additional generation from renewable energies or new electricity demands, such as battery-electric vehicles (BEVs), whose owners buy a part of the additional generation. it will depend on the relative economic situation, such as electricity prices, and political framework for P2P trading vs. the classical market model, whether P2P trading may induce such additional generation and demand that would not arise in the classical market model.

For example, If the P2P trading enables the continued operation of a renewable energy generator post-FIT or the operation of a new generator without FIT or FIP, then supply within this DSO area will increase compared to the classical market model. But also in this case, the P2P trading of the additional electricity per se does not care about *flexible* operation of the new generator *in its operation.* The generator will feed in to supply his or her customers just like the generation is available. Whether this feed-in that has been induced by the P2P trading will alleviate or aggravate grid constraints, will therefore not be under the control of the DSO or TSO (except for eventual curtailment) without additional action taken by grid operators or the P2P trading platform.

We may therefore conclude: A P2P trading scheme may only change anything in physical flows between existing generators and demands *during its operation*, if the P2P trading explicitly provides or includes incentives for DSM, flexible generation, system-driven use of batteries/BEV, and smart chargers, or if new generators, demands, and flexibilities are induced by *the existence of* P2P trading. According to the figures and considerations above, it is doubtful whether such incentives are a genuine feature of the P2P trading *during its operation*. They will need smart meters and smart contracts that enable the incentives. To the extent that P2P trading accelerates the installation of smart meters, it will also enhance the possibilities for supporting flexibility options. However, they still will likely need to be added to the market model by the platform provider and/or the DSO/TSO (as in the Sonnen/TenneT pilot), and they will likely also need DSO/TSO control of the physical assets.

However, there is also an incentive for the P2P platform provider and / or retail energy supplier that is the *balancing group responsible* to offer flexible tariffs in exchange of real-time control of generators and consumers' assets, in order to allow real-time or short-time control of imbalances in the balancing group made up of the P2P trading community. This will be attractive, if the cost is below that of balancing energy from the balancing market. P2P trading of renewable energies would then advance the *market integration* of renewable energies. If the P2P trading and the balancing group is strictly local or regional (as in model G2 or possibly G3), this may also contribute to some alleviation of grid constraints.

Therefore, in the case of on-grid P2P trading, if any changes in energy system and energy market with changes in physical flow of electricity are expected by P2P trading, **it is crucial to explicitly promote DSM, flexible generation, system-driven use of batteries/BEV, smart chargers and real-time/short-time control of generators' and consumers' assets through P2P trading.**

What is the situation for **off-grid P2P trading**? If the prosumers just optimize their bills by supplying each other from their PV and storage (model J1), the result at the DSO area level will not be much different from the on-grid models: the sale and supply will just happen behind the grid connection point instead of over the local grid. In the classical model, one prosumer would sell into the grid, and the other would buy from the grid at the same time. If the prosumers have storage, the internal optimization between them may change storage in- and output over time somewhat, but the total load of their electricity purchase from or sale to the grid may not be very different. The same will be the case if the P2P trading community uses private lines. However, the electricity transport at a very local (sub-transformer/street line) grid level may be reduced, and may reduce the need for reinforcing it – but also the revenues of the DSO. Only the model J2, in which electricity is transported by car – the BEV – may change the timing of electricity feed-in and use, and sometimes even between DSO areas if the buyer is located in a different DSO area than the seller.

Again, if additional new demand is induced by P2P trading (such as EV charging by RES electricity purchased from a newly built PV plant located in the same off-grid area), then physical electricity flow within the area will increase, and may change in the grid outside the area. However, this will not be automatically led by the P2P trading operation per se to stabilize the grid outside the area, unless there are incentives for it.

Would there be **an alternative solution** to P2P trading in the classical supply structure that contributes to grid stabilization? Balancing power markets and VPP that could bundle flexible supply and demand assets can be the solutions that developed in Europe and are developing in Japan, as we discussed in the report from the first year of this study (Ninomiya et al. 2019). But for larger use of flexibility options, especially grid-supportive use, it would need flexible tariffs and/or DSO/TSO remote control just the same as we see needed in P2P trading.

The consumer perspective: a detailed analysis

A study conducted by PricewaterhouseCoopers GmbH (PwC 2016) on behalf of Verbraucherzentrale NRW underlines what has already been mentioned in the previous chapters: The extensive establishment of P2P energy trading using blockchain technology in the energy sector would be accompanied by major changes in the roles of the various players in the energy market. From a consumer perspective, this can have advantages, but also disadvantages.

One conceivable positive consequence for consumers is the reduction in transaction costs due to the elimination of intermediaries. As a result, other system costs could also fall; these include:

- No or lower costs and profit surcharges for companies that have been active in the system up to now but will play little or no role in the system in the future.
- No or lower operating costs for meter reading, billing, etc.
- No effort for dunning procedures, collection procedures
- No costs for payment transactions via banks (especially direct debits from customers)
- Possibly lower network charges
- No/low costs for the certification of green electricity

On the other hand, transaction fees for blockchain transactions as well as computer performance and their energy consumption must of course also be taken into account in order to estimate the *net* cost savings through blockchain. In addition, if P2P trading follows the wholesale market model outlined in chapter 2.1, power grids may need further upgrades, and the corresponding investments will have to be calculated.

Furthermore, Blockchain can increase transparency, as it enables the consumer to exactly retrace where the electricity he or she buys comes from. The transparency also includes the transaction history, which is stored in the blockchain so that it can be evaluated clearly.

In its study, PwC also identified the potential acceleration in the development of prosumers as a further advantage. Consumers thus benefit from a greater variety of offers and lower prices. In addition, blockchain models make it easier to implement community-based citizen energy models. The expansion of renewable energies could be further promoted by the simplified marketing possibilities for decentralized energy producers.

In addition to these basically positive opportunities, the use of blockchain technology can also have negative consequences, at least in terms of risks in view of the limited testing of this technology to date. One assumption made by experts is that blockchain technology may not be sufficiently scalable. The extremely rapidly increasing amount of data places high demands on security, speed, and costs.

Social acceptance is also a potential hurdle, as it is a completely new technology with an entirely new transaction model. A negative attitude, at least in parts of the energy sector, the consumers, and society overall, is therefore not unlikely.

There are open questions with regard to equity and chances of benefitting from the new technology that are not even discussed in the PwC study but are also highly relevant for its acceptance, and even acceptability:

- Will the benefits of the new P2P trading be available to all consumers or only to larger consumers or prosumers that promise higher revenues (i.e., cherry-picking by platform providers or decentralized autonomous P2P networks)?
- Will the transaction costs and finally the electricity costs be transparent, will it be possible to leave P2P networks if not satisfied, and how can excessive costs and profits be avoided (through the market or is regulation needed)?
- How smart are ‘smart contracts’? If the customer does not select the generator(s), from which he or she wishes to buy electricity: How do the smart contracts decide who

receives which electricity from which generator, in a way that minimizes everybody's energy bills, or will some consumers pay more and some less?

As the PwC study further points out, the anonymity of the blockchain concept carries the risk that illegal activities such as organized crime can be handled via the system. Such criminal activities have already occurred with crypto currencies such as Bitcoin.

In addition, the decentralized system of the blockchain without superior authority can also have a negative effect on the consumer, since at least in the models discussed or tested today, there is no responsible body that intervenes to regulate, offers simple services or can make subsequent changes to processes that have already been carried out.

A recurring problem with regard to blockchain technology is, for example, the handling of personal access data from one's own account that a user may have forgotten. In this case, the user irrevocably loses access to the account and the settings, information, and assets stored on it.

