IMPROVEMENT OF PVP4GRID CONCEPTS

D3.1

Public Deliverable

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Executive Summary

Significant changes in the electricity market design can be expected with the implementation of the "*Clean Energy for All Europeans package*" (CE4AE package), requiring, new concepts for prosumers. PV is one of the most critical technologies for prosumers and the local welfare[1] increases by new technologies. One aim of the project PVP4Grid is to classify, improve and test new concepts for current and future PV prosumers. In order to be able to do so, at the very beginning we classified PV prosumer concepts by three dimensions: (i) number of prosumers, (ii) time and (iii) technologies.

This report expands the concepts by the dimension of time with the focus on the investment and operational phase of assets. This document illustrates that the proposed concepts are designed in a way to addresses the future market design. In total, we see five concepts: (a) individual Investment, (b) joint investment, (c) single metering point, (d) virtual metering and (e) energy communities. Therefore, we improve the concepts in respect of technological components, namely distributed generation units (such as photovoltaic systems) and energy storage systems (e.g., batteries). Although potential prosumers are not only entirely motivated by monetary motives, an economic concept increases the probability of a favorable investment decision.

For the following task for PVP4Grid, we define the settings for concepts beyond single direct use (following the PVP4Grid nomenclature group 2 and 3 models), by defining the so-called "European Village". The "European Village" reflects the housing situation (e.g., the share of people living in an apartment or single-family houses), as well as the share of vehicles (and in future electric vehicles).

The real-life testing of the current and improved PVP4Grid concepts requires data. To allow the partners to collect the data from the testing sites, we developed spreadsheets for data acquisition. To make the tables understandable, we also

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[1] Welfare is an often-used metric in electricity markets, as it describes the producers and consumers perspective. The definition of social welfare is the sum of gross consumers' surplus minus producers' costs. (Willems, 2004)

provided a “Readme file” to describe the purpose and the data necessary for scaling the model.

The conclusions of this deliverable are currently on a qualitative basis:

- As the legislation in Europe will change with the decision of implementing the *Clean Energy for All Europeans* package, new concepts for consumer, prosumers, and generators are needed.
- New investment models, allowing community participation, may increase the local welfare of PV prosumers.
- Although different motivations may drive investments, community concepts help to share energy on a local level (e.g., in apartment houses or urban districts).
- The coupling of different technologies and the possibility of local trading (e.g., by energy communities), may increase the flexibility of the local system.
- Innovative concepts help to match supply and demand better and thus increase the degree of self-consumption (also by the substitution of fossil fuels (e.g., oil, gas, and petrol)).

Nomenclature

B

BESS. *Battery energy storage system*

C

CAPEX. *Capital Expenditure*

CE4AE. *Clean Energy for All Europeans*, *Clean Energy for All Europeans*

D

DER. *Distributed energy resource*

DSM. *Demand-side management*

DSO. *Distribution System Operators*

E

ENC. *Energy community*

ESS. *Energy storage system*

EV. *Electric vehicle*

H

HESS. *Heat energy storage system*

I

IEM-Dir.. *Internal Energy Market-Directive*

IEM-Reg.. *Internal Energy Market - Regulation*

II. Individual investment

J

JI. Joint investment

L

LCOE. *Levelized costs of electricity*

LV. *Low voltage*

M

MV. *Medium voltage*

P

PTP. *Peer-to-Peer*

PV. *Photovoltaic*

PVP. *Photovoltaic-Prosumer*

S

SMP. *Single metering point*

T

TSO. *Transmission System Operator*

V

VM. *Virtual metering*

1 Introduction

One aim of the project PVP4Grid is to classify, improve and test new concepts for photovoltaic prosumers. A significant design aspect of those improved BMs address opportunities defined in the "*Clean Energy for All Europeans package*" (CE4AE package). In comparison with the actual EU legislation, the CE4AE-Package is likely to set more detailed obligations for the Member States and expands guarantees that are helpful with respect of the legal and regulatory barriers impeding the implementation of the improved concepts (Pause and Wimmer, 2018).

(Pause and Wimmer, 2018) analyzed the CE4AE-Package in the BestRES project, and shows that many provisions (Internal Energy Market -Regulation = IEM-Reg., the Internal Energy Market-Directive = IEM-Dir., and the Renewable Energy-Directive = RED II) mention renewable self-consumers, active consumers[2] and renewable energy communities[3] in different contexts. Consequentially, it has to be differentiated between consumer and energy community concepts.

One aim of this deliverable is to introduce concepts for prosumers keeping in mind the CE4AE package. In order to be able to do so, at the very beginning chapter 1 starts with the current classification of PV prosumer concepts and improvements of

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[2] Following the details in the CE4EA, (Fleischhacker et al., 2017) summarized: "*As stated in Article 15 of the draft IEM Directive, Member States shall ensure that final customers will become "active customers" to generate, store, consume and sell self-generated electricity in all organised markets. Market participation shall be possible either individually or through aggregators. In both cases, active customers shall not be subject to disproportionately burdensome procedures and charges that are not cost reflective. Further, the energy installation required for the activities of the active customer may be managed by a third party for installation, operation, including metering and maintenance. Additionally, Article 21 of the draft Renewable Energy Directive implements the concept of the so-called "Renewable self-consumers", which shall have the right, inter alia, to sell their excess production of renewable electricity.*"

[3] As before, the details of CE4EA were mentioned by (Fleischhacker et al., 2017):"*… Article 16 of the draft IEM Directive introduces the concept of so-called "Local energy communities". The Member States shall be obliged to ensure that these communities have the possibility to own, establish, or lease community networks and to autonomously manage them. Further, they shall have access to all organized markets either directly or through aggregators or suppliers in a non-discriminatory manner. This concept is accomplished by the Commission's proposal to introduce so-called Renewable energy communities in Article 22 of the draft Renewable Energy Directive. A Renewable Energy Community, which fulfills the requirements set out in Article 22, shall be entitled to generate, consume, store and sell renewable energy.*"

those in terms of three dimensions: (i) number of prosumers, (ii) time and (iii) technologies. The previous PVP4Grid report “*Existing and Future PV Prosumer Concepts*” (Lettner et al., 2018) defines the starting point of future PV prosumer concepts by expanding the number of prosumers (namely concepts beyond single direct use). This report expands the concepts by the dimension of time with a focus on the investment and operational phase of assets. Although PV is the most critical technology for prosumers, the local welfare increases by new technologies. Therefore, we improve the concepts in respect of technological components, namely distributed generation units (such as photovoltaic systems) and energy storage systems (e.g., batteries).

Chapter 3 gives insights in the following task of the PVP4Grid project, the simulation of improved PV prosumer concepts. To do so, we define the settings for concepts beyond single direct use (following the PVP4Grid nomenclature group 2 and 3 models), by defining the so-called “European Village”. The “European Village” should reflect the housing situation (e.g., the share of people living in an apartment or single-family houses), as well as the share of vehicles (and in future electric vehicles). In a next step, we describe which simulations will be conducted in the future work of the PVP4Grid project. So, we show the link between current and improved PV prosumer concepts. The chapter intends in describing how we apply the improved PVP4Grid concepts to the groups.

The final chapter 4 is the link from the current and improved PVP4Grid concepts to the future real-life testing. To allow the partners to collect the data from the testing sites, we developed spreadsheets for data acquisition. To make the tables understandable, we also provided a “Readme file” to describe the purpose and the data necessary for scaling the model.

2 Definition of PVP Concepts

One fundamental assumption of the PVP4Grid is that PV prosumer concepts are a crucial element to push the energy transition. Starting from the current classification of PVP prosumers (2.1), this chapter proceeds with an improved classification of PVP prosumer concepts (2.2) describing PVP concepts more in detail.

2.1 Current classification of PV Prosumers

In the following, we expand the prosumer concepts of (Lettner et al., 2018) with further dimensions. (Lettner et al., 2018) introduced three groups of PVP concepts (see Figure 1 and more in detail Figure 2) and defined them as the following:

(1) Single use: One consumer directly uses the generated PV electricity on site (both cases are conceivable in this context: (i) generator legally identical to consumer, (ii) generator legally not identical to consumer). The public grid is only used for the residual electricity consumption and possible feed-in of excess electricity. Self-consumption can be increased due to the implementation of energy storage systems, electrification of heat production (heat pumps, boilers), demand-side management (DSM), etc.

