D2.1 Guidelines for the implementation of new business models

Final Version

Deliverable

Antonioli Mantegazzini, Barbara : *Lecturer and researcher in Public Economics SUPSI*

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	Date	Person(s)	Organisation
Author(s)	2019-01-07	Barbara Antonioli Mantegazzini	SUPSI
Verification by	2019-01-21	Susen Döbelt	TUC
Approval by	2019-01-28	Maria Kreußlein	TUC

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ABOUT THE NEMoGRID PROJECT

The NEMoGrid Project is mainly focused on the definition of innovative business models that could ease the penetration of renewables into the distribution grid, with a particular emphasis on the definition of a peer-to-peer strategy based on the blockchain technology. The new business models will encourage the active participation of citizens and the assumption of their new role of prosumers, by allowing them to enter new markets as players. Among the tested scenarios, the most innovative one will be based on a peer-to-peer market. In this case, new decentralized platforms based on the blockchain technology will allow zero marginal cost transactions. In order to test the new business models effectiveness, a simulation framework will be developed. Each scenario will be evaluated base on a number of KPIs. Existing demo sites in Rolle (CH), Björklinge (SE) and Wüstenrot (DE) will be used to validate the business model that gives the best simulation results. Real loads will be controlled by the algorithms developed in the simulation phase. Technical developments within NEMoGrid will be supported with user research, gathering empirical data on prosumers decisions and interactions. The results will be used to develop an adoption model and to continuously refine the simulations.

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PREMISE

The analysis and forecasts presented in work package (WP) 1 has pointed out several key information:

- The average price for electricity will rise significantly by 2030. This is mainly due to the variation of fixed cost (in particular the grid ones) and to the increasing weight of tax on fuels and ETS. At the same time, fuel cost will decrease.
- The average cost of PV systems, summarized by the LCOE, is strongly declining and this trend will realistically continue also in the next decade. This is particularly true for the south of Europe.
- Concerning storage, assuming continued electric vehicle sales growth, costs near to $200 per kWh are possible without further improvements in the cell chemistry.

The above-mentioned results, added to the recent mega-trends for the energy market – decarbonisation, decentralization and digitalization – represent the basis for the definition of new, alternatives energy market architecture and design, where innovative business models permit to take advantage of all the emerging opportunities, giving room likewise to private, bottom-up solutions. This also implies as a prerequisite the adoption of a clear and effective regulatory framework, where traditional and novel players find their right place and role, coordinated by public bodies and institutions. The following sections are dedicated to the description of such possible business models.

1 INTRODUCTION: GENERAL BACKGROUND AND POSSIBLE DEVELOPMENTS

Governments across the OECD (Organisation for Economic Co-operation and Development) are committed to ambitious reductions in CO_2 emissions. Electricity is central to this agenda and huge quantities of low carbon investment, mostly in renewable power plants, are needed. Therefore, the energy industry is changing and the new challenge seems to be the provision of affordable, sustainable and secure electricity supply in a market where production, transport and consumption are rapidly evolving.

The growing decentralisation of electricity production, mainly with the increasing use of micro-renewables, is pushing the transition towards a smart energy system, more and more digitalized, calling for a market redesigning.

The dominant paradigm for production and supply which is mainly large-scale and fossil-fuel based, where consumers are still viewed as passive actors and the Distribution Network Operator (DNO) is a monolithic, classic operator that manages the infrastructure and where utilities have their own consolidated and remunerative business model is under great pressure. This model realistically will be no more applicable in the future. Moreover, traditional business models insufficiently consider stakeholders analysis, externalities and spatial optimality given the existing network. Therefore, a new generation of business models, considering all these elements, is needed (see Bridge Horizon 2020 Working Group on Business Models conclusions and recommendations).

The wide scale deployment of distribution-connected renewable generators and the major changes in new technologies will affect how energy is bought and consumed, calling for new, challenging roles for major actors currently involved, mainly "prosumers" (a mix between consumers and producers) and DNOs, whose importance is becoming more and more strategic. In particular, mainly because of the merit order effect, (Sensfuß, Ragwitz and Genoese 2008;Cludius, Hermann, Matthes and Graichen 2014;Clò, Cataldi and Zoppoli 2015). Transmission System Operators (TSOs) and DNOs will have a more prominent role in ensuring the smooth working of the system. DNOs are evolving into DSOs (Distribution System Operators): from the control and maintenance of distribution network to a more active role in managing local electricity generation and use. At the same time, the emphasis on management and coordination of the system for the TSOs is increasing too. Simultaneously, the combination of regulatory frameworks favoring the introduction of renewables sources and progress in Information and Communication Technology (ICT) in reducing the fixed cost of entry into the market determined the emergence of new players in RES deployment as well as in the management of variability through demand response, storage or capacity provision. As we will see in the next sections, a huge increase in the complexity of the market leads to an increase in the importance of the coordination activity.

While there is widespread consensus about the depth of the disruption under way in the electricity sector, a consensus on a new paradigm is still some time away. Nevertheless, elements of exciting research begin to emerge in the field of empirical as well as in normative analysis.

Within this renewed environment, according to the most recent EU energy regulations and directives – the "*Clean Energy for all Europeans package*"[1] -, an interesting and challenging electricity market design should be based on the extended opportunity for prosumers to buy, sell or exchange self-produced electricity within the market, fully interacting with each other, individually or through new players such as local energy communities or aggregators.

This involvement could give room for an emerging peer-to-peer market, at the beginning at a small-case community, then on a more extended scale, taking advantage from innovative technologies such as more convenient storage facilities and, in a broader sense, the blockchain, and a form of distributed ledger design. All of these developments will significantly change the

[1] The package includes 8 different legislative texts as shown below (as of December 2018):

- Energy Performance in Buildings Directive
- Renewable Energy Directive
- Energy Efficiency Directive
- Governance
- Electricity Directive
- Electricity Regulation
- Risk-Preparedness Regulation
- Rules for the regulator ACER

known distribution system of the past: DSOs will have to rise traditional investments - mainly in grid stability - as well as new ones in intelligent technologies that could also be used to allow end consumers a more active role in the energy market. Flexibility and stability will become activities – or even services, in new emerging markets – of crucial relevance. Tailored and supportive regulatory framework should take into account the ongoing regulation process.

Through this altered energy market, individual members (alone or aggregated) and businesses will be able to engage in direct energy trading, buying excess solar power generated locally by other members, instead of relying solely on big utility companies; the possible benefit of storage facilities could give an impressive acceleration to this process. For physical energy transfers, consumers will use the existing DSO's grid, but in the future the components forming the grid could be owned and managed by several stakeholders with a much higher degree of flexibility. As already mentioned, transaction between neighbours could rely on a blockchain technology and smart, secure contracts that keeps track of physical exchanges and related transaction prices. The settlement of financial position could be alternative realized with money or token.

Exploiting the opportunities of local energy markets, the money goes back into the pockets of people in the community, increasing the local social welfare engagement in the local energy production and supply. We could in a certain way talking of an "energy collective" approach (Wu and Varaiya 1999). At the same time, there could be positive effects on the environment: energy generated and traded within the neighbourhood means that less colossal infrastructures are required. In the long run, this could mean a more cost-effective and sustainable management. Once finally taken off, this model could also enable people to set preferences to maximize savings and potentially sell energy cheaper to lower-income residents in a mutual way. Again, in the future, in a more challenging perspective, and according to regulatory framework, we can imagine prosumers engaged in some kind of spread trading on the spot market: by buying cheap in one place and selling at a higher price in another. On the other hand, more realistically, players such as aggregators become key actors in collecting and selling self-production excess to DSOs, contributing to the overall grid balancing and stability.