Chances	Risks
• **Reduction of transaction costs by bypassing intermediaries** • **Lower prices due to increased market transparency** • **Easy way to become a provider of electricity and services** • **Fundamental simplification of transactions (documents, contracts, payment)** • **Increased transparency through decentralized data storage** • **Flexibility of many products (tariffs) and in change of supplier** • **Strengthening of the prosumer through independence from a central authority (direct purchase/sale of energy)**	• Complete data loss in case of ID loss • Currently high transaction costs for public blockchain • Lack of acceptance by consumers possible • Missing authority in conflicts, no immediate possibility of escalation • Problem of fraud in the transition from the real world to the digital blockchain world (e.g. interface Smart Meter in the blockchain) • Risks due to the lack of long-term experience • Initial technical problems with the first applications possible • Functional inadequacies and security risks due to lack of standards • Electricity network must cope with increased flexibility • Will all consumers/prosumers benefit in the same way, or will some benefit more?

Table 10: Chances and risks of P2P trading (Source: based on PwC 2016)

Note: Risks of data loss, lack of authority, and fraud may be more relevant or only relevant for decentralized autonomous P2P trading models

The judgement as to whether blockchain has more advantages than disadvantages depends on the type of implementation. Applications that focus primarily on the decentralized documentation of transactions will show a positive balance more quickly than comprehensive applications that enable decentralized transactions with Smart Contracts. Private blockchain models (such as those offered by the platform provider in a centrally controlled P2P trading) will probably be associated with lower costs, but with the loss of the principle of decentralized organization. The question also rises, which advantage such private blockchain solutions would have over previous database-based processes, since in particular the aspect of the decentralized and thus manipulation-safe storage of data is pushed into the background.

An application of blockchain technology for P2P energy trading in its most advanced form of the decentralized autonomous approach, as described above, also has long-term social consequences that need to be considered. The independence from human decision-making power promises a non-corruptible transparency and automation of transactions and thus a new quality of security.

In its analysis, PwC even goes so far as to say that blockchain technology makes it possible to create a self-regulated, self-organized economic and social system that is run by computer programs and conducts business on the basis of self-executing digital contracts (PwC 2016: 37). The central challenge is how to implement a social concept without a control mechanism in such a socio-technical system. In social concepts, such a control mechanism has evolved through cultural evolution and has produced a series of interconnected systems that create a degree of elasticity with respect to incorrect or malicious behavior of individual participants. A social interaction creates a relatively stable, fair, and just social system. Technical systems, on the other hand, use deterministic, isolated concepts to make quick decisions that can have severe consequences for the participants (cf. ibid.). As said above, for example, how does the machine decide who receives which electricity from the many generators feeding into the network, at which price? When applying blockchain technologies, it is therefore important to think through and weigh up the question of standards, laws and rules, their feasibility and the regulation of the program code with foresight and wisdom, and to adapt the technology accordingly in order to ensure that the technology serves the users and not vice versa.

Further considerations on potential problems and risks of blockchain technology

In another report, the Research Group on Energy Economics at TU Munich has identified a number of problems and risks of blockchain technology (FfE 2018a: 54 et sqq.; translation by the authors of this study):

1. The discrete blocks and the limitation of the block sizes set limits for the scalability. Currently, only a manageable number of transactions per second can be processed in known networks. The scalability of the technology is still very limited and cannot be solved easily:
   a. Larger blocks allow higher transaction rates in the network, but increase the computational and communication effort for the consensus mechanisms. This can lead to centralization in large data centers and increased energy consumption, especially in the ‘proof of work’ technology, and increase the hardware requirements for participation.
   b. The block size cannot be increased arbitrarily, because otherwise the amounts of data to be sent and stored become too large. The limitation is set by the amount of data that can be transferred. Participants with too low bandwidths would increasingly be excluded from the system.
   c. Due to the constant provision of all information from past transactions in the form of the entire chain, the storage requirements of the nodes involved are constantly increasing.
   d. The more complex the possibilities for Smart Contracts on a blockchain are, the more computing time, duration, and costs rise. This is due to the redundant execution of Smart Contracts on many decentralized computing units.
2. Some blockchain technologies (e.g. Bitcoin) prefer to mine using specialized hardware. Private users can hardly make a contribution to the ‘proof of work’ (PoW). Large mining pools undermine the decentralized idea of technology and aggregate power.

3. The resource consumption of the technology is heavily dependent on the consensus mechanism used. The PoW requires extreme amounts of energy in order to serve blockchains with a large number of validators and correspondingly high competitive pressure (such as Bitcoin or Ethereum).
4. Many components of the blockchain are based on the fact that encrypted data can only be manipulated using disproportionately long and uneconomical computing times. With the development of quantum computers, however, some of the security mechanisms used could be overcome in a relatively short time.
5. Due to the consensus mechanisms, power is unequally distributed within a blockchain network. This can lead to abuse if too many voting shares (e.g. due to computing capacity at PoW) are in the hands of too few people. If an actor can combine more than 50% of the computing capacity within a blockchain network (PoW), the blockchain can theoretically be manipulated.
6. If a user's access data is lost or hacked in a public blockchain, there is no way to restore it.
7. Incorrectly executed transactions (e.g. a typo in the recipient's address) cannot be reversed.
8. Although anonymity in blockchain applications is given by pseudonymization using public key, each transaction can be traced and, if necessary, transaction habits can be derived using big data analyses. If at some point an interface to the identity of the user is established (e.g. the Bitcoin payment of an order with clear names), all past activities can be traced.
9. Depending on the design and application of blockchain technology, a number of legal challenges may also arise. The right to deletion ("right to be forgotten") under EU DSGVO Art. 17 is technically not possible in a decentralized public blockchain at present. There is also no "responsible person". Legal questions regarding Smart Contracts and their compatibility with applicable law also remain unresolved ("Code is Law").
10. Interoperability between different blockchain technologies (e.g. between Bitcoin and Ethereum) has not yet been achieved. Industry-wide or cross-industry standards have not yet been defined.
11. The governance problem exists in public blockchains. Changes to the system infrastructure are only possible if a sufficient number of participants accept the changes. Otherwise a fork may occur. Basic changes (including improvements) are therefore difficult and protracted.
12. In public blockchains, a (monetary) incentive or advantage is always needed for nodes, so that they voluntarily participate in the network. Running other applications than crypto currencies is therefore also not possible without such currencies.
13. Not all consensus mechanisms can be implemented without associated crypto currencies (e.g. Proof-of –Stake, PoS).
14. Regarding the P2P trading itself, the code of Smart Contracts is publicly available. If there are any weaknesses, they can be found and exploited by all network participants. Detailed and time-consuming review processes and quality controls are necessary for correct implementation.

15. Innovations for solving problems often take place under different protocols and are not directly compatible with other chains. The fragmentation and lack of standardization is therefore both an advantage and a disadvantage; while the concepts and the code are openly accessible and developed by many different actors with different goals, they must be adapted for each block chain and inserted into the individual protocols (for example in privacy chains vs. smart contract platforms).
16. Blockchains require a functioning digital infrastructure for mass adaptation in the respective sector.
17. "Security-by-design" is a strength of the blockchain technology. However, security through redundancy in public blockchains is very data and power intensive and therefore fundamentally less efficient than central solutions ("inefficiency-by-design").

4.2 PPAs

4.2.1 Overview of incentives and barriers for market actors in each model

In a similar fashion as for P2P trading, possible incentives/opportunities and barriers/threats of PPAs can also be summarized in the following table.