(2) Local collective use of PV in one place (e.g. in one building): Several consumers share the generated PV electricity using the public or private grid (owned and/or operated by DSOs). The public grid is used for the residual electricity consumption and possible feed-in of excess electricity. Each consumer can increase the share of self-consumption by specific measures (storage, demand-side management, etc.).

(3) District power models: Several consumers directly consume locally generated PV. The PV energy is shared using the public or private local grid on low voltage level (limitation is the same substation [note: this is the project-specific deliberation/definition in this project; this does not necessarily need to be a generally accepted classification]). District storage devices can be used to increase the share of self-consumption, in addition to the individual measures.

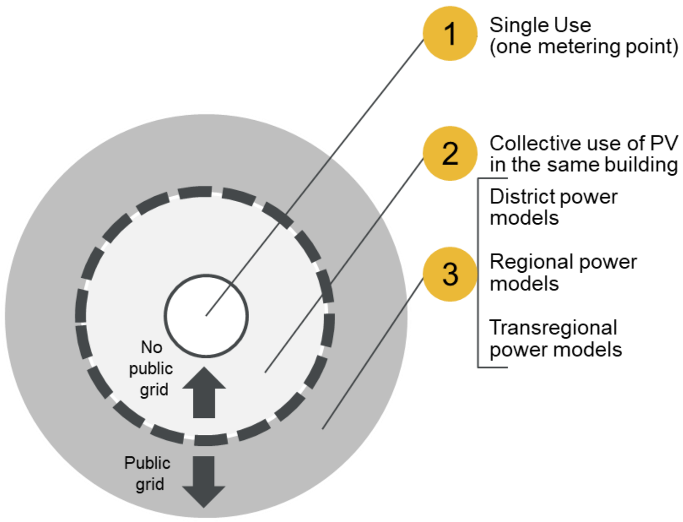

Figure 1: Spatial classification of PVP concepts according to their system boundaries. Source: (Lettner et al., 2018)

These three groups differentiate mainly regarding spatial parameters (e.g., whether generation and consumption are located in the same building) and the number of prosumers. Another assumption is that (Lettner et al., 2018) describes concepts for the operation of distributed energy resources (DER) and energy storage systems (ESS) (such as battery (BESS) or heat energy storage systems (HESS)).

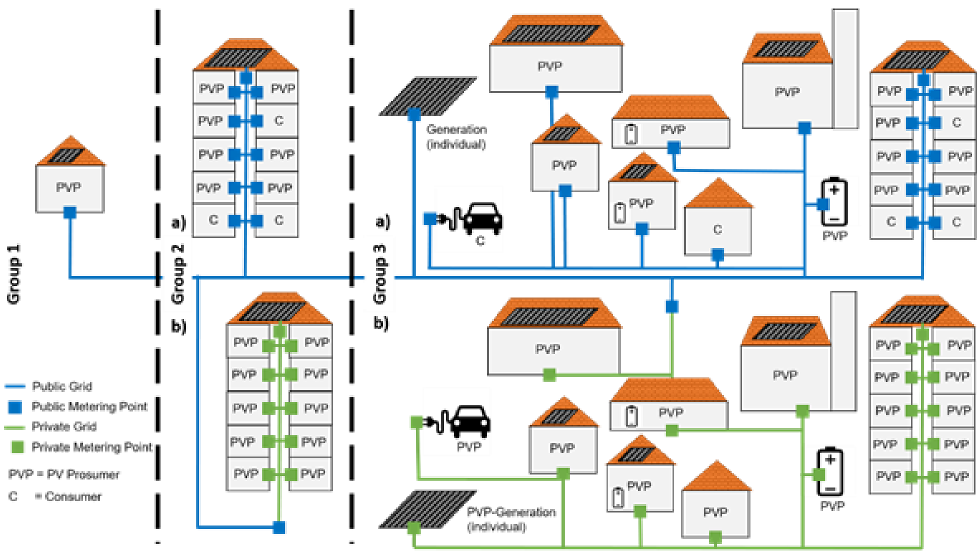

Figure 2: Classification of possible PVP concepts according to their system boundaries. Source (Lettner et al., 2018).

2.2 Improved classification of PVP4Grid concepts

Consequentially, we improve these concepts from the perspective of investments. Investment costs are essential for DER and ESS, as they are the main component in terms of Capital Expenditure (CAPEX) of the levelized costs of electricity (LCOE), see (Ueckerdt et al., 2013; Weniger et al., 2014). Therefore, Figure 3 shows potential prosumer concepts according to a further parameter: time. Figure 3 introduces the time of investment (until the start of operation of DER and ESS). In total, we see four groups of concepts: **(a) individual and (b) community concepts** and **(c) investment or (d) operational concepts**. For operational concepts, the security of the investment is an essential parameter. Although potential prosumers are not only entirely motivated by monetary motives, an economic concept increases the probability of a positive investment decision.

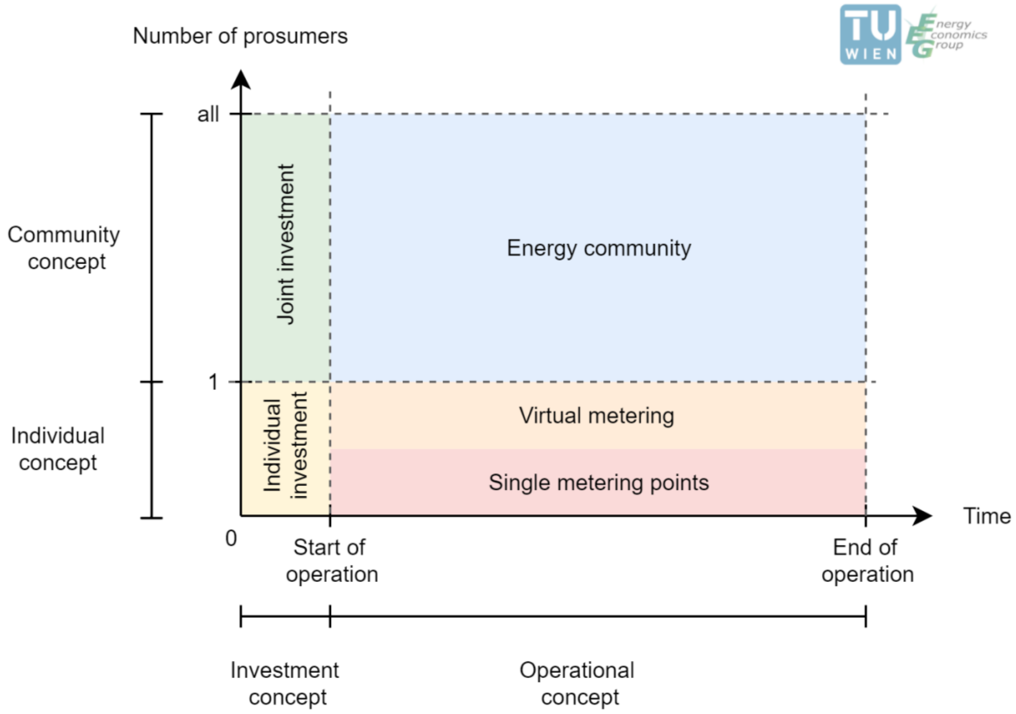

Figure 3: Classification of PVP concepts according to the parameters time and number of prosumers.

For the investment concepts, we see two possible concepts:

- ***Individual investment (II)***: the prosumer investment in a DER or ESS alone and
- ***Joint investment (JI)***: a group of prosumers (we name them community) will invest in a DER or ESS together.