2 BUSINESS MODEL COMPONENTS

2.1. SELF-PRODUCTION, SELF-CONSUMPTION AND TRADING

Self-consumption could be described as the local use of photovoltaic (PV) electricity aimed to reduce the buying of electricity from other producers, mainly the local retailer. The basic idea is that PV electricity will be used first for local consumption and that all this electricity should not be injected into the grid (Masson, Briano and Baez 2016). It can theoretically vary from 0%to 100% mainly depending on the economic opportunities.

If self-production is higher than consumption, we could have self-sufficiency and self-producers can engage in trading with their PV excess. This overproduction situation is usually limited to several hours during the entire day; its contribution to the reduction of the net load is clearly represented with the so called "duck curve" (*Figure 1*).

Figure 2 highlight the contribution of different renewables to the total net load.

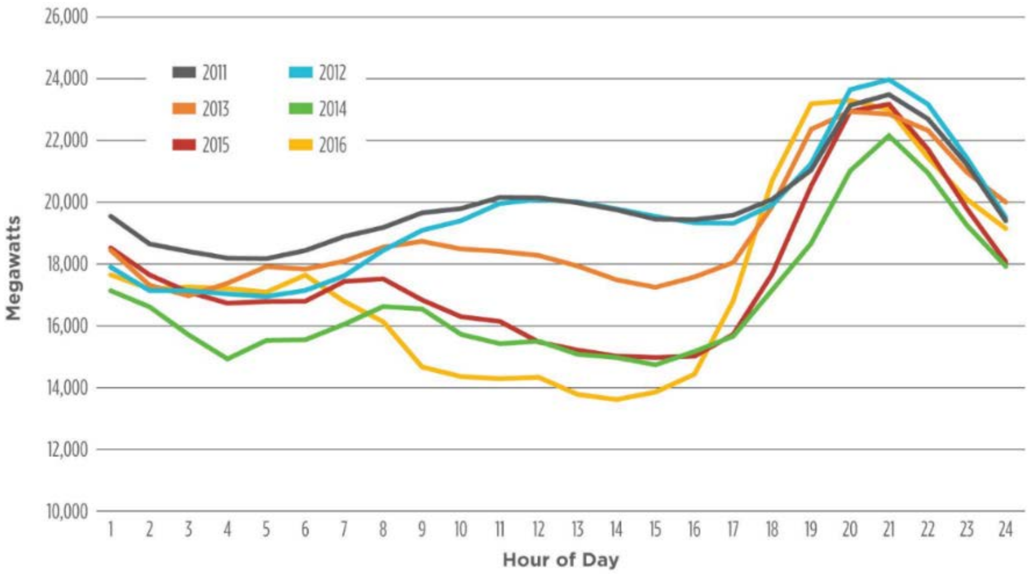

Figure 1. Lowest California Daytime Load in March: 2011-2016; Source: Scottmadden, "Energy Industry Update" 2016

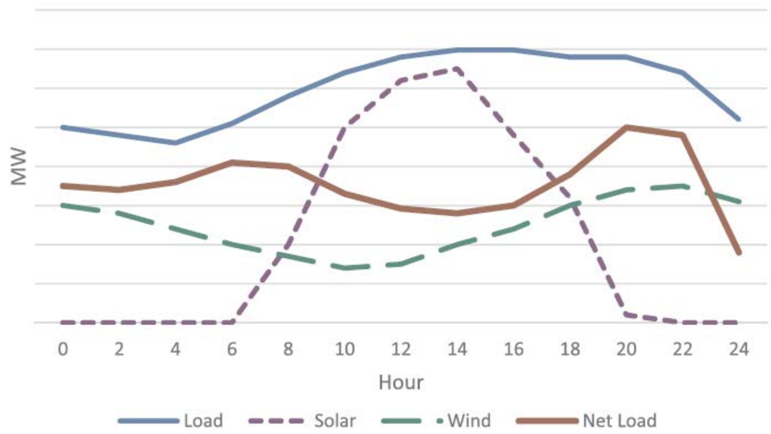

Figure 2. Net load curve with integration of solar and wind, Source: Scottmadden, "Energy Industry Update" 2016

Depending on countries or regions, there are several mechanisms promoting production and self-consumption of PV electricity. Self-consumption promotion is based on the idea that PV electricity will be used first for local consumption and that all this injection to the grid is reduced (with positive effects in terms of network stress reduction). This reduction could be compensated in different ways: with direct incentives self-consumption is rewarded with a premium (see former DE and IT schemes), while with indirect incentives, a Feed-in-Tariff (FiT) or a financial support are allowed if cost are lower than the retail electricity price.
The PV production exceeding consumption, if present, could be valorised through grid injection (electricity will be bought by the retailer) or, in a more challenging market design, with a neighborhood trading scheme. With the latter, the presence of storage facilities seems to be an important prerequisite for the economic feasibility of such a market design (Litjens, Worrell and Van Sark 2018).

Depending on the presence or absence of a decentralized renewable power plant, there could be two alternatives:

A) Consumers without self-production

Due to the absence of a self-generation, "pure" consumers have to satisfy their demand buying electricity from authorized third parties, that usually means from the local retailer (or the DSO/retailer, if they are not unbundled) with the current retailer price.

As an alternative, pure consumers could buy the electricity from other local producers, the prosumers, if allowed by the regulatory framework.

B) Consumers with self-production

In this case, the status of consumer is combined with the one of a producer. The economic behaviour of the prosumer is strictly influenced by the weight of self-production on total demand. More precisely:

- *Self-sufficiency*: consumption is totally covered by self-production, with a residual production quota (excess quota or surplus), that could be traded/exchanged. The economic issue is related to the right valorisation of physical flows. In particular, the economic value of self-consumption is represented by its levelized cost of production2 (LCOE), while the economic value of the surplus is represented by its selling price. The latter is related with reference to the market design and regulation:
    - Surplus valorised with a feed-in-tariff price. This kind of remuneration is progressively losing importance as long as grid parity is closer and self-generation more convenient;
    - With a price at least equal to the average production price (approximated by the LCOE). The incentive for the growth of an electricity trading business is clearly linked to the definition of a selling price between the LCOE and the current retail price.
- *No self-sufficiency.* In this case, consumers will fill the gap of electricity buying electricity:

a. from DSO/retailer,

b. directly from spot market (if allowed), sometimes through aggregators,

c. from prosumers (if allowed)

[2] Levelized cost of electricity, in this case from PV (see WP1 report).

The market design strictly depends on quite a few issues of public /regulatory policy that should be addressed to draft possible business models for each of the previous situations. Technological and economics hypothesis should be considered too.
Using the IEA methodology for the analysis of PV self-consumption policies, we defined three different group of parameters to be shaped in order to sketch out the key points of a production-consumption-trading scenario (see Table 1).

PV Self consumption	Right to self-consume Revenues from self-consumed PV Charges to finance Transmission and Distribution (T&D)
Excess PV	Revenues from excess electricity Maximum timeframe for compensation Geographical compensation
Other system characteristics	Regulatory scheme duration, Third party ownership accepted, Grid codes and additional taxes/fees, PV system size limitation, Electricity system limitation, Additional features

Table 1. Main parameters defining a self-production/consumption scheme

More detailed: PV self-consumption

- Right to self-consume: identifies whether the electricity consumer has the legal right to connect a PV system to the grid and self-consume a part of its PV-generated electricity.
- Revenues from self-consumed PV electricity: it includes all the revenues from self-consumption, both in terms of savings on the monthly bill and potential bonus/premium given to self-consumer (to incentive it) as well as revenues from green certificates.
- Charges to finance grid (distribution and transmission) costs. It indicates whether the PV system owner has to pay part of the total grid costs on the self-consumed electricity. It is a crucial issue because it affects the effective convenience of self-consumption.