Germany and Japan:		
Type of market actor	**Incentives and opportunities**	**Barriers and threats**
Small to medium generator or prosumer	• Avoiding costs and risks of participation in auctions for FIP/MP; for on-site PPAs, possibly sharing part of the savings in part of the grid fees, taxes, and levies, depending on legislation • Secure longer-term revenue stream in a post-FIT era	• Risk of receiving lower price than with marketing in the wholesale power market or through auction for FIP/MP • Risk of losing off-taker when the contracted party has financial problems
Wholesale trade company, e.g. VPP operator	• VPP could aggregate smaller generators for PPAs	• same as for P2P model G1
TSO	• Has financial incentive to shift feed-in and loads (demand side management) to avoid bottleneck: can support this through flexible network charges if law allows	• small for on-grid PPAs: may lose revenue if a new generator for PPA is built in the same DSO area as the customer • may lose more revenue through on-site PPAs, depending on how regulated grid revenue depends on transport volume
DSO	• Has financial incentive to shift feed-in and loads (demand side management) to avoid bottleneck: can support this through flexible network charges if law allows	• none for on-site PPAs; may lose revenue through on-site PPAs, depending on how regulated grid revenue depends on transport volume
Electricity supplier	• could be the buyer in PPA contract to secure cheap power for its retail customers	• same as for P2P model G1
Consumer	• Possibly reduced power prices (if PPA uses very favorable production sites); for on-site PPA, saving a high initial capital investment on renewable power plant, and part of the grid fees, taxes, and levies, depending on legislation • Possibility to demonstrate low-carbon electricity supply	• Risk to pay more than with supply based on wholesale market prices

Table 11: Incentive/opportunities and barrier/threats of PPAs

Compared to the cases of a P2P trading discussed above, in the case of PPA, there are far less substantial barriers and threats for all of market actors. This is also true for incentives and opportunities, which can be generally well compatible with the existing market.

4.2.2 Potential positive and negative impacts for markets and the energy system in total

For the analysis, the same criteria apply as for P2P trading (cf. chapter 4.2.1).

1) PPAs could promote post-FIT renewable plants to continue their production and an investment on new renewable plants in a post-FIT era, as both the existing or planned projects (cf. chapter 3) and the analysis of incentives and barriers for market actors in the previous subchapter reveal. There seem to be far less barriers and threats for all actors in the market, suggesting that an implementation of PPA is much easier compared to a P2P trading. This also implies that PPAs could be employed for promotion of renewables in the short to medium term, while at least in Japan P2P trading could be seen as a much longer-term tool in the future, since even PPA has not widely been implemented yet in the country. In other words, over the next decade or so, PPAs could become a main driver to increase renewable energy at a large scale. This would be an important benefit for the energy system in total. At the same time, preparations for P2P trading, addressing a number of issues identified including costs of IT devices, or privacy risks of consumers/prosumers, would proceed for an eventual implementation of P2P trading. P2P trading also seems more appropriate for smaller to medium generators, prosumers, and consumers than direct PPAs. However, green power suppliers concluding PPAs with large generators (such as the Greenpeace Energy example in Germany), and aggregation of generators e.g. through VPP for marketing via PPA, could also enable the use of PPAs for smaller generators and consumers – although not so much for connecting prosumers to each other. A further exception from the empirical finding that PPA has so far mainly been available for big consumers or suppliers is the special model in Germany aiming to enable tenants to purchase electricity from a PV plant on the building they live in (named 'Mieterstrom' in German).

2) In contractual relationships between large generators, suppliers, and large customers, the margins are usually much smaller than in the traditional supply of residential and other smaller final customers. Therefore, the potential economic efficiency gains for society will also be much smaller.

For on-grid PPA, this may mean that smaller incentives and opportunities exist for PPA than for P2P trading involving smaller consumers. This may suggest that some incentives, such as improvement of the existing regulatory framework and legislation, could be needed by policy makers if they want to promote on-grid PPA.

3) A benefit from improved grid integration of variable renewable energies while maintaining grid stability is uncertain, as it will be very case-dependent whether there is an improvement in matching of regional supply and demand when moving from the classical model to the PPA model. As for the P2P, *the operation* of the PPA assets per se will not change physical electricity flows compared to the case, when the RES-E plant would have operated in the classical model too. Any flexible operation, DSM, storage etc. would need to be supported and induced through

other, additional instruments. This will be easier with on-site PPAs than with on-grid PPAs, since in the latter model, often PPA generator and customer may be located far away from each other.

Not in relation to these three criteria, a potential negative impact for the consumers not being able to engage in, or benefit from PPAs, may be that PPA contracts may take away the cheapest sites from public electricity supply. In the auctions for FIP/MP for new RES-E generators for the public electricity supply, then, only the less attractive sites may be left and cause higher prices for the other consumers. This would be a *distributional* effect.

The same would apply if some large consumers secured the production of some of the cheapest post-FIT generators for themselves at a low price. However, as long as the wholesale power price is the benchmark and is sufficient to sustain continued operation of post-FIT plant, this should not be a problem.

Another distributional effect for on-site PPAs, just as off-grid P2P trading, will be that the other connected consumers have to pay a higher share of total grid costs, which the PPA consumer saves.

5 Recommendations on P2P energy trading models and policies

5.1 Recommendations for both countries on models that would be useful in their respective markets by when

In the introduction to this report, we asked ourselves what could be the objectives of P2P trading and PPAs that would advance the energy transition. Supporting the expansion of electricity generation from renewable energies (RES-E) and its integration into the system are the overarching goals. To this end, we assessed whether these new market models would contribute to the following more operational objectives:

- enabling continued operation of RES-E plants after the end of FIT payments;
- financing new RES-E plants without FIP/MP-type payments, as it may be useful and possible in the long run to have a market design integrating RES-E assets without a FIT/FIP/MP system;
- meeting corporate green electricity purchase or decarbonization goals;
- matching supply and demand in total and in regional decentralized power markets;
- grid stabilization via targeted P2P trading.

5.1.1 Useful P2P trading models

As discussed in chapters 2 to 4, there can be both on-grid and off-grid P2P trading models.

For **on-grid P2P trading**, we found that in the short run, only those models will be possible in practice, which are offered by an existing electricity supplier operating a P2P trading platform, or a new P2P platform provider that either can take balancing group responsibility for the participating generators, prosumers, and consumers, or cooperates with a company that organizes balancing group responsibility (Models G1 to G3 in Germany, Model J4 and, if legal preconditions are created, Model J5 in Japan).

- This may reduce marketing and supply costs and margins compared to the classical electricity supply chain, allowing to share the savings between the generators, the customers, and the P2P platform provider.
- For this reason, it can be a model for regional or national marketing of RES-E generators post-FIT or new, non-FIT/FIP RES-E plants; other reasons are that there is a group of customers interested in green and/or regional electricity, including small to medium companies with green electricity purchase or decarbonization goals but that are too small to be offered PPAs; sometimes also customers who like to be part of a community of like-minded energy transition pioneers, such as in the enyway or Sonnen businesses.
- Depending on the relative economic situation and political framework for P2P trading vs. the classical market model and the FIT/FIP scheme, and on how well both the latter are supporting renewable power generation, P2P trading may therefore induce additional generation, e.g. from post-FIT renewable energy plants that would otherwise not have

continued to operate, or from new, non-FIT/FIP/MP renewable energy plants, and new electricity demands such as for BEVs using the additional generation, that would not arise in the classical market model.

- P2P trading usually uses blockchain technology for the economic transactions. In contrast, it does not always require a smart meter but can also be done with standard load profiles.
- Therefore, the operation of a P2P trading scheme will not per se stimulate the use of flexibility options such as DSM, flexible generation, system-driven use of batteries/BEV, and smart chargers. P2P trading will be able to perform this task, if smart meters are installed and incentives for market- or grid-stabilizing feed-in or demand behavior are given, either directly or through variable supply prices and grid fees.
- In this direction, the blockchain infrastructure and smart contracts established for P2P trading could more easily and quickly enable the implementation of flexibility incentives as an additional feature, as soon as smart meters and associated IT devices are used. There are incentives for the balancing group responsible to use these flexibilities.

In conclusion, on-grid P2P trading seems to offer some potential for the continued use of post-FIT renewable energies as well as new investments in renewable energy plants without a FIT/FIP/MP payment, but the future development is difficult to estimate. In addition, the use of flexibility options for grid stabilization will be facilitated through the P2P trading platforms and contracts but needs to be added to P2P trading through separate incentives.