While II is applicable for all groups 1-3, JI is only valid for group 2-3, as a community is necessary for a JI. Also, there are other investment concepts for DER and ESS (e.g., as described in (Dallinger et al., 2018)), such as third-party investments or joint ventures between consumers' and third-party's. Two third-party investment concepts may be:

- <u>Investments by electricity retailer</u>: Distributed generation effects the electricity retailer, by the reduction of delivered quantity. Self-consumption influences the turnover of such a company. If the retailer decides to invest in the generating plant, he can probably generate additional revenues through the sale of locally produced energy.
- <u>Investments by contractor</u>: In the case of contracting, the contractor builds DER or ESS on his own risk. Contractors, also called Energy Service Company or Energy Savings Company (ESCO's), offers various types of energy-related measures to increase efficiency, decrease consumption, reduce CO2 emissions while still meeting the customers projected energy-related needs. Usually, there is also a contract with the consumer for the delivery for electricity, heat, hot water, etc. at an agreed price. Typical contractual agreements are: Power Purchase Agreements (PPA) and Energy Performance Contracts (EPC). The contractor bears the technical and economic risk. The aim of plant contracting is to relieve customers of energy supply issues so that they can focus on their core competencies.

The advantage of third-party investors is that experienced market actors may reduce the investment costs and lower the barriers. The legal situation is manifold between the European countries. Therefore, it is expected that the composition and role of the investors (consumers or third party) is a result of the legal framework.

In the operational phase, we see three concepts (partly also described in (Lettner et al., 2018)):

- **Single metering point (SMP)**: one single prosumer uses the DER and ESS directly on site
- **Virtual metering (VM)**: if generation and consumption happen at the same time (if no storages are considered) but at differing locations and
- **Energy communities (ENC)**: are either organized in a <u>decentralized</u> way, e.g. Peer-to-Peer (PTP) to sell/buy directly from other market participants or

centralized uses platforms to enable consumers to buy directly from generators or other consumers.

Following (Lettner et al., 2018), SMP may be allocated to group 1-3 (if the consumers and prosumers do not join the community), VM to group 1-3 and energy communities to group 2-3.

In reality, two different concepts may be combined upon need. For example, if a consumer does not invest in PV, he is still able to join an energy community. Alternatively, if a PVP invests in a PV plant individually (II), he is also able to join an energy community. In practice, investment and operation concepts are highly connected. Only, if there is a feasible operation concept, the prosumers are willing to invest into DER or ESS.

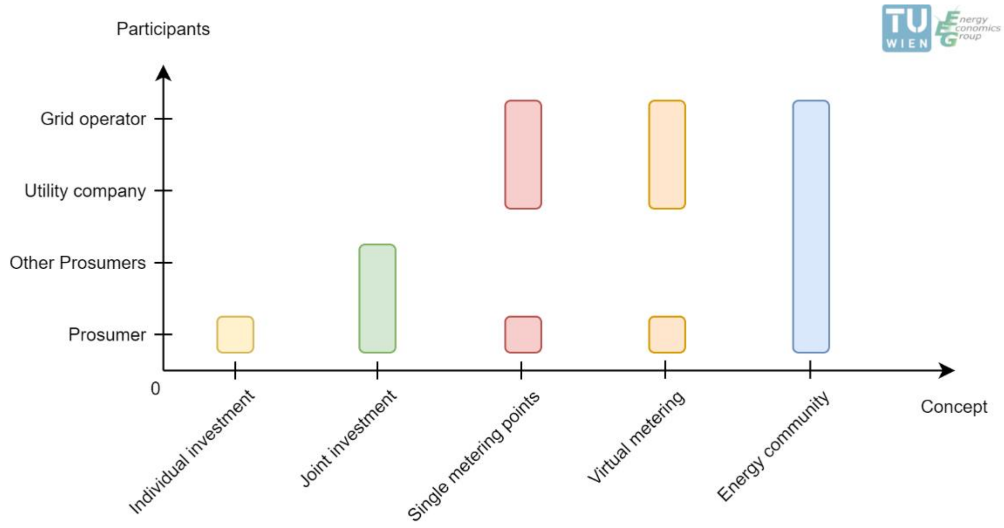

Figure 4: Participants of each concept.

Following, we elaborate on the details of the previously introduced concepts. First, we focus on investment concepts, secondly on operational concepts.

2.2.1 Investment concepts

2.2.1.1 Individual Investment (II)

II is the status quo for group 1 investments. In this case, each prosumer invests and owns the DER and ESS by himself. For example, prosumers living in single-family houses often use this concept, as they own the house as well. Usually, the investment decision in DER or BESS is linked to the operation of the assets and not to forget the effect of the substitution of fossil fuels (e.g., oil, gas, petrol). Also, the investment costs and the amount of self-consumption directly affect the profitability analysis.

When considering the cost-effectiveness of DERs and ESSs, the investor usually assumes a given lifespan of the plant. Essential factors for the investment decision in PV, in addition to the degree of self-consumption and market price for feed-in, are (i) module type and quality, (ii) alignment and roof pitch as well as shading, (iii) solar radiation at the planned location of the plant, etc.

2.2.1.2 Joint Investment (JI)

JI is a concept for a community, for example, prosumers living in the same house (group 2) or an area closeby (group 3). The advantage of JI is that the community has an advantage of economies of scale[4].

An important question for JI is how the investment costs are split among the members of the community. According to literature dealing with joint investments, different approaches show how to share the investments costs:

- per capacity: if each prosumer owns a defined share of the capacity,
- per living space: often uses to share the costs for heat generation or
- per energy: the annuity may be allocated on an annual basis, which bases on the total consumption
- per property: each consumer owns a share of the total property, including new investments on energy assets.

Recent work on the viability of energy communities (Abada et al., 2017) shows that most of the mechanisms fail regarding stabilizing the community. As a consequence, the community breaks apart into smaller sub-communities with lower economic potential and smaller saving potential of greenhouse gases. (Abada et al., 2017; Fleischhacker et al., 2018) shows improved concepts. The concepts based on the

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[4] Definition according to (“Cambridge Dictionary,” 2018): “*The reduction of production costs that is a result of making and selling goods in large quantities, for example, the ability to buy large amounts of materials at reduced prices.*” For DER and ESS this means, that a higher capacity may be invested at lower specific investment costs.

coalitional game theory, where the payoff is allocated in a way to prevent the community from breaking apart. Therefore, there are no incentives for the members of the community to leave it.

JI is often linked to the operational concept. So, a community may decide only in a JI, if the operational concept gives advantages, e.g. increases the economic benefit / local welfare.

2.2.2 Operational concepts

2.2.2.1 Single metering point (SMP)

This operational concept is the most used concept for DER with ESS. This concept is closely linked to "self-consumption". Self-consumption means that the consumer uses or stores locally generated energy at the point of production[5]. Only the surplus electricity is fed into the public grid for remuneration according to the conditions of the corresponding market player. The economic viability of this model lies in the fact that local generation covers a significant part of the electricity consumption (in exceptional cases even the total electricity consumption) and therefore less energy bought from a retailer has to be purchased from the grid. Savings thus result from every self-consumed kilowatt-hour. The maximum of self-consumption optimization has already established itself in the field of private home ownership and a paradigm shift is also noticeable in the commercial segment. (Teoh and Liebl, 2016)

As described in (Lettner and Auer, 2012) fluctuating DER generation during a day, replaces the external procurement from the grid partially or completely. If the PV generation is higher than the load, the surplus energy can be fed into the grid or be saved in ESS if available. The electricity feed-in is remunerated by a market price. Market prices can be fixed feed-in tariffs, green premium tariffs or the "wholesale" price.

[5] Strictly speaking, in legal terms, the role of the generator and the role of the consumer are both held by the same legal entity; consequently, any constellation with non-matching roles needs to be considered as the supply of a third party, resulting in specific implications.

The cost of self-consumption without storage is determined by the LCOE of the DERs and energetic self-consumption. By using ESS, the LCOS (Levelized Cost of Storage) has to be considered and added to the LCOE of DER has, leading to higher total LCOE. Nevertheless, a DER-ESS combination leads to a higher degree of self-consumption and other potential benefits, such as peak shaving, tariff shifts, etc. If the PV generation exceeds the consumption and if no ESS capacity is available, surplus DER generation is fed into the grid.