Excess PV production

- Value of excess electricity: explains which kind of economic or other compensation the PV system owner will receive when PV electricity is injected into the grid. There could be different pricing scheme, according to different country or players policies. For example, PV surplus could be remunerated:
  - ✓ with the same value of retail electricity price (according to retailer/DSO tariff scheme);
  - ✓ with a value based on the retail electricity price but reduced through specific fees or taxes;
  - ✓ with a market price, practically a spot market price. In this case, it is important to define the timeframe (usually spot market prices are 15 minutes scheduled);
  - ✓ with a feed-in-tariff (currently less and rarely applied) or with green certificates. In this case, PV electricity gets a value defined by regulation.

If regulators will opt for the non-valorisation of the electricity surplus, the corresponding economic value will be lost.

The possibility to couple the decentralized generation system and consumption with an algorithm aimed to flat and optimize the consumers' load profile. It could also contribute to a better definition and functioning of the system, preferably with a storage facility. Potential benefits of the flattening are summarized below (*Table 2*).

Market participant	Impact or benefits
Power producers	Less efficient and expensive peaking plants can be displaced (Kaun and Chen 2013, Yang, Li, Aichhorn, Zheng and Greenleaf 2014, Chang, Chen, Huang, et al 2014, Chiş, Rajasekharan, Lundén and Koivunen 2016, Jayasekara, Masoum and Wolfs 2016**;**
T & D grid operators	The need of expensive upgrades for T & D systems will be delayed as peak shaving allows the existing T & D systems to be used for a longer time (Eyer and Corey 2010, Banerjee, Dasgupta, Kumar, et al 2015).
Electricity traders	Electricity traders can take advantage of electricity price difference. They can store energy at off-peak period when price is low and sell out to customers when electricity demand and price are high.
Electricity consumers	Monthly electricity bill can be reduced by shifting some of the load from peak hours to off peak hours when the price of electricity is relatively low (Eyer and Corey 2010, Chua, Lim and Morris 2015, Comodi, Carducci, Sze, Balamurugan and Romagnoli 2017).

Table 2. Potential impacts and benefits of peak load shaving; source: Uddin, Romlie, Abdullah, Halim and Kwang 2018

The latter is one of the most effective resources to enable power system flexibility, as it can balance power supply and demand instantaneously.

Maximum timeframe for credit compensation

This parameter refers to schemes that allow credits for all electricity injected. Such credits can in general be used during a certain period of time during which compensation is permitted. (e.g., real-time/15 minutes, credits during: a day, a month, a year, or indefinitely).

Geographical compensation

This parameter indicates whether consumption and generation can be compensated in different locations. (e.g., "Virtual net-Metering", "Meter Aggregation", and "Peer to Peer").

Other system characteristics

It comprises different issues such as the duration of the compensation scheme in term of years, whether policies are permitting a third-party to own the generation asset when a self-consumption scheme is installed, potential additional costs have to be borne by PV system owners (self-consumption fees, balancing costs, back up costs, etc.), rules for aggregation of renewable energy sources, a maximum penetration of PV above which the self-consumption regulation does not apply anymore.

2.2. Local storage facilities

The presence of local storage facilities, mainly batteries, could facilitate and stimulate the shift to self-generation as well as the development of new markets. This is particularly true for those countries with high retail prices (such as, for example, Germany and Italy). Current literature

(Lewis 2007, Brekken, Yokochi, Von Jouanne, Yen, Hapke and Halamay 2011, Larcher and Tarascon 2015) and empirical evidences highlights a scalability problem for such a facility: while on a large-scale batteries could compete with peaking plants by 2025, and in some markets renewables combined with battery storage already cost less than cola generation. Storage represents an important component of the overall system flexibility and, in these terms, an equally important part of a smart market design. Concerning their financing, instrument such as public subsidies, at least at the beginning, could be recommended to favour their effective exploitation. Focusing on their ownership, as already pointed out by several players and institutions, if batteries belong to regulated actors (DSO or TSO) they should not be active players of the flexibility market. In this way, they will not impede to other investors to participate with the possibility to recover their investment with an adequate rate of return.

2.3. The role of flexibility

Flexibility could be defined as the modification of generation injection and/or consumption patterns, on an individual or aggregated level. This modification often in reaction to an external signal, in order to provide a service within the energy system or maintain stable grid operation. The parameters used to characterise flexibility can include the amount of power modulation, generation forecasts, the duration, the rate of change, the response time, and the location. In our specific context, flexibility means the integration of intermittent and/or inflexible low carbon generation technologies into the grid.

The delivered service should be reliable and contribute to the security of the system. For energy market based on fossil fuels, flexibility is not so important - large fossil fuel power stations can adjust their production quickly when needed, and in practice, the need to do so is limited because both supply and demand are relatively predictable. With different mix of production, strongly unbalanced on the renewables, flexibility became an important service for which it is worth paying. Usually flexibility includes – but is not limited to - a wide range of the so-called ancillary services, for example scheduling and dispatch, reactive power and voltage control, frequency control and operating reserves. Actually, flexibility should no longer be intended as ancillary to the market for energy and capacity but as a per se, real service. Its value due to the increasing willingness to pay, related to the increasing need, represents the basis for a corresponding market, where a new category of flexibility service providers (FSP) will play an important role. According to our scenarios, aggregators or the community of consumers and prosumers within the peer-to-peer market could act as FSP, with significant economic effects. To assure that flexibility will be provided by the most efficient FSP competitive, adequate markets mechanism should be sketched and adopted.

3 Scenarios and main characteristics of business models and corresponding market design

As already pointed out, the energy market is becoming more and more complex; new players are emerging and an effective general coordination is needed. In particular, also according to recent policy makers' orientation, the electricity market in the next years is going to become consumer-

centric. The consumer will be a relevant actor also from the demand side, when its status is combined with the one of producer. The result is a prosumer, both engaged in (decentralized) generation and consumption, potentially acting also in the electricity trading. This section is dedicated to the analysis of different business models, as well as to the role of players involved, starting from the state of the art up to the most collaborative and decentralized scenario.
In any case, we assume that several basic hypothesis should be hold on for the scenarios we will present:

- Self-consumption should be allowed: electricity consumers should have the legal right to connect a PV system to the grid and self-consume a part of their PV-generated electricity.
- PV excess could be sold/valorised (not lost). This will contribute to maintain PV installation at a high level even after the end of subsidies schemes.
- Usually PV surplus will receive alternatively a Feed-in-Tariff, a retail price or a negotiated price.
- The possibility to opt for a storage facility could help to better redistribute self-consumption or gain higher revenues in case of PV grid injection (due to the possibility to arbitrate prices between peak and off-peak periods).
- If a decentralized algorithm is used, it could additionally support in load shift from peak to off peak hours, in increasing self-consumption (thanks to a better overlap between loads consumption and self-production), with higher overall savings.
    - To incentive self-consumption, prosumers should not have to pay charges/fees concerning total grid cost quota (transmission and distribution) proportionally to their self-consumption. In any case, this option could have social/redistributive negative implications: network prices will increase, because of a lowering in prosumers contribution (same cost, nearly all fixed, over a lower quantity). At the same time, lower network charges will mean lower taxes or fees for public finance. As an alternative, only a discounted on T&D variable costs avoided could be allowed.