Self-organized, decentralized autonomous models without the support from an external retailer or balancing group responsible are unlikely to flourish for on-grid P2P trading without major changes in legislation and regulation, but can be useful for off-grid P2P trading within a certain site or building behind the grid connection and metering point.

Off-grid P2P trading may be understood as a kind of a multi-party energy management system (N.B. this is also the case for the on-grid models J6, J7 for Japan). Off-grid P2P trading may thus reduce the electricity flow through the connection point with the public grid and thus reduce needs to reinforce distribution grid in very local areas, as it motivates optimization of supply and demand (using batteries) on site. But as for the on-grid P2P trading models, the possibilities for flexibilities in generation, storage, and demand will only be used for market or grid stabilization, if retail prices or grid fees are variable to reflect market prices and grid bottlenecks, or special incentives for individual participants and for their joint purchase from or sale to the grid are offered.

There are also a number of **risks** associated with P2P trading, creating needs for further analysis and development at some points.

- A feature of P2P trading is that the individual consumers can choose to purchase electricity from different generators at different prices. While this provides increased consumer choice, it also raises questions typically associated with it: is it desirable that not all consumers of a retail electricity supplier receive a standardized product? Who will get the best deal? There are uncertainties both for consumers and generators, whether the P2P trading will be economically advantageous compared to the traditional supply model with choice between standardized offers.

- There are also a number of open questions and risks associated with the blockchain technology used for the P2P trading (cf. chapter 4.1.2). However, they may not be so relevant in a model involving a traditional supplier as the P2P trading platform provider (models G1 to G3, J4 and J5), as then the usual regulations for consumer protection relative to electricity suppliers apply.
- Privacy risks of consumers/prosumers may also arise through the use of the smart meters (however, regulation in Germany for the smart meter gateways is very strict, which caused years of delay in smart meter roll-out) or from using a P2P network that is not operated by a registered electricity supplier.

We therefore recommend that policy allows and enables the use of P2P trading of models G1 to G3 and J4 and J5, but closely monitors the development to learn about its potential as well as its possible positive or negative impacts. Further support for appropriate P2P trading models may be useful, if monitoring reveals that other existing options are not sufficiently able to secure the operation of post-FIT plants and to stimulate the construction of new RES-E plants, e.g., if auctions for FIP/MP for the latter have problems in securing the volume of capacity from new plants needed to achieve RES-E expansion targets.

In addition, in order to support the use of flexibility potentials of RES-E generators and particularly of demand and storage, policy should accelerate and support the roll-out of smart meters, especially in Germany which is lagging behind, and other IT needed, as well as their use for stimulating flexibility options. This will be particularly useful for participants in existing or new P2P trading, as the blockchain transaction infrastructure built up for P2P trading makes it easier to integrate the transactions for flexibility as well. In addition, we see a need to support investments in creating flexibility options that can be controlled using the smart meters.

5.1.2 Usefulness of models of Power Purchasing Agreements

On-site PPA, just as off-grid P2P trading, is also attractive since it will (partly) avoid retail electricity prices (incl. grid fees, taxes and FIT surcharge in Japan, but it will not avoid the FIT levy in Germany for PV plants larger than 10 kW) for the PPA parties. In Japan, this model is still the mainstream of PPA, which is relatively easier to be implemented compared to on-grid PPA, since the Japanese electricity market is less matured and the country is not abundant in renewable electricity as much as Germany.

This model would increase the share of grid costs for the other connected consumers to pay, which is a distributional effect. Still, as it is a model that may accelerate construction of RES-E plants, especially building-integrated PV, outside of the FIP/MP system, it should be allowed by laws and regulations.

It could also be coupled with P2P non-FIT/FIP/MP trading for electricity surpluses or even with allowing feed-in of surplus power at a FIP. Otherwise, there is a risk that the full potential for on-site PV will not be used, but only the fraction of the potential capacity that is below a typical daytime load of the site. For example, in Japan, the capacity of on-site PPAs is often intentionally set well below the maximum load of the site.

A special model in Germany is aiming to enable tenants to purchase electricity from a PV plant on the building they live in (the German name for this model is ‘Mieterstrom’, which means ‘tenant electricity’). This is trying to put tenants on par with households owning their house, who can invest in a PV plant and self-consume the power or earn the FIT. However, the rules and economic parameters are currently not supportive enough for mass roll-out of the concept.

On-grid PPA: 1) This can be a useful model for sustaining post-FIT operation of PV or wind power plants; but either the wholesale power price is sufficient to sustain continued operation of post-FIT plant, so that a PPA is not needed; or the wholesale power price is too low or too uncertain, so PPAs can provide certainty or enable the continued operation at all. The question may in that case be: Should this continued operation not be for the benefit of all consumers, who paid for the plants thoughout the FIT period? And if so, how can the benefits and costs be equally shared between all consumers? Theoretically, this may be achievable either through a kind of “macro-PPA” – i.e. the government regulating that TSOs or DSOs, or a public single buyer as in Austria, should buy the power of all post-FIT generators in their area at a negotiated or fixed price and sell it as a certain share of electricity supplied at the average price achieved in the grid area to all suppliers serving customers in the area, or averaged across the country – or through a “2nd FIT period” regulation, which would mean a new but much lower FIT is set or a feed-in price determined by auctions for these generators[5]. Such a follow-up regulation may be needed anyway to ensure continued operation of those generators still fit to produce but not finding a PPA contract, for the benefit of GHG mitigation. So why not apply it for all post-FIT generators? These are questions concerning the sustaining of post-FIT operation of PV and wind plants, which are still left to be answered. The answer probably would need to be given by a political decision.

2) On-grid PPA can also accelerate expansion of new RES-E capacities, since it avoids the need for going through the auction for FIP/MP procedure. This procedure may be too costly or risky for the potential RES-E generators, if the volumes awarded a FIP through the auction are smaller than the supply of new projects. The direct purchase from new non-FIT/FIP/MP RES-E capacities also appears attractive to corporate consumers willing to demonstrate green power procurement (cf. examples in chapter 3).

A distributional problem could be that it may take away the cheapest remaining sites for new RES-E projects from public electricity supply. An alternative could be to not allow further on-grid PPAs, but to offer a special slot in auctions for FIP/MP to customers interested in direct power purchase from new installations. This may ensure that both these consumers and the general public pay the same average price for electricity from new RES-E capacities.

For PPAs too, the useful models should be coupled with smart meters and flexibility incentives, in order to promote the use of flexibilities.

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[5] Note: if the price in the „macro-PPA“ model is fixed and the average price is determined across the whole country, this will be the same as a „2nd FIT period“ scheme.

5.2 Policies and regulations needed for successful introduction of the models recommended

5.2.1 P2P trading

In chapter 5.1.1, we recommended that policy allows and enables the use of P2P trading of models G1 to G3 and J4 and J5, but closely monitors the development to learn about its potential as well as its possible positive or negative impacts.

Are P2P energy trading and PPAs the best solutions to support the expansion of renewable energies in the electricity system and market? Or are there alternatives? Whether concrete policy support for the renewable energy P2P trading business itself may be needed and wanted, will depend on whether there are other options 1) to secure the operation of post-FIT plants, such as a kind of “macro-PPA” or “2nd FIT period” regulation (see chapter 5.1.2), and 2) to stimulate the construction of new RES-E plants, e.g. via a sufficient volume of capacity awarded through auctions for FIP/MP for the latter. These are, in the end, political decisions on which route for expansion of renewable energies is preferred:

- Should the target be to end fixed FIT schemes as well as auctions for FIP/MP for new renewable power plants, and to support market solutions such as P2P trading and PPAs for certified green electricity instead?
- Or is it wiser to secure politically defined paths for expansion of the various types of renewable energies through auctions for FIP/MP and continued fixed FIT schemes for prosumer-scale to medium-sized PV, and including support for post-FIT generators?