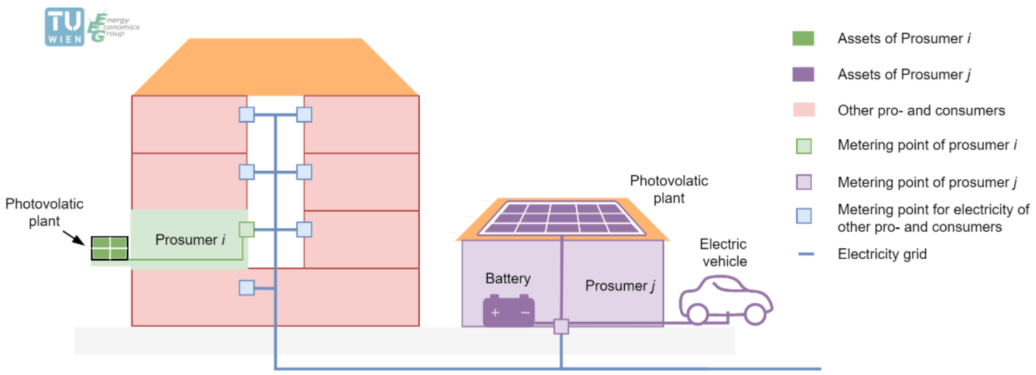

Figure 5: Single metering point from the perspective of two prosumers *i* and *j*.

Figure 5 shows the SMP for two exemplary prosumers *i* and *j*. While prosumer *i* lives in an apartment house, prosumer *j* lives in a single-family house.

The SMP model for prosumer *j* is well established in most European countries, also labeled as group 1 model within the PVP4Grid project. Prosumer *j* operates the assets (in this example BESS, EV and PV) at a metering point assigned to him. The operation strategy may address increasing the degree of self-consumption or using the possibility of arbitrage if the retailer forwards real-time pricing tariffs.

Prosumer *i,* on the other hand, owns a small PV mounted on the balcony[6]. In this case, the concept is similar to those of prosumer j. Prosumer *i,* also meets his remaining electricity demand via grid consumption. The difference is, that

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[6] Concepts of small mountable PV plants are available. One example is simon.energy (Energetica Industries GmbH, 2018)

investments in PV on the rooftop or charging a vehicle of prosumer i requires improved models, such as VM or ENC.

2.2.2.2 Virtual metering (VM)

An improvement for single prosumers is the VM approach. Figure 6 shows an example of VM from the perspective of prosumer *i*. The prosumer lives in an apartment house and owns three assets:

- a share of the PV plant
- a battery not located on the housing site and
- an EV.

This model increases the matching of generation and consumption for prosumers. Figure 6 shows the assets allocated to prosumer i with the dotted line. This model is very interesting for EV, as it is not always possible to park and connect the EV at the physical metering point of the generation site.

VM enables prosumers to access DER produced energy, even if they cannot put solar on their roofs or do not have suitable land for a solar array. In its most basic form, VM allows prosumers to generate energy in one place and use it in a different place. VM is applicable in scenarios where an organization or homeowner wants to install solar, but does not have suitable property conditions (legal issues, small roof, too much shading, in need of repair, structural issues, etc.) for on-site solar. (Solect Energy, 2015)

The achievable gain highly depends on the grid tariff design (e.g., €/a vs. €/kW vs. €/kWh, no charges within a specific area), as well as the time resolution of the metering (e.g., 15min, 1h)

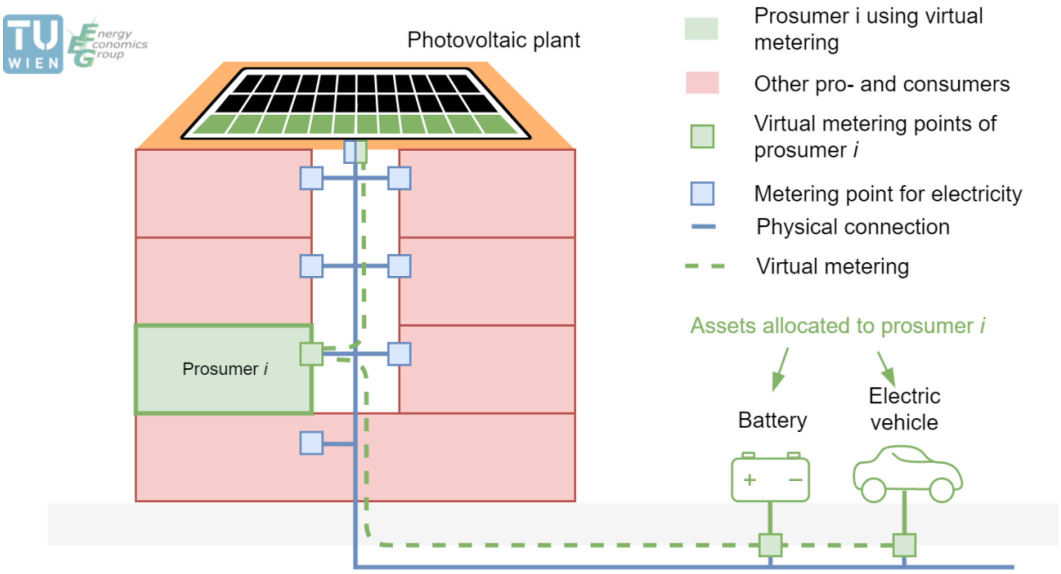

Figure 6: Virtual Metering from the perspective of prosumer *i*.

2.2.2.3 Energy community (ENC)

As stated in the introduction, energy communities will be part of the future market design in the European countries namely, the CE4AE package. As (Pause and Wimmer, 2018) described:

> *While the Commission and the Parliament directly addresses local energy communities in Art. 2 No. 7 and Art. 16 IEM-Dir. and, inter alia, define, grant rights and oblige Member States to enable a framework, the Council only refers to energy communities and provides that they can be engaged in aggregation and are subject to the provisions relevant for such activities and to the same rights and obligations when acting as final customers, generators, suppliers, DSOs, or other market participants. According to Art. 2 No. 7 a local energy community is an association, a cooperative, a partnership, a non-profit organization or other legal entity that has to be effectively controlled by local shareholders or members.*

Very important is the <u>local</u> aspect of the energy community, which means that the consumption and generation will get a local component.

Furthermore, *the Parliament adds that they adequately contribute to the costs of the electricity system they remain connected to and operate on the market on a level playing field without distorting competition (Art. 16 para. 1 lit. ca), cb) IEM-Dir.), but* *also that they are entitled to share electricity from generation assets within the community between its members or shareholders through peer-to-peer trade arrangements for example (Art. 16a) IEM-Dir.).* (Pause and Wimmer, 2018).

Many experts (Park and Yong, 2017, Zhang et al., 2018, Fleischhacker et al. 2018) as well as the Commission expect energy communities' electricity trading with and without the need for retailers or conventional utilities to increase, as the awareness of the shared economy has grown and DERs and ESSs are spreading. Furthermore, the development of renewable energy technology and internet technology will accelerate the dissemination of the new system.

Concept

As shown in Figure 7 and Figure 8, energy communities may be organized in two different ways: (1) centralized or (2) decentralized. While the first one requires a central platform to match generation and consumption, the second one foresees this capability to the consumers/generators. Central trading platforms (at least for larges sized generators, retailer, etc.) are widely established in the energy markets, but not for small-sized entities. Decentralized trading applications are currently under research but not implemented yet.

Besides the setup of the energy community, the most relevant actors are generators, consumers, the trading platform and the retailer. Most importantly is the role of the DSO and Transmission System Operator (TSO) as shown as an underlying layer in Figure 7 and Figure 8, as they define the technical restrictions (especially of electricity flows) of the energy community. Such a model requires a high rate of data exchange between the participants via the platform.