2.4. Scenario "0": Business as usual

It represents the current scenario for market actors, with few improvements.
The prosumer has its own generation power plant, in our case a residential PV power plant. In addition, a decentralized algorithm aimed to locally control load profile is available as well as the possibility to store and consume in a later time the self-production's surplus (if present). Therefore, in addition to the basic picture, two different sub-cases have been outlined: with or without load control, both with storage involved.
We assume that the consumer does not produce an electricity surplus but has to fill the gap of its self-production buying electricity from the DSO/retailer.
We assume that the retailer's tariff is the most common of all, i.e. the Time of Use (ToU). The ToU is, the less dynamic price scheme, with rates differentiated on a daily base with a low level of granularity (usually there are two rates, a peak price from 8 a.m. to 8 p.m. and off peak price the remaining hours).
The general self-production/consumption scheme is illustrated in the *Figure 3* Electricity consumption satisfied by self-production has as economic value the LCOE; in terms of network stress, self-consumption finds correspondence in the non-use of the grid.

Self-production/consumption scheme (economics

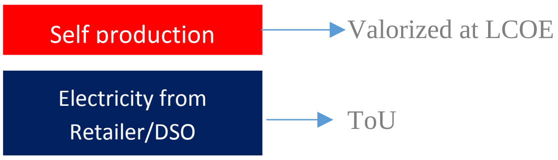

Figure 3. Self-production/consumption scheme (physical flows)

The total price paid for electricity (without taxes) is represented by the following components:

- Network component: Quota of the monthly bill related to network services (transmission and distribution, TSO and DSO remuneration)
- Energy component: Quota of the monthly bill related to energy purchase.
- Tariffs (transmission and distribution) and rates (energy) are intended as quite static (night and day rates)
- In case of self-consumption/PV excess trade, net metering/net billing are settled directly in the bill
- There could be additional expenses due to new services/facilities (e.g., storage in the sub-case 2 below)

Network component	DSO tariff
Energy component	Time of Use rates
	Monthly Bill

Figure 4. Scenario 0 – Business as usual. Sub-case 1: loads are not controlled and batteries are not present

In this sub-case, the consumers' monthly bill is invariant.

In the sub-case two (*Figure 5* and *Figure 7*), we add the possibility to include the load management (with the use of a dedicated algorithm); benefits for consumers in terms of load and cost optimization could be further increased combining the above-mentioned algorithm with a storage facility. The latter could be alternatively bought or rented (realistically by the DSO). The net result should be a reduced monthly expenditure, due to the positive difference between additional costs (algorithm use and purchasing/rent of storage battery) and savings. Literature agreed on the economic advantages of storage (Atzeni, Ordonez, Scutari, Palomar and Fonollosa 2013) argue that the users with storage systems are able to reduce their monetary expenses to a greater extent than consumers without storage systems. In addition, Rajasekharan and Koivunen 2015 highlighted the importance of electrical energy storage in shaving peak energy demands and filling valleys in system load. With ESS, a reduction in energy cost is guaranteed.

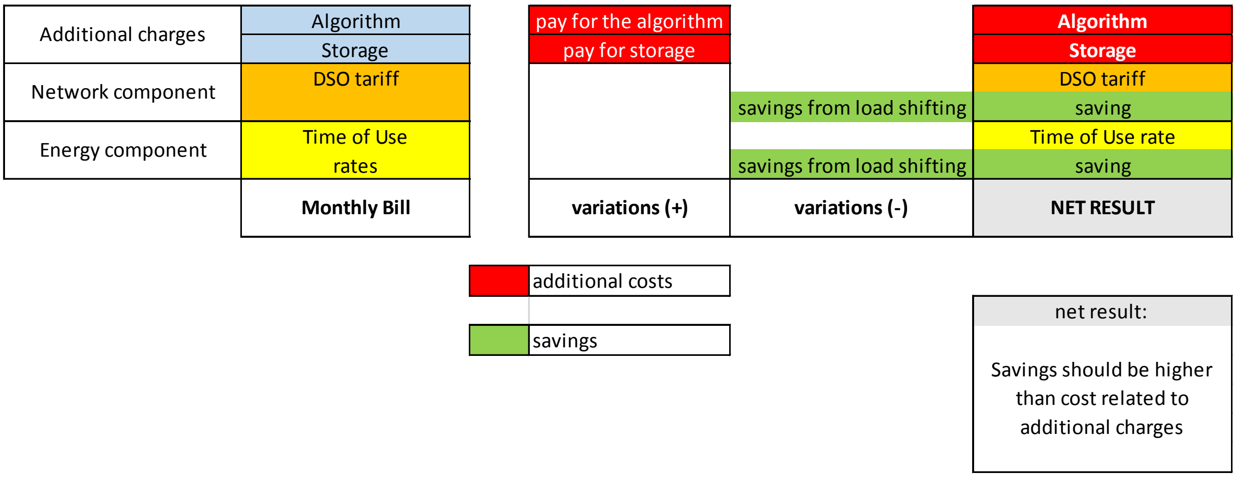

Figure 5. Scenario 0 – Business as usual. Sub-case 2: loads are controlled

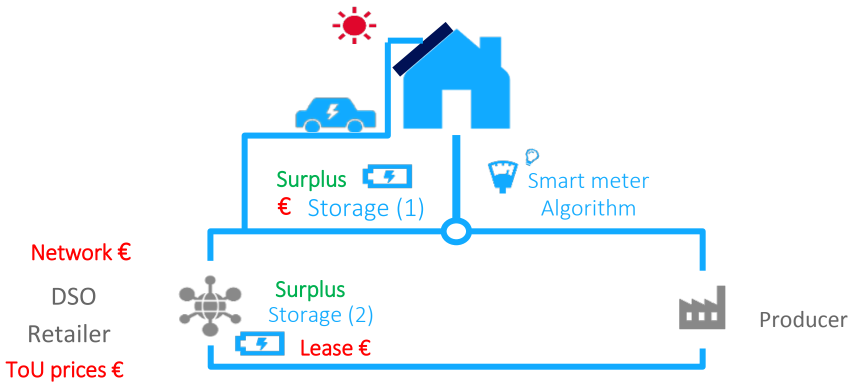

Figure 6. Scenario 0 – Market arrangement

DSO could pursue an invariance in revenues with load management business (with the above mentioned algorithm), as well as the rent or leasing of storage facilities.

2.5. Scenario 1: "DSO planned"

This scenario is shaped on the role of DSO as planner, a referent for all electricity transactions. Within this scenario the transformation of the distributor network operator into a distributor system operator is complete. The DSO will assume a central role within the market design, in some cases replacing the consumer, acting as his substitute.
In the current scenario, the DSO will take over the overall process, from local, decentralized generation to the consumption profile's management. In detail, the DSO will:

» Use of the optimization algorithm, also shifting the load according to the energy and network tariffs, to benefit from the greatest possible advantages.
» Manage the storage facility. More precisely, the DSO owns a central battery, linked to a pool of users that pay a rent/lease for its utilization. A stable storage capacity on Low Voltage (LV) grid that could be used as electric buffer for peak shaving and other ancillary services is available. The storage optimization by the DSO is cost efficient, meaning costs minimization

and benefit maximization. The cost of the storage facility is supported by prosumers but it could be balanced by possible additional savings/shifting.