Proponents of the first paradigm argue that RES-E generation is ripe for the market, and markets are more efficient in reducing overall costs. Opponents, who may support the second paradigm instead, argue that although some RES-E technologies are now cheaper than some conventional power plants on a full-cost basis, i.e., if the latter have to be built now, the *existing* conventional power plants are often still cheaper on a marginal cost basis than *new* RES-E facilities. There is broad agreement that *existing* RES-E plants should be integrated into the market as much as possible. On the other hand, one may argue that a scheme that integrates *all* renewable energy generators in the supply to *all* consumers, so all benefit and pay equally, is fairer than a system in which *some* consumers enter into bilateral contracts with *some* generators. The latter may provide higher benefits to the quick, the big, and those who can invest time in searching for the best deal, and (relatively) higher costs for all the others.

If the monitoring reveals that other existing options are not sufficiently able to secure the operation of post-FIT plants and to stimulate the construction of new RES-E plants, a P2P trading scheme can be considered as a functional option which could be developed by the following policy actions or instruments to support:

In Japan, they may include specifically 1) revision of the existing measurement law, which requires too high precision, so the cost is too high to conduct P2P trading by prosumers; 2) establishment of a legal/regulatory framework to address the privacy risk associated with individual private data collected by smart meters; 3) establishment of an appropriate level of the grid fee, which currently is often considered too high for very small amounts of electricity traded by prosumers; 4) clarification of an imbalance responsibility of the P2P platformer; 5) clarification of the requirement of electricity retail registration for P2P platformer and prosumer; 6) revision of the existing regulation on partial electricity supply to small consumers/prosumers by multiple suppliers (specifically in the case of model J5, so that this model would be allowed by law)(METI, 2019).

In Germany, there are a growing number of pilot or full commercial schemes for P2P trading already in operation, as discussed in chapter 3. So there may not be the need to remove any legal barriers or to provide clarifications about retail licenses or balancing group responsibilities. However, as we have seen, the halt that was put on the smart meter roll-out (see chapter 2.3.1 above) meant that many providers of P2P trading platforms also or exclusively offer the trading to customers with standard load profiles. However, now the competent authority officially stated that the preconditions are fulfilled, so that the smart meter roll-out can start, and they can be used for P2P trading. In addition, the government could develop standard rules / templates for smart contracts, which particularly meet data and consumer protection requirements (cf. policy suggestion 2) for Japan). Although the smart meter gateways now certified for the German market are required to meet high data security standards for data storage and transmission, the protection of data for use in the market, including P2P trading, may need to be regulated further.

We also recommended in chapter 5.1.1 that policy should not only accelerate and support the roll-out of smart meters, no matter if for P2P trading or not, but also their use for stimulating flexibility options. In addition, we see a need to support investments in creating flexibility options.

Regarding what are appropriate policies to stimulate the investment in flexibility options and their use for market balancing and grid stability, there is an ongoing debate particularly in Germany. Some experts assume that the best way would be to develop shorter-term trading, also for smaller assets, which could reduce the need for balancing markets and VPPs, and would be combined with a general electricity market model with capacity markets. This may be technology-neutral and thus stimulate development of the cheapest options both for electricity generation and for flexibility, and possibly even for energy efficiency schemes, providing NEGAWatt capacities.

Other experts argue in favor of keeping the energy-only market design but adding specific and detailed flexibility instruments. These would need to be technology-specific, because different options will be needed for different purposes, have different costs and barriers, need action by different market actors, and may have different potential for future development and cost reductions. A “neutral” capacity market may in fact favor some established technologies but hinder the development of alternatives with more promising future potential.

Some experts point to the fact that storage, including through electrolysis, is treated as a consumer and has to pay all taxes and levies. However, we recommend not to alleviate this problem by reducing electricity prices for all consumers: electricity still is the most costly of the standard energy carriers, and its price should incentivize energy efficiency and new generation from renewable energies. Whether storage facilities run by energy companies (e.g. TSO, DSO, or suppliers) should receive selective exemptions from taxes and levies, will need careful analysis. It could be an instrument to stimulate both investment in, and operation of storage. However, there should also be incentives for DSM, which is usually cheaper than storage.

Flexibility options and instruments can be used to stabilize either markets – through improved balancing – or grids. Hence, their use can be stimulated or organized by both suppliers or TSOs and DSOs. Variable electricity prices for consumers may incentivize DSM and market-oriented use of storage; in addition, differentiated prices or grid fees could be offered for allowing remote control of assets by suppliers or grid operators in order to optimize the balancing group or stabilize the grid, respectively.

In Germany, the SINTEG pilot projects have been testing new forms of flexibility markets also for gris stabilization since 2018. The evaluation of their usefulness and impacts is still ongoing.

However, regarding the special aspect of flexibility markets for redispatch, the German energy regulation authority argues strictly against these and other business models for grid-supportive flexibility. It commented on the P2P trading pilot project by Sonnen and TenneT as follows (BNetzA 2019; summary and translation by the authors of this study): The Sonnen/TenneT pilot project ended in Mai 2019. It showed that it is technically possible that batteries can be used for redispatch. However, all plant operators are obligated today by law to contribute to system security. No payment is legally allowed for a service (offered in competition, with the chance of earning a profit), but only a compensation for any negative impacts is allowed. Hence, no business models for grid-supportive flexibility are possible. These would in the BNetzA's view also not be useful, as the procurement of redispatch through markets bears the risk of strategic behavior (called Increase-Decrease-Gaming).

5.2.2 PPAs

For deciding on whether to support the development of PPAs through policies, and if so, how to support it, policy should take the same principal decision: does it wish to continue with a FIT/FIP/MP scheme, including auctions for FIP/MP, or rather with market solutions?

The crucial requirement for broad success of PPAs is that the cost of FIT-expired renewable energy generators or even of new generators is lower than the supply prices achievable or consumers in the general electricity market or at least the green electricity market. Currently, given the projects mentioned in chapter 3, this seems to be the case for on-site PPAs using PV in both Germany and Japan, and for on-grid PPAs with FIT-expired wind power plants and new large-scale PV in Germany.

Even with a continued FIT/FIP/MP scheme, there may be market niches for these types of PPAs. Just as for P2P trading, we recommend that policy-makers should continue to legally allow and enable the use of PPAs but closely monitor their development.

For example, if on-site PPAs grow a lot in capacity, this may erode the revenues of DSOs and TSOs. It may create the need to change the grid fees for consumers benefitting from such PPAs, so that they cover a fair share of grid costs. In Germany in any case, the model that has been created by law o supply tenants from a PV plant on the roof of the building they inhabit (called "Mieterstrom" in German) should be improved to make it more successful. Japan may consider to analyze the usefulness and feasibility of similar on-site models for multi-family houses.

If, on the other hand, it turns out that on-grid PPAs are not sufficient to support the continued operation of a large share of the FIT-expired plants, policy may need to create other forms of support, e.g. to install one of the alternatives discussed in chapter 5.1.2: 1) a kind of “macro-PPA” regulation or 2) a “2nd FIT period” scheme.

As discussed in chapter 5.1.2 as well, an alternative to on-grid PPAs for new investments without the FIP could be to offer a special slot in auctions for FIP/MP to customers interested in direct power purchase from new installations. This may ensure that both these consumers and the general public pay the same average price for electricity from new RES-E capacities.

6 Conclusions, Recommendations and further needs for research

6.1 Conclusions and recommendations for P2P trading and PPAs

This paper has examined a series of questions on P2P trading and PPAs set at the beginning, which concern purposes/objectives of P2P trading and PPAs, models of P2P trading and PPAs, preconditions for the implementation of the models, current status of the development in Germany and Japan, incentives/opportunities and barriers/threats for market actors, potential positive/negative impacts for markets and energy system, and opportunities/threats for market actors and consumers/prosumers, in order to draw recommendations on P2P trading and PPAs and policies needed for their successful implementation.