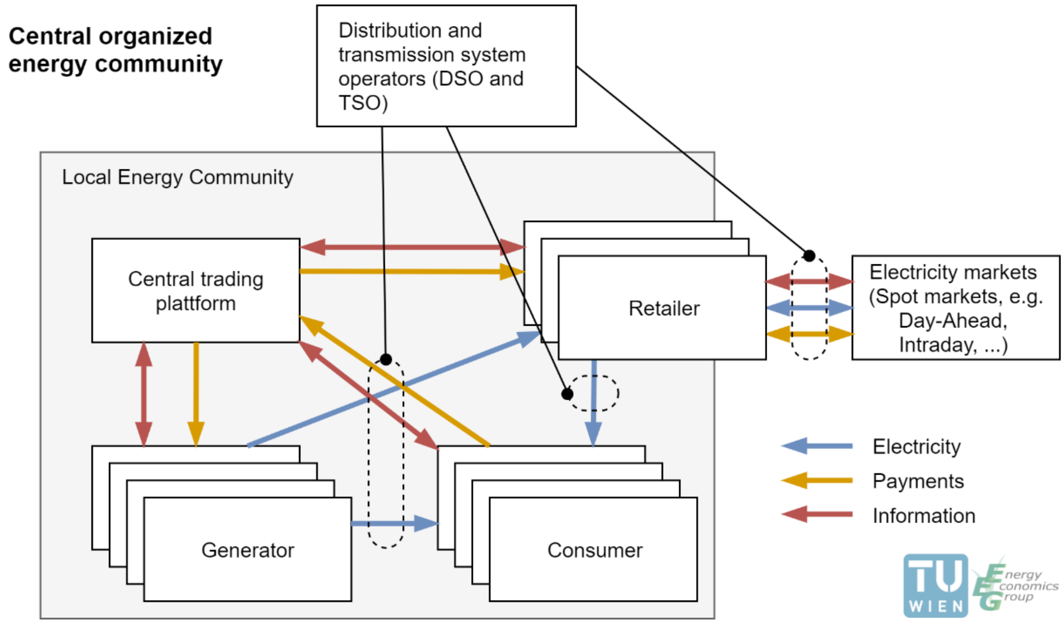

Figure 7: Participants and interactions of a central organized energy community. Grid payments are explicitly not included in this graphic. Own representation based on (Hall and Roelich, 2015)

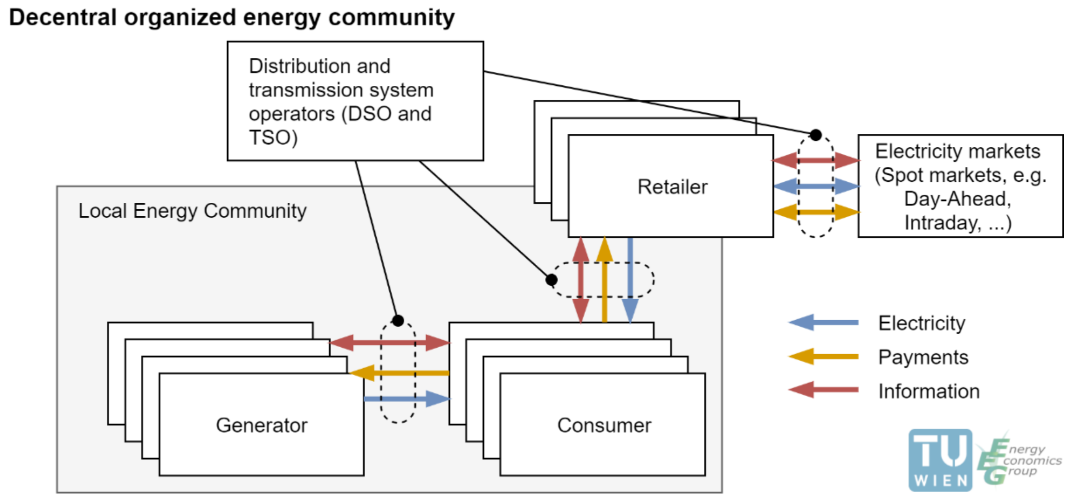

Figure 8: Participants and interactions of a decentralized organized energy community. Grid payments are explicitly not included in this graphic. Own representation based on (Hall and Roelich, 2015)

The role of prosumers may change from generators to consumer and vice versa. Most important is the local matching of generation (generators) and consumption (customers). A synchronized matching requires a technical solution, e.g., by a central software platform (including an operator) or decentralized applications performing this task on behalf of the generators/consumers. Not only matching of generation and consumption can be provided by such a common platform, but additional information such as prices and the origin of electricity generation and consumption may also be visualized. Similar to the food retail sector such a concept allows to satisfy the customer's need in consuming "local products" and increases the economics of DER and ESS. As stated by the Commissions, local aspects will play an important role in energy communities. As there is either an over- or underproduction of electricity, market actors, like retailing companies are necessary to balance the energy community in this respect (Fleischhacker et al., 2017).

The difference to the standard energy-only-market (EOM) is that grid characteristics may be included in the matching algorithm. So, potentially it removes the need for costly future improvements to create additional network capacity to meet increased peak demand flows or gives the prosumer the possibility in monetarizing their investments by a new way (Open Utility, 2018).

Although the design of grid charges and taxes does not reflect and support the local matching, we expect that it will play a role in the future. E.g., in the UK, Open Utility concluded that the current grid tariff design offers no financial incentives to either generators or end-users to join an energy community. In response to this, Western Power Distribution funded Open Utility to explore different grid charging models that might encourage energy communities – and to investigate the potential cost savings that could come from that matching.

Design aspects of energy communities

To understand the design of energy communities, (Zhang et al., 2018) introduced a four-layer model shown in Figure 9. This helps to identify and categorize the key elements and technologies involved in local energy trading based on the roles they play.

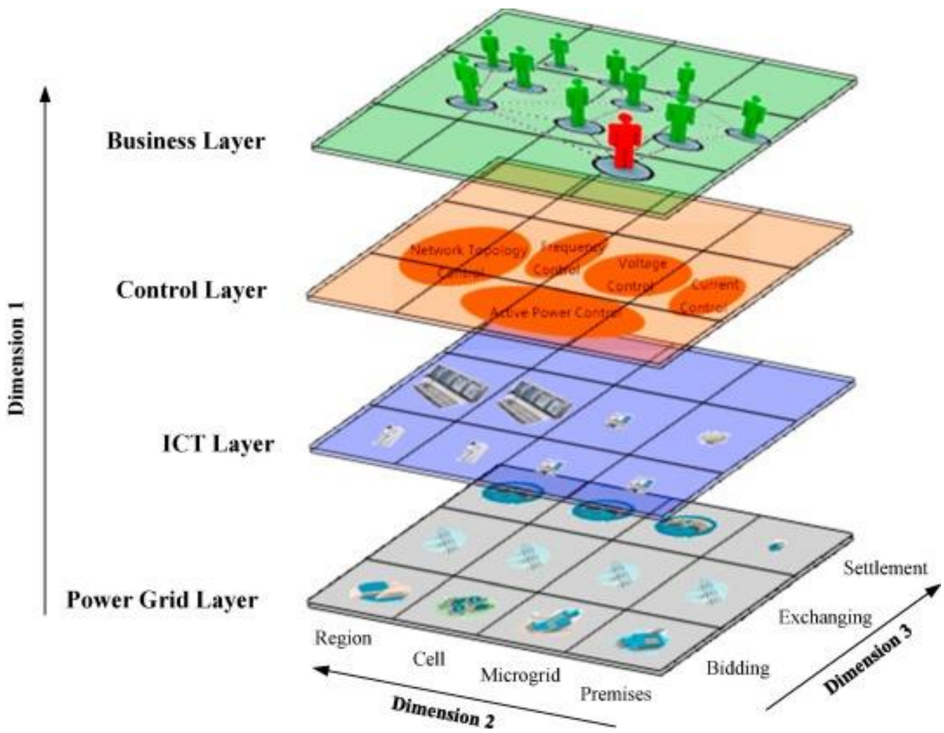

Figure 9: A four-layer system architecture of Peer-to-Peer energy trading introduced in (Zhang et al., 2018)

In the ***first dimension*** described in (Zhang et al., 2018), the key functions involved in local energy trading are categorized into four interoperable layers. Each layer is introduced as follows:

a) The ***power grid layer*** consists of all physical components of the power system, including feeders, transformers, smart meters, loads, DERs, etc. These components form the physical electricity distribution network where P2P energy trading is implemented.

b) The ***ICT layer*** consists of communication devices, protocols, applications and information flow. Communication devices refer to sensors, wired/wireless communication connections, routers, switches, servers and various types of computers. Protocols include TCP/IP (Transmission Control Protocol/Internet Protocol), PPP (Point-to-Point Protocol), X2.5, etc. Communication applications can be various, such as information transfer and file exchange. The information flow refers to the senders, the receivers, and the content of each message transferred among communication devices.

c) The ***control layer*** mainly consists of the control functions of the electricity distribution system. Different control strategies are defined in this layer for preserving the quality and reliability of power supply and control the power flow. Voltage control, frequency control and active power control are examples of possible control functions in the control layer.

d) *The* ***Business layer*** determines how electricity is traded among peers and with the third parties. It mainly involves peers, suppliers, distribution system operators (s) and energy market regulators. Various kinds of business models could be developed in this layer to implement different forms of local energy trading.