» Charge to consumers an attractive price scheme such as the Direct Load Control (DLC): the DSO has full control over the registered load in direct load control demand response program. Also, the consumer has some control to his/her own load. However, the consumer cannot overwrite the utility control. Consumers are then awarded with a discounted price scheme.

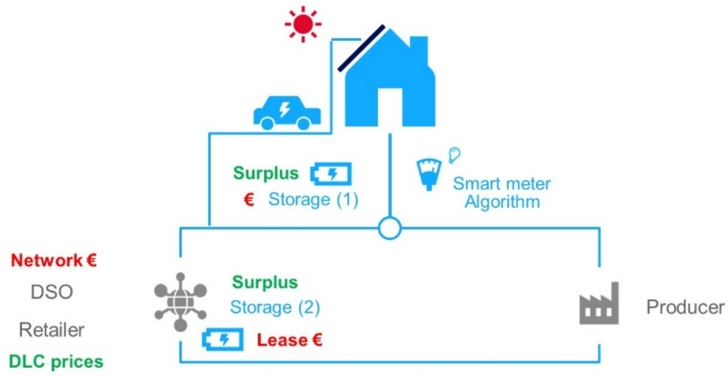

Figure 7. Scenario 1. Market arrangement

Also in this case, the total price paid for electricity (without taxes) is represented by energy and network components defined according to Direct Load Control programme price's scheme. As for scenario 0, self-consumption/PV excess trade are settled directly in the bill with net metering. Storage is available and managed by the DSO. DSO will offer to prosumers some kind of "solar storage leasing package" DSO could also offer a battery to consumer with, for example, a 50% discount under constraint that he can keep for example a certain percentage of storage capacity to use freely.

The net result should be a reduced monthly expenditure, due to the positive difference between additional costs (rent of storage battery from DSO) and savings. To this goal, clearly the DLC price should be lower than the Time of Use one (*Figure 8*).

Additional charges	Storage	pay for storage		**Storage**
Network component	DSO tariff		savings (if DLC < ToU)	DSO tariff saving
Energy component	DLC rates (Direct Load Control)		savings (if DLC < ToU)	Time of Use rate saving
	Monthly Bill	**variations (+)**	**variations (-)**	**NET RESULT**

(red)	additional costs
(green)	savings

net result:
Savings should be higher than cost related to additional charges

Figure 8. Scenario 2 – "DSO planned"

An important evolution of this business model includes the opportunity for the DSO to use its role and its load shifting to actively participate to short-term markets (day-ahead, intra-day and ancillary services); this will require an additional adjustment of market design and regulatory framework. In detail, the bid size for entering the market should be reduced, both for DSO and aggregators; with current size they might need to engage an important number of customers to reach a critical dimension and this could represent an important barrier to entry. A recommendation of the BRIDGE EC working group on Business Models is that centralized batteries should not be allowed to participate in any flexibility market if they belong to or are operated by a regulated entity (e.g., a DSO or a transmission system operator, TSO).

2.6. Scenario 2: Voltage tariffs

In this scenario, an algorithm is used to fix local congestion problems minimizing at the same time the overall consumers cost of energy. As for the previous scenarios, the total price paid for electricity (without taxes) is the sum of the energy and network quota but, in this case, both component could be reduced due to special voltage tariffs: for a peak power reduction, a discounted rate is applied. Storage and load optimization with a specific algorithm is possible also with this market arrangement.
The net result should be a reduced monthly expenditure, due to the positive difference between additional costs (algorithm and purchasing/rent of storage battery) and savings (in case of peak reduction). The DSO profits due to its load management service could be shared (profit sharing agreement) with consumers (*Figure 9*).

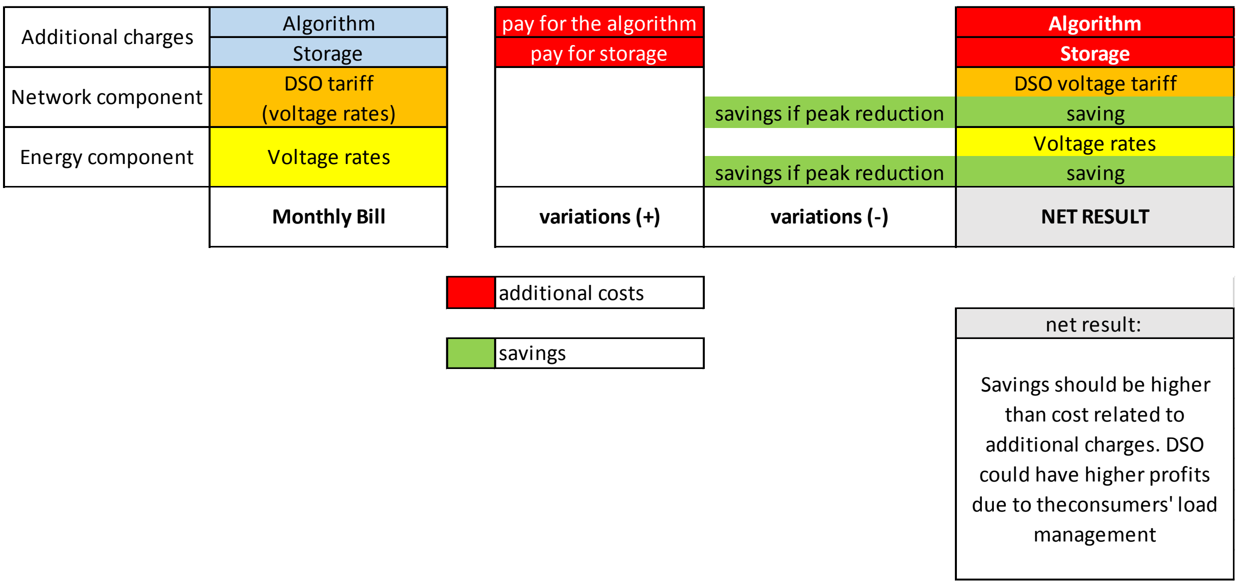

Figure 9. Scenario 3 – Voltage tariffs

2.7. Scenario 3: Peer-to-peer (P2P) market

It represents the most challenging market design arrangement; consumers and prosumers have the possibility to freely trade with a central part or, in its purest form, between each other.

According to the literature (see Sousa, Soares, Pinson, Moret, Baroche and Sorin 2019 for an extensive review), the simplest formulation of a P2P market is the following:

$$\min_{D} \quad \sum_{n\in\Omega} C_n \left(\sum_{m\in\omega_n} P_{nm} \right) \qquad (1a)$$

$$\text{s.t.} \quad \underline{P_n} \le \sum_{m\in\omega_n} P_{nm} \le \overline{P_n} \qquad \forall n \in \Omega \qquad (1b)$$

$$P_{nm} + P_{mn} = 0 \qquad \forall (n,m) \in (\Omega, \omega_n) \qquad (1c)$$

$$P_{nm} \ge 0 \qquad \forall (n,m) \in (\Omega_p, \omega_n) \qquad (1d)$$

$$P_{nm} \le 0 \qquad \forall (n,m) \in (\Omega_c, \omega_n) \qquad (1e)$$

» C represents the costs and the decision variable,

» P_{nm} corresponds to the trade between agents n and m, for which a positive value means sale/production and a negative value is equal to a purchase/consumption.

The general idea is that this market design arrangement will minimize the cost of electricity trade between agents.