Purposes/objectives of P2P trading and PPAs

The purposes/objectives of P2P trading have been identified as;

1) enabling the continued economic operation of the post-FIT renewable plants, for which their FIT support period ended; their numbers and capacity will be increasing, particularly for wind and solar plants from 2021 in Germany, and a large number of residential roof-top solar plants even from 2019 in Japan;
2) financing new renewable power plants in a post-FIT era without FIT/FIP-type payments, as it may be useful and possible in the long run to have a market design integrating renewable assets without a FIT/FIP scheme;
3) meeting corporate green electricity purchase or decarbonization goals;
4) matching supply and demand in total and in regional decentralized markets;
5) grid stabilization via targeted P2P trading.

Similarly, the purpose/objectives of PPAs are found as;

1) the promotion of newly built renewable power plants over the longer period in a post-FIT era, providing security of price and green electricity supply for both, generator and buyer;
2) supporting continuous operation of “FIT-expired” renewable energy plants without explicit financial support from the public sector or energy consumers;
3) meeting corporate green electricity purchase or decarbonization goals.

However, several distinct differences between P2P trading and PPAs are highlighted, which are the capacity size of power plants (typically those in PPAs are much larger than in P2P), the type of consumer (the consumer/buyer side of PPAs is likely to be a large organization which is typically larger than P2P, or a green electricity supplier, whereas it is often smaller consumers for P2P trading), and the duration of contracts (duration of PPAs is normally much longer, for instance 3 to 20 years, which is longer than P2P trading contracts that probably usually have the same duration as normal supply contracts). All of these differences imply that an amount of electricity traded under a P2P trading contract can be far smaller than in PPAs.

Models for P2P trading and PPAs

A number of models for P2P trading have already been both theoretically proposed and practically tested in Germany and Japan. In this paper, they are recategorized according to centrality of whole system of operation, focusing on who has operational responsibility of network, between a centralized model (controlled P2P network model) and a decentralized model (decentralized autonomous P2P network model). The controlled P2P network model is further classified into three sub-category models with respect to the object of each model which are; Wholesale market model, Regional/local electricity procurement model and P2P trade serving grid stabilization model. In the same way, the decentralized autonomous P2P network model is further sorted into two sub-category models between on-grid trading and off-grid trading (local microgrid model). As a result, in total, five categories of models of P2P trading are identified for Germany and Japan, which are summarized in Table 2 in chapter 2.2.2.. The models proposed in Germany cover all five categories (specifically, Model G1 to G5 for each category), while the models proposed in Japan are sorted into two models (Model J1 -3 into the off-grid model within the decentralized autonomous P2P network model and Model J4 -J7 into the wholesale market model within the controlled P2P network model).

PPAs can simply be distinguished into on-site and on-grid PPAs.

Preconditions of P2P trading and PPAs

With regard to the preconditions of P2P trading, a large-scale deployment of smart meters, also known as ‘intelligent metering systems’ in Germany, is identified as the primary precondition to implement P2P trading with its full potential of supporting flexible markets and grids. The current status and plan of smart meter roll-out in Germany and Japan highlights a clear difference between two countries that an installation of smart meters is expected to be completed by 2024 in Japan, whereas it is expected by 2032 in Germany. This implies Japan is, at least in a technological infrastructure basis, in an advanced position for an implementation of P2P trading in nationwide scale compared to the case of Germany. In Germany, there are now P2P trading models working with standard load profiles instead of loads measured and transferred by smart meters. However, the roll-out of smart meters now started in Germany.

The second key precondition is a digital system for data transmission and handling with an economic transaction system, which often employs a blockchain technology, but other systems using a central database and data processing technologies and software would be feasible too.

Current status of development of P2P trading and PPAs

The current status of development of P2P trading in Germany is quite promising. There may currently be more than 15 schemes in total. Most of them are on-grid P2P trading controlled by a utility or a new, specialized platform provider. While most of them are pilot projects, there are full commercial products of P2P trading for renewable electricity available from at least two providers. In Japan, only a few numbers of projects have been developed on a pilot basis. None of them are commercialized yet and have opened tangible results in public. The stage of the development of P2P trading is still at a very beginning at least in Japan.

Regarding PPAs, the examples in Germany indicate that PPAs have been developed in the country, though not as much as the Netherlands and the UK. It is expected to grow increasingly, especially for FIT-expired plants, but also for new PV plants that wish to avoid the cumbersome auctioning process and the risk not to be awarded. In Japan, the development of PPAs is behind Germany but likely to grow in the near future.

Incentives and barriers of P2P trading and PPAs for market actors

In terms of incentives and barriers of P2P trading for market actors, the most heavily impacted area would be the business opportunities of traditional electricity retailers. There would be the significant risk of losing their business margin as their customers move to P2P trading. Wholesale trade companies, including VPP operators, would also be affected since the direct P2P trading will reduce their business opportunity. Therefore, the traditional electricity retailer and the wholesale trade company would have a strong incentive to become P2P platformers themselves to avoid losing their business margin; that has actually been observed in Germany and Japan. In contrast, small to medium renewable generators, prosumers and consumers would have substantial positive opportunities to enter P2P trading. They can avoid the margin of classical electricity supply and share these savings between them, if the costs and the risks associated with an implementation of P2P trading are effectively addressed. Risks include those of privacy and data security as well as other potential risks of blockchain technologies. In addition, P2P platformers and P2P platform technology providers would see enormous business opportunity in the field of P2P trading.

The impacts on TSO and DSO would be a mixture of positive opportunities and threats. This is because it is found that on-grid P2P trading per se is unlikely to change anything in physical flows of electricity compared to the classical electricity market model, unless either the P2P trading explicitly includes or induces additional demand/supply changes through DSM, flexible generation, system-driven use of batteries/BEV, or they are induced otherwise by grid operators or government policies. It would, therefore, per se not provide any additional benefits for the alleviation of grid bottlenecks and the grid integration of renewable energy without additional measures to induce changes in demand/supply. Therefore, the impact on TSO and DSO is depending on whether or not additional demand/supply change can be induced by supplemental measures associated with P2P trading.

The incentives and barriers for on-grid PPAs are quite similar, but their impacts are far less substantial for all of the market actors, implying that PPAs are generally well compatible even in the existing market.

On-site PPAs as well as off-grid P2P trading are particularly attractive for the parties involved, since they will (partly) avoid retail electricity prices (incl. grid fees, taxes and FIT surcharge in Japan, but in Germany, they will not avoid the FIT surcharge for PV plants larger than 10 kW) for the parties.

Impacts of P2P trading and PPAs for markets and the energy system in total

The already existing P2P trading business models and PPA contracts in both countries indicate that both could contribute to the continued use of post-FIT renewable energies as well as new investments in renewable energy plants without a FIT/FIP/MP payment. This will be increase the amount of renewable energy in the system and therefore benefit society. If both models reduce the margins of classical electricity supply, as some P2P trading schemes in Germany seem to indicate, this will benefit society too.

However, as stated above, neither on-grid P2P trading nor on-grid PPA models will per se contribute to market or grid stabilization through supporting the use of flexibility options in their operation. Incentives for generators and consumers in this direction will need to be added the same as in any other market and supply model. To the extent that P2P trading accelerates the installation of smart meters, it will also enhance the possibilities for supporting flexibility options through its smart contracts and blockchain transaction infrastructure. If off-grid P2P trading and on-site PPAs involve storage and an energy management system between P2P trading participants or within the PPA site, this is likely to lead to some grid stabilization effects at the local (at least substation) level.

To the extent that customers in on-site PPAs as well as off-grid P2P trading save grid fees, taxes, and FIT surcharges, this would cause a distributional effect, since the other connected consumers would have to pay a correspondingly higher share of total grid costs and FIT surcharge, and the community of taxpayers will lose a certain amount.