The ***second dimension*** of the system architecture is categorized based on the size of the peers participating in local energy trading, i.e. group 2 or group 3 models. (Zhang et al., 2018) named the entities premises (group 1 and 2), Microgrids, Cells, and regions (group 3). Individual premise refers to one single house connected to the electricity distribution system. Microgrids are electricity distribution systems containing loads and DERs, which operate in a controlled and coordinated way either connected to the main power network or islanded. A Microgrid consists of a collection of individual premises and DERs in a local geographical area that shares the same medium-voltage/low-voltage (MV/LV) transformer. A Cell may contain several Microgrids, and may also operate in either grid-connected or islanded mode. A region can be as large as a city or a metropolitan area which consists of multiple Cells. The European Commission sees the spatial extension of energy communities as premises, microgrids or cells but not as a region.

The **third dimension** shows the time sequence of the local energy trading process. Bidding is the first process of local energy trading when energy generators or consumers reach trading agreements with each other before the energy exchange (central) or a matching algorithm (decentralized). During the bidding process, energy customers interact with the trading platform (central) or each other (decentralized) and agree on the price and amount of energy to be traded. Energy exchanging is the second process, during which energy is generated, transmitted and consumed. The settlement is the final process when bills and transactions are finally settled via settlement arrangements and payment. New applications introduce the blockchain technology into local energy trading to simplify the metering and billing system in the energy markets. Considering the physical network constraints, especially those of the distribution system and the uncertainty of DERs, new settling algorithms are necessary to deal with those. (Zhang et al., 2018)

Value creation of energy communities

Energy communities unite customers and generators on a local level and create values for both participants. On the one hand, energy communities generate values for consumers: It helps the consumers to decrease the total costs by (i) a reduction of market participants between the value chain and (ii) an increase of competition. It may also help to establish not-economic technologies currently for residential consumers, e.g., using batteries for arbitrage. As mentioned above energy communities are currently mostly not economical due to the design of grid charges and taxes. With the implementation of the CE4AE package, it is expected to provide value for consumers. The proposed technical solutions may keep track of energy flows within the community and increases the transparency. As DERs and ESSs are mostly installed on a local level, it fits to the real physical flows. Energy communities increase the possibilities of local flexibilities for valorization. Finally, the implementation of energy communities increases the consumption of local energy. Another, value for consumers is that the can express their preferences (e.g., cost reduction, value for emission reduction an individual share of local consumption). The preferences may result in the different level of willingness-to-pay.

On the other hand, it generates values for generators: It opens the possibility to market their generation directly to the consumers. Therefore, they can apply a premium to their power purchase agreement (PPA). The role of prosumers changes between generator and consumer. Therefore, the composition of the energy community changes with time, especially by the behavioral aspect of energy consumption and volatility of (renewable) generation. So do the direction of payments and energy flows.

It also creates values for the retailer: If the retailer runs the trading platform, monetary losses may be compensated. Still, the balancing party is necessary to balance the community (or single consumers if they have individual contracts). The retailer may be capable of providing this service. So, the retailer generates additional costs (imbalance, balancing, metering, and billing) and revenues. Also, the retailer also has an opportunity, because the individual marketing of generators and supply of customers might lead to higher profits.

The lack of tracking energy flows on a local level, the lack of visibility of the generation, potentially leads to a grid being used less efficiently. Also, a grid potentially needs investments to meet the future power flows. As an alternative, energy communities match their generation and consumption on a local level to meet the restrictions of the grid. Therefore, new grid investments may not be necessary, and both the DSO/TSO and consumer/generator benefits from the savings.

Overall, we expect a higher total local welfare by the implementation of energy communities. E.g., (Wachter, 2018) quantifies the locally generated welfare, generated by the implementation of PTP. The future tasks in the PVP4Grid project will elaborate on those as well.

Real world examples

Four real-world applications are:

Brooklyn Microgrid is a decentralized organized powered energy community (called microgrid) in Brooklyn/USA. The participants can engage in a sustainable energy network and choose their preferred energy sources, locally. LO3 Energy is a blockchain based model where energy flows can be bought and sold, all at the local level. (“Brooklyn Microgrid,” 2018 and LO3 Energy, 2018)

Allgäu Microgrid in Allgäu/Germany, a decentralized organized energy community, also powered by the LO3 Energy blockchain. The marketplace will initially consist of five pilot customers who simulate the peer-to-peer electricity trading among each other. Each consumer is equipped with a digital counter and an app. The technology allows setting the preferences for the consumer's electricity purchase or sale. (“Allgäu Microgrid,” 2018)

Piclo in the United Kingdom is a central organized online platform that performs peer-to-peer energy trading for generators and business consumers with a 15min time resolution. It uses a matching algorithm to match local generation and consumption. Data visualizations and analytics are provided to customers. The meter data, generator pricing, and consumer preference information are used to match electricity demand and supply every half hour. Generators have control and visibility over who buys electricity from them. Consumers can select and prioritize from which generators to buy electricity (“Piclo,” 2018). Accordingly to Piclo, existing PTP energy customers are signing up primarily as a demonstration to the increasingly environmentally conscious consumers of their support for local, low carbon energy producers.

Vandebron is a central organized online platform in the Netherlands where energy consumers can buy electricity directly from independent producers, such as farmers with wind turbines. Similar to Piclo, Vandebron acts as an energy supplier who provides incentive tariffs for consumers and generators for exchanging energy. Prosumers who inject surplus energy to Vandebron can purchase energy from Vandebron at a lower price compared with other suppliers. (“Vandebron,” 2018).

3 Definition of the Simulation Use Cases

The purpose of the simulation is the quantification of improved PVP4Grid concepts described in chapter 2. The simulation is part of future work in PVP4Grid. This section describes the setup of the simulation use cases to give an insight into the connection of the current use cases of (Lettner et al., 2018) and improved PVP concepts. This section consists of two sections: the definition of settings for group 2 and 3 (3.1) and the description which simulations will be conducted in the future work of PVP4Grid (3.2). While the first section describes the setups of the groups defined in (Lettner et al., 2018), the second section describes how we apply improved concepts to the groups.

3.1 Definition of the setting for group 2 and 3

When specifying the groups, we want to reflect the European (EU) building situation, in terms of inhabitants per household, share of apartment buildings and single-houses. Therefore, we specify as group 3 the typical housing situation in Europe with considering commercial consumers (Eurostat, 2018). We decided to neglect industrial consumers, because of their very individual consumption profile related to specific processes. Furthermore, industrial consumers are very price sensitive and optimize their energy portfolio (Labandeira et al., 2016).

In the following, we call the setup of the case study “European Village” (see Table 1), as it represents the situation in group 2 and 3 according to (Eurostat, 2018). The “European village” consists of residential single housing units, commercial buildings and a mixed-use property with residential and commercial consumers. In group 2, we observe the same mixed-use property like in group 3.