Cost optimization is widely reported as a major motivation for bilateral energy transactions among peers (Tsui and Chan 2012, Cappers, MacDonald, Goldman and Ma 2013, De Angelis, Boaro, Fuselli, Squartini, Piazza and Wei 2013, Bilil, Aniba and Maaroufi 2014, Alam and Bhattacharyya 2017). Cost optimization can be achieved through reductions in generation costs, transport costs, energy demand or through profit maximization. In addition, minimized losses and energy cost in distributed micro-grid have been considered as a motivation for prosumers' participation in energy trading (Hu, Liu, Zhang, Su, Ngai and Liu 2015). Moreover, if a peer market enters successfully, it will realistically lower (energy) market price, crowding out professional sellers (Einav, Farronato and Levin 2016).

From a social point of view, excess energy produced can be shared, traded or freely supplied to another consumer in need. By delivering energy as a resource that can be given away as a social capital by individuals to a target party, the values derived from such gestures can be used as a strategic tool to promote social cohesion and improve the sense of community.

To participate in energy trading and sharing, a prosumer should be able to either generate, consume and be willing to trade or share energy. DERs are an attractive technology for P2P energy trading and sharing. P2P electricity trading cases are starting to emerge worldwide: Piclo, Vandebron, SonnenCommunity, Yeloha and Mosaic are all national or regional online platforms that support P2P energy trading among their members and these platform owners acted similarly to a supplier's role in the electricity sector. They only focus on the development of business models, and ignore the possibility of introducing those models to smaller-scale local energy market. The design of ICT and control systems was not considered.

In our opinion, due to the hierarchical nature of the distribution networks, the future P2P energy trading should be carried out at a different level. A local energy market and a sophisticated ICT and control system is essential for managing the balancing of the system; Blockchain is considered to be a very promising techniques which can simplify the metering and billing system of the P2P energy trading market.

According to the recent literature (Sousa, Soares, Pinson, Moret, Baroche and Sorin 2019) three main type of P2P market could be considered (*Figure 10*):

i) "Pure", full P2P market.

In this market arrangement all the agents interact through multi-bilateral transactions in order to sell or purchase electricity; there is no need for any kind of third party entity control or management.

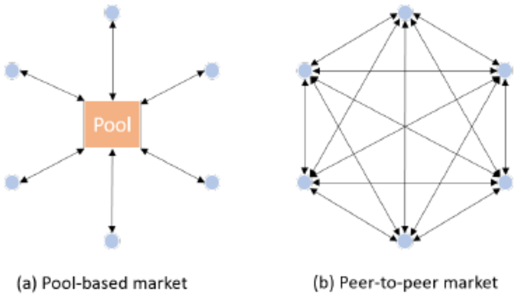

Figure 10. From the pool based to the full P2P; Source: Sousa, Soares, Pinson, Moret, Baroche and Sorin 2019

The definition of the optimal transaction prices and quantity result from the adoption of decentralized optimization technologies (see Gabriel, Conejo, Plazas and Balakrishnan 2006, Morstyn, Farrell, Darby and McCulloch 2018, Kargarian, Mohammadi, Guo, et al 2018, Sousa, Soares, Pinson, Moret, Baroche and Sorin 2019). In particular, the common basic idea is that each agent reveals at what price is willing to trade a certain quantity of electricity; the problem is iteratively disentangled. In our opinion, this market arrangement is very interesting and challenging, and could better represents a more advanced organization form, once the basic model will be much more well defined and relations between agents and actors better analysed and shaped.

ii) Community-based P2P market

In this market, the architecture relies on the presence of a central, third entity that acts as a supervisor, coordinating electricity trading between agents involved in the negotiations.

iii) Hybrid P2P market

It is clearly the combination between the previous market designs; it is based on the presence of different layers for trading electricity.

Despite the third type is of some interest and could permit to add benefits, we think that our model could be better explained with the second arrangement type.

1.1.1 P2P market: general assumptions

As already pointed out, it is the most challenging market design.

In recent years, different business models for local supply have been proposed and tested (Hall S, Roelich K, 2015) e.g., local white label model, local aggregator model, local pool model, etc. These business models were all designed based on existing business models in large-scale electricity wholesale markets. Therefore, a new business model for local P2P energy trading should be based on a different paradigm, such as an eBay or a spot wholesale market style.

It relies on several assumptions:

- DSO and users are both players within a deregulated market. In the future, P2P electricity trading should continue to expand as the number of areas where electricity brokerage business is permitted increases and renewable energy and storage devices costs decrease.

- Since the generation of RESs is uncontrollable, P2P energy trading among prosumers relies on the schedule and control of flexible demand and energy storage.
- All the rents of the model are fairly distributed:
  - Revenues earned from P2P transactions are distributed across all prosumers in proportion to their export.
  - Benefits of reduced electricity rates are spread proportionally among all customers.
- Two scenarios are considered:
  - An initial scenario without the introduction of batteries and discretionary load.
  - An advanced one with load shifting and storage.

The critical issue to build up a peer-to-peer market starts from the cost stacks, as represented in the *Figure 11* below.

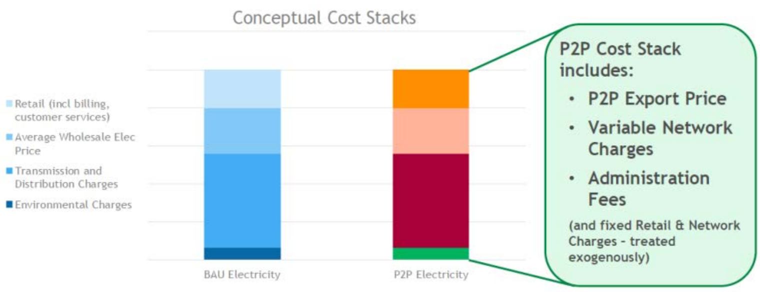

Figure 11. The cost stack; Source: «Peer-to-Peer Distributed Ledger Technology Assessment, 2017, AGL Energy Limited

In detail:

P2P export price: is the price paid by the market to PV excess (export) prosumers

In general, to create the market the electricity price should be:

- Higher than FiT (if present).
- More attractive than self-consumption price (cost) (in case that FiT are not present), for example just below the retail price. Difference between the export price and the LCOE represents the P2P prosumers' revenues. From the consumers' side, the P2P market condition is that the P2P cost stack is lower than consumers' costs under standard tariff.
- More generally, the business model should have a structure that benefits both prosumers, who sell electricity from renewable energy and consumers that purchase electricity from the prosumers. To take an example of the German's Sonnen Community, consumers pay 25 cents/kWh to power producers, which is lower than the electricity price paid to utilities by consumers and bigger than the profits earned from the FiT for prosumers. This business model is possible if renewable energy or electricity supply costs are lower than the existing electricity rates.

The energy offer price determination within the above mentioned range (minimum LCOE, maximum retail price) can be determined by each actor by solving a local optimization problem

(Matamoros et al., 2012). The goal is to determine the equilibrium price to trade/buy energy as a function of the total cost of production/transportation including energy losses.

The attractiveness of storage increases as the difference between the retail price and the LCOE coupled with the storage cost (LCOE or lease) increase.

Energy trading algorithms, whose importance is increasing due to the development of smart grids and the intermittent supply of distributed generation, mainly rely on the game theory, used as analytical tool for microgrids energy trading.