Useful models of P2P trading and PPAs

Insofar as they contribute to the objectives listed above, P2P trading and PPA models will be useful.

For on-grid P2P trading, we found that in the short run, only those models will be possible in practice, which are offered by an existing electricity supplier operating a P2P trading platform, or a new P2P platform provider that either can take balancing group responsibility for the participating generators, prosumers, and consumers or cooperates with a company that organizes balancing group responsibility (Models G1 to G3 in Germany, Model J4 and, if legal preconditions are created, Model J5 in Japan).

Self-organized, decentralized autonomous models without the support from an external retailer or balancing group responsible are unlikely to flourish for on-grid P2P trading (Model G4) without major changes in legislation and regulation, but can be useful for off-grid P2P trading (Model G5 and Model J1 to J3) within a certain site or building behind the grid connection and metering point.

Both on-site and on-grid PPA models can also be useful for sustaining post-FIT operation of PV or wind power plants and accelerate expansion of new RES-E capacities.

However, the open questions as well as potential risks and distributional effects mentioned above should be considered when assessing the usefulness of these models.

Policy recommendations regarding P2P trading and PPAs

Are P2P energy trading and PPAs the best solutions to support the expansion of renewable energies in the electricity system and market? Or are there alternatives? Whether concrete policy support for the renewable energy P2P trading business itself may be needed and wanted, will depend on whether there are other options 1) to secure the operation of post-FIT plants, such as a kind of “macro-PPA” or “2nd FIT period” regulation (see chapter 5.1.2), and 2) to stimulate the construction of new RES-E plants, e.g. via a sufficient volume of capacity awarded through auctions for FIP/MP for the latter. These are, in the end, political decisions on which route for expansion of renewable energies is preferred:

- Should the target be to end fixed FIT schemes as well as auctions for FIP/MP for new renewable power plants, and to support market solutions such as P2P trading and PPAs for certified green electricity instead?
- Or is it wiser to secure politically defined paths for expansion of the various types of renewable energies through auctions for FIP/MP and continued fixed FIT schemes for prosumer-scale to medium-sized PV, and including support for post-FIT generators?

It will depend on such general political decisions and paradigms, to which extent policy will need to and should support the wide-scale implementation of the useful models identified before. Even if a general decision towards FIT schemes and auctions for FIP/MP is taken, P2P trading and PPAs may be useful in boosting renewable energy development further.

Since there are a number of open questions and risks still to be clarified or resolved, we recommend that policy allows and enables the use of P2P trading of models G1 to G3 and J4 and J5, but closely monitors the development to learn about its potential as well as its possible positive or negative impacts. Further support for appropriate P2P trading models may be useful, among other policy options, if monitoring reveals that other existing options are not sufficiently able to secure the operation of post-FIT plants and to stimulate the construction of new RES-E plants, e.g., if auctions for FIP/MP for the latter have problems in securing the volume of capacity from new plants needed to achieve RES-E expansion targets.

In addition, in order to support the use of flexibility potentials of RES-E generators and particularly of demand and storage, policy should accelerate and support the roll-out of smart meters, especially in Germany which is lagging behind, and other IT needed, as well as their use for stimulating flexibility options. This will be particularly useful for participants in existing or new P2P trading, as the blockchain transaction infrastructure built up for P2P trading makes it easier to integrate the transactions for flexibility as well. In addition, we see a need to support investments in creating flexibility options that can be controlled using the smart meters.

The required specific policies to enable the use of P2P trading of model J4 and J5 in Japan have been identified, which include those related to the existing measurement law, privacy risk, grid fees, imbalance responsibility of P2P platformers and the existing regulation on partial electricity supply to small consumers by multiple suppliers.

For Germany, as the growing number of pilot or fully commercial schemes shows, on-grid P2P trading is already possible. Policy should promote their coupling with flexibility options, i.e. by accelerating smart-meter roll-out. In addition, the government could develop standard rules / templates for smart contracts, which particularly meet data and consumer protection requirements.

For PPAs, we also recommend that policy-makers should continue to legally allow and enable the use of PPAs but closely monitor their development and impacts, as well as potential alternatives.

6.2 Outlook on further fields of digitalization and the energy transition

In this study, we analyzed just a few potential uses of digitalization for the energy transition that may be important for the further development and system integration of renewable energy sources: Virtual Power Plants (VPPs) in the first year (Ninomiya et al. 2019), and P2P trading as well as PPAs in the second year. However, there are many more potential uses of digitalization, and policy-makers as well as energy market actors have to further analyze them. For example, is there a roadmap for the digital transformation of the energy sector and which needs and options for action result from this for the different actors? For as Preuss et al.(2017) notes not without justification: "The term 'digitalization' no longer describes a technical process, but an economic, social and individual change in the perception and shaping of the world. Above all, networking has enormous social and economic effects. This means that the change is happening between the utility company, its customers and new market participants." (Preuss et al. ibid.: 16, translation by the authors). The traditional energy supply companies in particular are affected by the changes in the energy market that P2P trading and blockchain potentially entail and must position themselves accordingly.

In this context, Doleski (2020) argues for the formulation of possible reference targets along the energy industry value chain and identifies potential fields of activity and action regarding the use of digitalization as shown in Figure 5. Still, these fields are likely to be far from a comprehensive picture of the potential uses of digitalization for the energy transition.

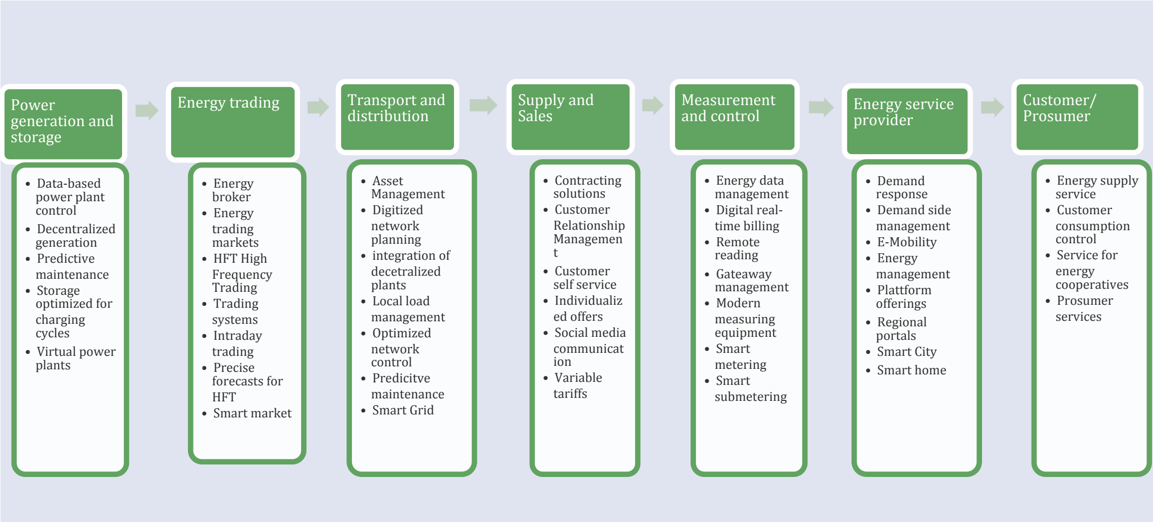

Figure 9: Possible fields of activity for the use of digitalization

Source: own graphics based on Doleski (2020: 50)

However, the analysis of all these options is beyond the scope of this study.

6.3 Further research needs

This paper has focused on a range of aspects of P2P trading and PPAs which is one of the series of outputs by the 2nd year activities of GJETC. This can be seen as a sequential paper to Ninomiya et al. (2019) on VPPs, which is an output of 1st year activities of GJETC. However, we need to notice that VPP, P2P trading, and PPAs are merely a part of the broad opportunity of digitalization for the energy transition. Due to the very wide application potential and very fast development of digital technology, it is not easy to grasp the perspective of linkage between digitalization and the energy transition. On the other hand, it calls for strong efforts of academia including the GJETC. We shall seek a way to bring the full benefit of digitalization to the energy transition of both countries though further research.