Table 1: Housing situation of EU (Eurostat, 2018) compared to group 3

	EU (Eurostat)	**Setting of group 3 “European village”**
People per household	2,3	2,3
Share of people living in flats	42%	43%
Share of people living in houses	58%	57%
Cars per person	50%	48%
Single households	30%	30%
Double households	30%	30%
3 people households	15%	20%
4 people households	15%	20%
5 people households	10%	0%

We expect high penetration of electric vehicles in future (Mihov and Rademaekers, 2018). Due to the high electricity consumption of EVs, it is necessary to consider them as part of the total demand per household. For residential car use, we assume a 100 % substitution of fossil fuel vehicles. In average, the share of EV per inhabitant in the EU is 0.5 cars, so we apply the same share of EVs on group 3. Since we expect a higher share of cars in rural areas with more single housing units than in cities with more apartment or mixed-use buildings, we define the density of cars for single housing units higher than for the mixed-use property. As parking space is a scare good in cities, virtual metering may be of importance for a substantial charging profile.

Also, the time of investment (e.g., 2020, or 2025) will play a role in future analysis. As this use case reflect the situation in the future, we expect that all consumers within the groups are equipped with smart meters (European Commission, 2018).

The purpose of the optimization model applied in the simulation part of PVP4Grid is to allow the optimization-model to find a solution for the optimal investment in technologies like photovoltaics, storage systems, and heating or cooling devices. To neglect orientations of the roof-orientation of PV-systems with the input data, we define the rooftop- and PV-orientation with 50% south and each 25% east and west at the optimal elevation angle.

3.1.1 Group 2

Group 2 (Figure 10) is a mixed-use building of residential and commercial consumers. All consumers share a building, where every party is equipped with its own electricity meter. The public grid for group 2 ends at the border of the building as the lines beyond that point are private property. In total, 6 residential and one commercial party lives in the group 2 building with a total of 10 people. The individual load includes the charging demand of three electric vehicles. Figure 10 shows the number of consumers per flat as a symbol, as well as the flats with an EV.

We assume that group 2 has a rooftop suitable for PV installation. As the consumers do also have a demand in heating and cooling, we assume that electricity is used to generate heat/cooling. Additionally, ESS devices may be installed to increase the degree of local self-consumption. Figure 10 shows as BESS as an example for an ESS. Figure 10 already shows possible installations in DER and ESS.

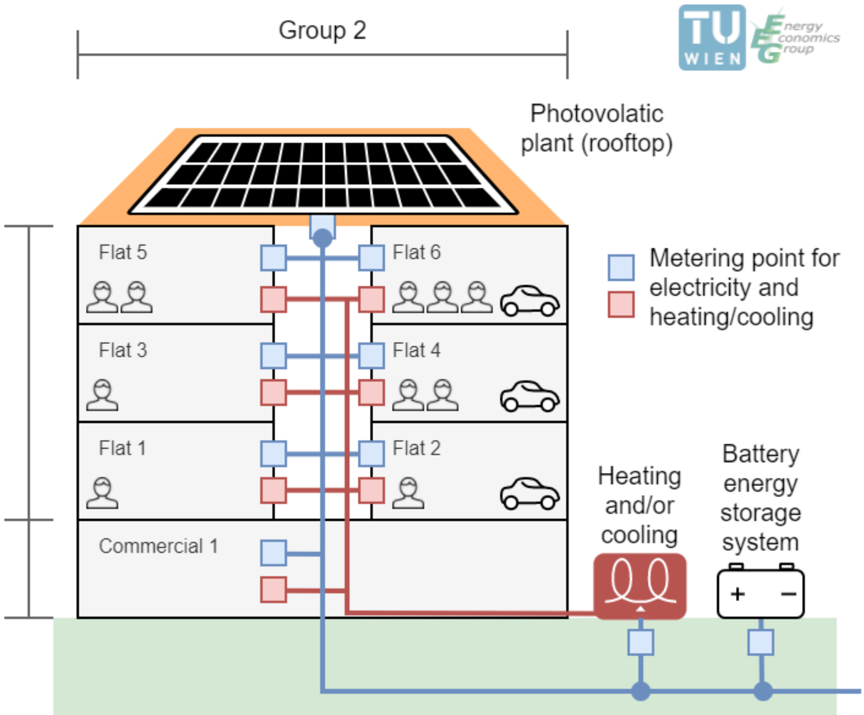

Figure 10: Schematic of group 2

Table 2: Consumer structure of group 2

Consumer	People per housing	EVs per housing
Commercial 1	-	-
Flat 1	1	1
Flat 2	1	
Flat 3	1	
Flat 4	2	1
Flat 5	2	
Flat 6	3	1

3.1.2 Group 3

As introduced above, the “European village”, group 3, shown in Figure 11 reflects the average housing situation in the EU countries. It includes four single housing units, one stand-alone commercial consumers and apartment building of group 2. Table 3 lists up the consumer structure in group 3.

For the investment in DER and ESS, we assume for group 2 the same situation as introduced above. Additionally, the rooftop of the single-houses is also suitable for PV installation. Also, there is an area available for stand-alone PV power plant of up to a capacity of 200 kW.

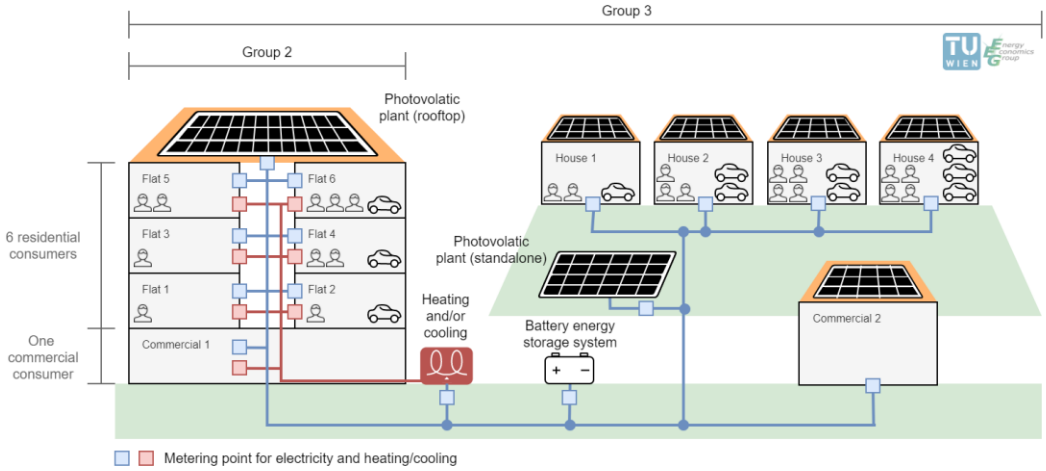

Figure 11: Schematic of group 3

Table 3: Consumer structure of group 3

Consumer	People per housing	EV's per housing
Commercial 2	-	-
House 1	2	1
House 2	3	2
House 3	4	2
House 4	4	3
Mixed-use property	10	3

3.2 Description of the simulation of improved PVP4Grid concepts

As baseline scenarios, we use the approach described in 2.2.2.1, the single metering point (SMP). To calculate the status quo for all baseline scenarios, we assume that no investments in DER nor ESS are possible. For the improved PVP4Grid concepts, Virtual metering (VM) and Energy community (ENC), investments in DER and ESS are possible. Table 4 shows an overview of the baseline and improved PVP4Grid concepts.

For the use cases of Virtual Metering we focus on group 3, since we want to evaluate the effects on distributed PV systems, battery energy systems and EV’s. Peer-to-Peer trading is useful in group 2 as well. Therefore, we require 2 individual use cases for group 2 and group 3 for the ENC scenario.

Due to this high local renewable generation and higher local demand, we can improve the usage of the local system and active distributed generation (DER) and flexibility (ESS). Therefore, the results shall give an insight of a possible future energy system. We describe the use cases in detail in the following.

Table 4: Overview of simulation scenarios

Scenario	Group	Baseline	Improved PVP4Grid concepts
VM	3	SMP without PV, BESS nor EV	VM with PV, BESS and EV
ENC	2	SMP without PV, BESS nor EV	VM with PV, BESS and EV
	3	SMP without PV, BESS nor EV	VM with PV, BESS and EV

4 Technical requirements for the real-life tests

Every country can specify its individual settings for the real-life tests. To handle all the different use cases, we provide a spreadsheet, which is used as model input. For easier comprehension of the input parameters, we created a readme file, where all details are described.