For instance, each actor pursuing selfish or altruistic goals can model the optimum energy price as a non-cooperative game with each actor defining its objective function and different pricing strategies to optimize profit. Saad et al. (2012) provides a broad overview of game theory for smart grids. Other authors (Atzeni et al., 2013; Tushar et al., 2015; Rajasekharan et Koivunen, 2015; Wang et al., 2014) proposed a game theory approach to energy trading and sharing. Another important theory relevant for the pricing definition is the auction theory, an analytical framework aimed to study the interaction between sellers and buyers, optimizing their objectives. The outcome is represented by prices at which a trade takes place and goods are exchanged. Several authors (Lam, Huang, Silva and Saad 2012, Uddin, Romlie, Abdullah, Halim and Kwang 2018) presented a double auction mechanism for P2P trading match.

Again, in matching buyers to sellers, strategies based on auction theory are commonly used: buyers and sellers can submit quota at any time during the trading period – usually one hour – and the market clears continuously. Furthermore, future game theory applications in prosumer energy trading could involve several types of games such as facility-location games, Stackelberg games, advanced hash games, and others.

<u>Administrative fees</u>: represent the cost of hosting and administrating the distributed ledger that would underpin such a market. Their weight will realistically increase with the P2P market enlargement. The structure of fees will be important. Whether the platform charges a fixed fee to all sellers or fees are raised per transaction. This latter will be particularly attractive to flexible sellers because they only have to pay the fee when they trade.

<u>Variable network charges</u>: represent the marginal cost of utilising local network assets. At least from transmission side, to push a P2P market creation they should not be considered. Usually, T&D are largely fixed and local generation does not reduce peak demand or reduce the need for a network expansion or are "distance travelled" independent; in this case, P2P does not determine a reduction in network costs and should still be present. Otherwise, if we want to incentive local transactions, discounted local fees/distribution charges (differentiated with refers to the distance from buying/consumption place) could be set up.

In general, P2P can create additional value through trading, it shifts revenues from the retailer/DSO to the prosumers/consumers.

1.1.2 Load shifting

With a load shifting – because of the presence of an algorithm, DSM and/or storage facilities - a "smoothed" net grid consumption profile could be realized, with greater adherence between PV surplus and peak consumption. In this case, retailers could lower their purchase cost while DSO could improve grid optimisation; additionally, prosumers will have greater export potential and saving due to reduction in network charges.

Focusing on the consumers' side, we can see that the total price paid for electricity (without taxes) is represented by the following components:

- Network component: Quota of the monthly bill related to network services (transmission and distribution). A discounted P2P tariff could be charged.
- Energy component: Quota of the monthly bill related to energy purchase. To incentive the creation of a trading between consumers/prosumers, rates should be higher than the feed-in-tariff (if present) or lower than real time prices rates.
- To increase the overall efficiency also discriminating between consumers, different rates could be offered, i.e. standard user/low user price. In both case, the best option should be a two-part tariff, with a daily/weekly/monthly charge and a kWh charge. The fixed part for standard users should be higher, while the variable one should be lower.
- There could be additional expenses due to new services/facilities (e.g., storage).

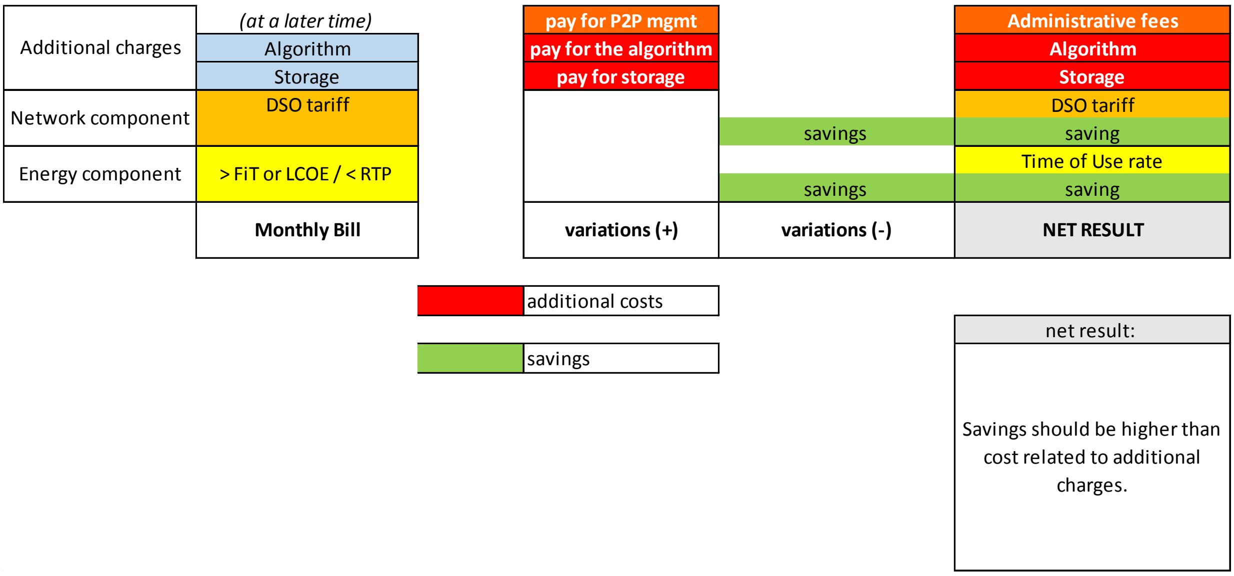

Figure 12. Scenario 4 – Peer-to-Peer Market

The net result should be a reduced monthly expenditure, due to the positive difference between additional costs (algorithm, purchasing/rent of storage battery and, maybe in a second step, administrative fees) and savings (mainly related to the price difference between P2P rates and electricity current prices). The DSO could have higher profits in case of P2P market administrative management. In any case, the actual profitability of this scenario for each consumer/prosumer will depend on a) size and frequency of their trading involvement, b) the weight of administrative fees.

With a load shifting – because of the presence of an algorithm, DSM and/or storage facilities - there could be "smoothed" net grid consumption profile, with greater adherence between PV surplus and peak consumption. In this case, retailers could lower their purchase cost while DSO could improve grid optimisation; additionally, prosumers will have greater export potential and saving due to reduction in network charges.

Interesting questions deal with the relation between the actual savings/profits for consumers and prosumers as the exchanges increase and the effects on the volume and diffusion of PV investments. Recent literature (Roy, Bruce and MacGill 2016, Zizzo, Sanseverino, Ippolito, Di Silvestre and Gallo 2018) analyse the topics in case of ToU and inclining bock tariff price schemes finding that:

- At a low level of PV penetration, the P2P trading seems to be very profitable for solar PV customers, while non-PV customers receive only little benefits and would not buy a smart meter to join the market. As an alternative, community managers or aggregators could try to create additional incentives for non-PV to join the market, for example reducing margins or adopting some kind of profit sharing approach;
- Non-PV customers are substantially better off at a high PV penetration level; on the other hand, above the 50% of PV penetration, investment decision for investing in new solar PV is worse than it could be in the BaU scenario.
- Further research should focused on the definition of the appropriate margin that would attract non-PV customers to participate.
- Focusing on the storage, in markets where PV systems are widely adopted, incentives to buy storage capacity increases with the possibility to become entirely independent from the grid. On the other hand, this will mean the cut off of net metering schemes, with important consequences on the payment of solar facility investments. Unless the cost of residential storage is competitive enough, or there is an economic incentive to install it, this business model is not viable. This means that a realistic business model will be based on a rent of storage capacity.

1.1.3 The settlement for electricity transactions

Consumer and prosumers complete electricity exchange payment and digital certificate of commodity transaction quantity through the blockchain after trade matching. Consumers transfer token to the prosumers as an electricity purchase cost through the blockchain system, and the prosumers transfers token as a digital certificate for the sale of electricity.