- What other applications and benefit but also challenges of digital technology for the energy transition are anticipated?
    - For example, Home Energy Management Systems (HEMS) in Japan/Smart Home Systems in the EU, Building EMS (BEMS) in Japan/BACS – Building automation and control systems in the EU, and other optimization systems for individual premises, city districts, or even smart cities are one example.
- Which application would bring larger benefits and thus should prioritized?
- One aspect we were not able to address is the energy and resource use caused by digitalization, and how it could be reduced.
- In which of these fields do Germany and Japan already cooperate, and what are further promising areas of cooperation?

7 Bibliography

Agentur für Erneuerbare Energien (AEE) (2018): Metaanalyse: Die Digitalisierung der Energiewende. Forschungsradar Energiewende (in German).

Bloomberg NEF (2019): Corporate Energy Buying Surged to New Record 2018. New York, London. https://about.bnef.com/blog/corporate-clean-energy-buying-surged-new-record-2018/

Buchmüller, Christian (2018): Plattformökonomie und Blockchain-Technologie. Neue Impulse für die Peer-to-Peer-Lieferung von Ökostrom?. In: EWeRK, Zeitschrift des Instituts für Energie- und Wettbewerbsrecht in der Kommunalen Wirtschaft e.V., 18. Jahrgang, Heft 4, S. 117-125. Nomos Verlagsgesellschaft. Baden-Baden (in German).

Bundesnetzagentur (2019): Die Blockchain-Technologie. Potenziale und Herausforderungen in den Netzsektoren Energie und Telekommunikation. Bonn (in German).

Bundesnetzagentur/Bundeskartellamt (2019): Monitoring report 2018 in accordance with section 63(3) in conjunction with section 35 of the Energy Industry Act (EnWG) and section 48(3) in conjunction with section 53(3) of the Competition Act (GWB). Editorial deadline: 29. May 2019. Bonn.

Doleski, Oliver (2020): Energieversorgungsunternehmen neu denken: Utility 4.0. In: Doleski, Oliver (Editor) (2020): Realisierung Utility 4.0 Band 1. Praxis der digitalen Energiewirtschaft von den Grundlagen bis zur Verteilung im Smart Grid. Springer Vieweg. Wiesbaden. pp. 3-62 (in German).

EnergieAgentur.NRW (ea.nrw)(2020): Innovation&Energie. Das Magazin der EnergieAgentur.NRW. 1/2020. Düsseldorf: EnergieAgentur.NRW (in German).

Energie&Management (2019): “Viel Traffic bei PPA bereits jetzt zu spüren”. PPA Barometer vom 01. Juni 2019. (in German)

EnergyBrainpool (2019): Power Purchase Agreements II: Marktanalyse, Bepreisung & Hedgingstrategien. White Paper. Berlin (in German).

Enyway (2019): Whitepaper Blockchain Ökosystem. Version 1.0.3 vom 27.05.2019. Hamburg (in German).

FfE (Forschungsstelle für Energiewirtschaft e.V.) (2018a): Die Blockchain-Technologie. Chance zur Transformation der Energieversorgung? Berichtsteil: Technologiebericht. München (in German).

FfE (Forschungsstelle für Energiewirtschaft e.V.) (2018b): Die Blockchain-Technologie. Chance zur Transformation der Energiewirtschaft? Berichtsteil: Anwendungsfälle. München (in German).

GJETC (2019): Digitalization and the Energy Transition: Virtual Power Plants and Blockchain. Report on analysis in Japanese FY 2018: The role and status of Virtual Power Plants and blockchain technology. Study for the GJETC, adopted and commented at the 6th meeting in March 2019.

Peer-to-Peer (P2P) electricity trading and Power Purchasing Agreements (PPAs)

Hilpert, Johannes (2018): Rechtliche Bewertung von Power Purchasing Agreements (PPAs) mit erneuerbaren Energien. Würzburger Studien zum Umweltenergierecht Nr. 12. Stiftung Umweltenergierecht. Würzburg (in German).

IRENA (2018): Corporate Sourcing of Renewables: Market and Industry Trends – REmade Index 2018. International Renewable Energy Agency, Abu Dhabi.

Kreuzburg, Michael (2018): Rechtliche und marktorganisatorische Anforderungen an den P2P-Stromhandel. Frankfurt School Blockchain Center. FSBC Working Paper. Frankfurt (in German).

METI (2019): Business model classification on advanced distribution sector. A presentation at Study Group on the Approach to New Power Platforms Using Next-Generation Technology. Ministry of Economy, Trade and Industry, Japan. 10 May 2019 (in Japanese). https://www.meti.go.jp/shingikai/energy_environment/denryoku_platform/pdf/007_03_00.pdf

Minna Denryoku (2018): Commercialisation of traceability on electricity trading with blockchain technology. Press Release. 5 December 2018 (in Japanese). https://minden.co.jp/personal/wp-content/uploads/2018/12/release_20181205.pdf

Miyake, Seiya (2019): Supply of traceable electricity to maximise the value of renewables. A presentation at the committee meeting at METI. 25 July 2019 (in Japanese). https://www.meti.go.jp/shingikai/enecho/denryoku_gas/denryoku_gas/seido_kento/pdf/033_06_01.pdf

Ninomiya, Y., Schröder, S., Thomas, S. (2019): Digitalization and the Energy Transition: Virtual Power Plants and Blockchain. Tokyo, Wuppertal: IEEJ and Wuppertal Institute.

NTT Facilities (2019a): Supply F-Green electricity to SUBARU. Press Release on 29 May 2019. (in Japanese) https://www.ntt-f.co.jp/news/2019/190529.html

NTT Facilities (2019b): Supply F-Green electricity to Dai-ichi Sankyo Chemical Pharma. Press Release on 8 October 2019. (in Japanese) https://www.nttf.co.jp/news/2019/191008.html

Pimentel, David (2018): Japan’s Kansai Electric Power Co. To Trial P2P Renewable Energy Trading. Block Tribune. 25 April 2018. https://blocktribune.com/japans-kansai-electric-power-co-to-trial-p2p-renewable-energy-trading

Power Ledger (2019): Power Ledger and KEPCO bring P2P energy trading to Osaka, Japan. Press release on 12 August 2019. https://www.powerledger.io/article/power-ledger-and-kepco-bring-p2p-energy-trading-to-osaka-japan

Preuss, S., Rauschert, A., Köhler-Damm, A., Riemer, S., & Seidel, M. (2017). Energieversorger 4.0: Studie zur Digitalisierung der Energieversorger – In 5 Schritten zum digitalen Energiemanager. Studie. Leipzig: QUANTIC Digital GmbH. https://static1.squarespace.com/static/55c46d75e4b09468e6fb147e/t/58ecf2d7cd0f6874ad476903/1491923693130/Energieversorger+4.0+-+Studie+zur+Digitalisierung+der+Energieversorger_QUANTIC+Digital.pdf (in German).

Peer-to-Peer (P2P) electricity trading and Power Purchasing Agreements (PPAs)

PwC (2016): Blockchain – Chance für die Energieverbraucher?. Kurzstudie für die Verbraucherzentrale NRW. Düsseldorf (in German).

Tanaka, Kenji (2019): Electricity distribution and P2P-blockchain-electricity business in a post-FIT era. Ohmsha Publishing. Tokyo. 2019 (in Japanese).

Wuppertaler Stadtwerke (WSW) (2020): wsw.info. Wuppertal: WSW (in German).

Peer-to-Peer (P2P) electricity trading and Power Purchasing Agreements (PPAs)