The settlement process between the consumer and prosumers in the blockchain network is introduced as follows:

i. Issue token money: After the transaction matching, the prosumer issues one token money, which is proportional to the transaction volume in the blockchain network, as the input source of transaction script.
ii. Transfer ethereum: The consumer who transacts with this DG creates a common transaction of transferring ethereum, transferred to the address of the public key of this prosumers attached with a digital signature.
iii. Transfer token money: the prosumer creates a trade after receiving ethereum from the consumer. At this moment, the consumer and the prosumer accomplish the transaction.

1.1.4 The NEMoGrid model

Our assumptions

The functioning of the P2P market in based in several assumptions listed below:

- Goal: minimization of the overall consumers' expenditure
- Self-consumption is allowed, potential surplus could be sold to other consumers
- There are no more feed-in tariffs (only subsidies to investments could be present)
- Network charges, fees, levies and other are not considered at a first glance
- Consumers and prosumers do not participate to the wholesale market (but buy the electricity from the retailer/DSO)
- Central aggregator will trades with each participant (no bilateral relationships; a multilateral trading could represent a future improvement)
- The DSO will apply the most appropriate tariff scheme, lease the battery to a pool of users and manage the grid balance.
- Self-consumption and PV excess trading with a central aggregator should be allowed.
- The cost for algorithm and storage will be borne by prosumers
- The P2P value paid for solar is set just below the retail price, which means all prosumers wish to satisfy the P2P market.
- Electricity imported is limited to the unmet demand
- Electricity traded is the excess of PV production.

The overall functioning could be sketched out as in the *Figure 13*.

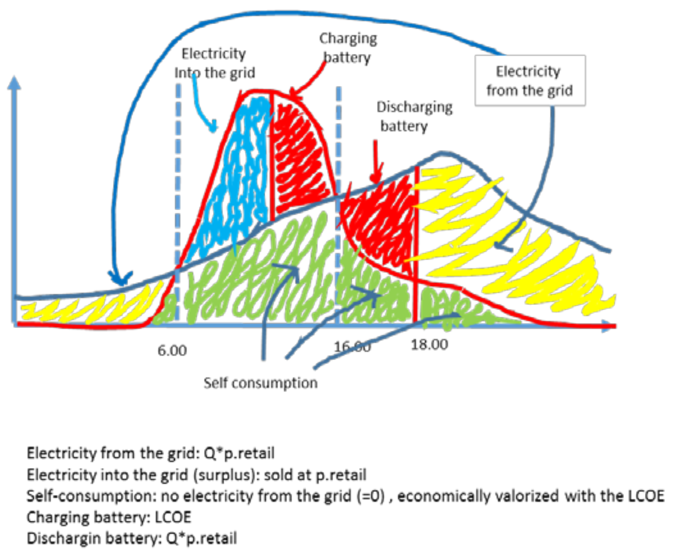

Figure 13. Daily electricity flows in a peer to peer market

The objective function

The objective function is the minimization of the expenditure. In both cases (with and without storage) we use an adaptation of the model of Litjens (2018).

Case a) without storage

Objective function = minimize (electricity expenditure from the grid – revenues from the PV surplus)

1) Electricity expenditure from the grid
   Price paid equal to the retailer price
2) Revenues from PV surplus

Price lower than retailer price but higher than LCOE
In case: cost of the algorithm (charged by the DSO as a cost component quota)

$$= \sum (d,t)(E_{import(d,t)} * p.import - PV_{exported(d,t)} * p.export + (algorithm) + (administrative\ fees)$$

With:
d is day = 1 - 365
t is hour = 1 – 48 (30 min timestep)
E_{import} = electricity imported from the grid
p.import = price of the electricity imported (retailer/DSO price)
$PV_{exported}$ = electricity exported to the grid
p.export = price of the exported PV surplus (lower than the corresponding retailer price)
(algorithm)= cost of the algorithm that shifts the load (pro quota)
(administrative fees) = amount of the fees related to the management of the system (pro quota, not necessary*)*
The cost of the algorithm and the administrative fees could coincide.

Once the optimization model is executed, a set of solutions is produced for each day of the year and each half-hour period of each day of that year.

Case b) with storage
Objective function = minimize (electricity expenditure from the grid – revenues from the PV surplus + electricity battery charging cost – electricity revenues from battery + cost of storage + algorithm + administrative fees)

$$= \sum (d,t)(E_{import(d,t)} * p.import - PV_{exported(d,t)} * p.export + P_{charhe_{grid(d,t)}} * p.charge - P_{discharge(d,t)} * p.export + p.storage + (algorithm) + (administrative\ fees)$$

With:
d is day = 1 - 365
t is hour = 1 – 48 (30 min timestep)
E_{import} = electricity imported from the grid
p.import = price of the electricity imported (retailer/DSO price)
$PV_{exported}$ = electricity exported to the grid
p.export = price of the exported PV surplus (lower than the corresponding retailer price)
$P_{chargegrid}$ = electricity necessary to charge the battery
p.charge = price of the electricity for charging the battery (LCOE)
$P_{discharge}$ = electricity exported from the battery to the grid
p.storage = price of storage (es: pro quota of the LCOS without electricity cost – included in p.charge) or lease by DSO)
(algorithm)= cost of the algorithm that shifts the load (pro quota)

(administrative fees) = amount of the fees related to the management of the system (pro quota, not necessary*)*

The prosumer bid offer for (p.export) the electricity surplus is then shaped on the following conditions:
(without storage)
LCOE < bid offer < retailer energy price
(with storage)
LCOS+LCOE < bid offer < retailer energy price

Bid offers by local producers will be placed on the market via auction and the merit order defined after the local optimization process.

2.8. Discussion and future work

We have delineated the distinctive features and characteristics of each of the identified scenarios. For each of them, particular attention was paid to the overall design of the market, to the role of the economic and institutional actors present and, therefore, to the economic variables at the base of the model's functioning and economy.

We started from the current scenario, appropriately integrated with some innovations such as the algorithm for optimizing the load and the possibility to rent a battery for the storage (Scenario Business as Usual) up to the most articulated and innovative, also in relation to the technology to be exploited the Peer-to-Peer market.

The latter requires a series of analysis tools, technical as well as economic, in order to verify the actual feasibility and convenience. And it is precisely future research developments that will have to be oriented towards this analysis, through a series of empirical, on site simulations.

The results of these tests could also contribute to providing a series of useful information to deepen a series of further questions, for example, how the profits of the community vary with the increase of its components or the relevance of possible administrative fees/remuneration of community manager.

In general, finally, in a broader perspective and policy, some key points deserve to be underlined. The first is the adoption of a network tariff policy, that allows to transmit the right price signal, i.e. reduced in the event of less stress on the network due to self-consumption or, in any case, proportional to the actual use in case of P2P market arrangement. Moreover, in a "high penetration" DER scenario, the definition of an appropriate and detailed charging framework for network access represents an important key pillar.

The second is the potential, interesting role of the P2P community, through its central aggregator, as flexibility supplier to the DSOs and the TSOs. The, focusing on the relation between actors involved, it should be clear that risks, responsibilities and rewards should be allocated appropriately between individuals, enterprises and public entities.

Third, it would be appropriate to use the lenses of the social, instead of private, analysis; this will permit a) to take into account positive externalities of smart metering and decentralized electricity storage; b) to consider a possible split of profits between prosumers and consumers.

A final interesting point could be the exploration of the feasibility of direct and fair transactions between large suppliers and small prosumers.

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