4.1 Readme file “Data requirements for testing”

We provide an Excel file for scaling the optimization model. The intention of this document is to help you to fill out the Excel file parameters.xlsx.

This readme uses an **exemplary testing site in Austria** (provided in parameters_AT.xlsx), as shown in Figure 12 below. The site consists of two buildings (A and B) with three and one residential flats respectively. Building A has installed a photovoltaic (PV), while building B has not. The inhabitants of building A satisfy their electricity and heat demand via electricity. The inhabitants of building B have only an electrical load with an electric vehicle (EV).

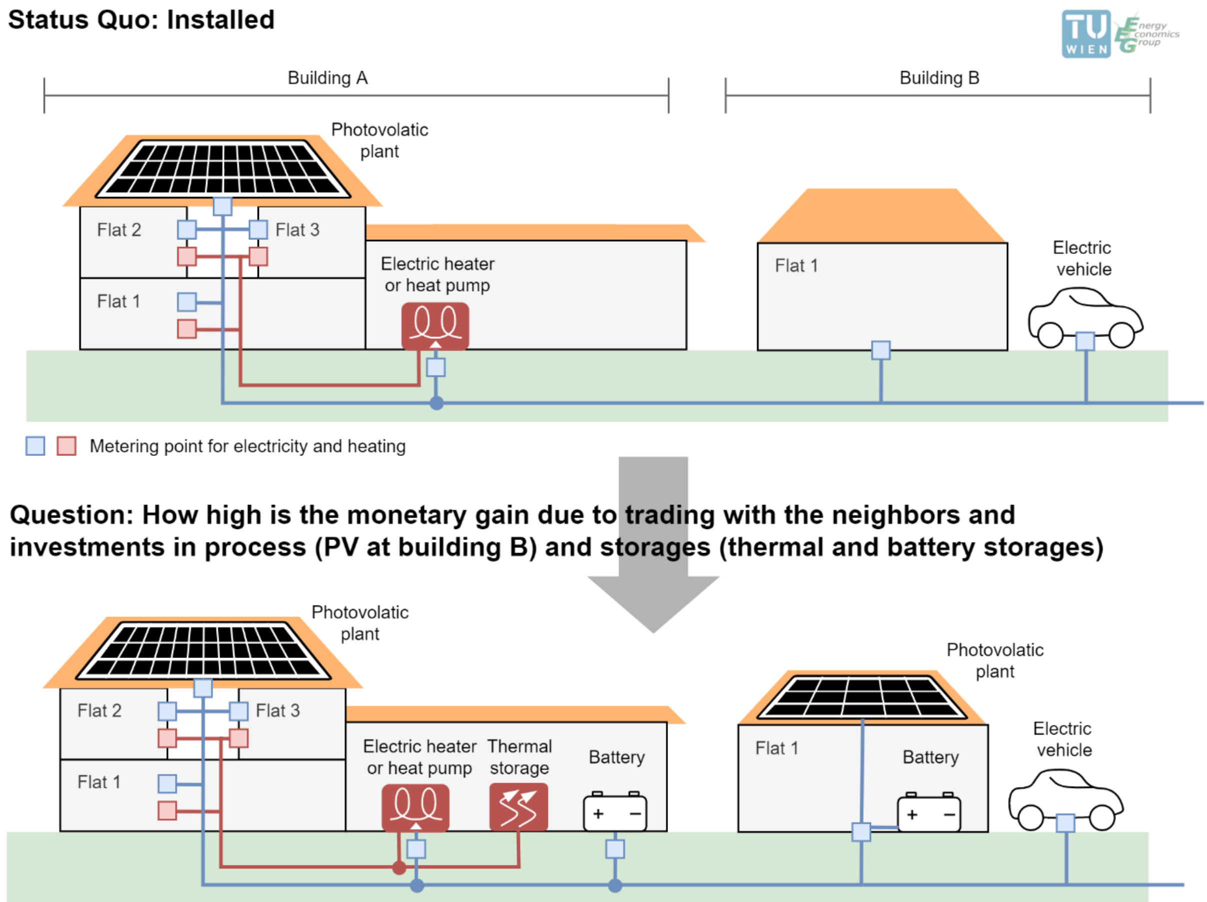

Figure 12: Exemplary testing site in Austria consisting of two buildings, with all current and possible technical options.

Please specify the testing site in the sheet “UseCase_and_question”. E.g. for the testing site we provided you it is as follows:

Description of Baseline and Improved Use-Case:
For this (example) use-case we consider 3 flats (in Building A) and one single house (Building B).
Baseline: Building A already invested in photovoltaics and heat generation (heat pump and electric heater), while Building B has not invested in any technologies.

Improved: We want to investigate, how high the economic benefits are if ***local trading*** is allowed. In this case, Building A is allowed to sell electricity to Building B (and vice versa). Also, which ***optimal investments*** in processes (PV for Building B) and storages (thermal and battery storages) technologies would be optimal.

4.1.1 The functionality of the model

Firstly, you have to understand the functionality of the model. Figure 13 below shows you all components of the optimization model. The aim of the model is

Satisfy a given energy demand (described as commodities) by optimal investment and operation of processes and storages in multiple buildings in respect of lowest costs.

It consists of five main elements:

- Building: describes each building and all consumers in the buildings (e.g. flats),
- Consumer: includes the load of each consumer. The load may be different energy carriers/commodities (e.g. Electricity, Heat, Cooling),
- Process: describes the transformation of energy (e.g. solar PV or heat pumps),
- Storage: describes the energy storage capabilities (e.g. battery),

The model differentiates between existing (installed) and possible assets (to be installed, causing investment costs). As we have the investment, operation and maintenance costs for process and storage technologies of interest, improvements may be identified. The model calculates these improvements, as well as optimum energy flows. If you are not interested in additional investments, please fill out the installed capacity as well as operational and maintenance costs.

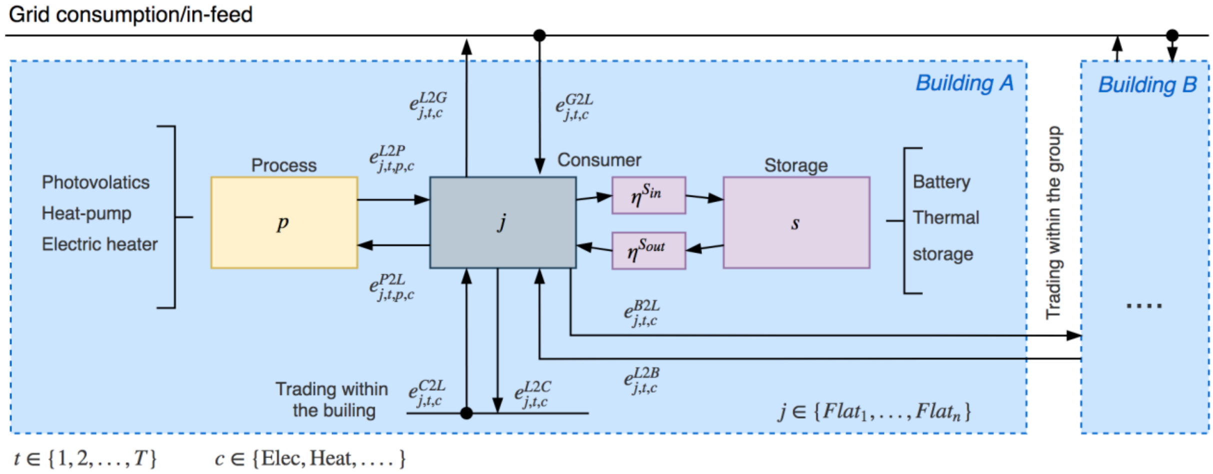

Figure 13: Components of the optimization model consisting of two buildings (A and B).

In the following, we give insight about each sheet of the excel file and describe the variables. Additionally, we will include screenshots for the testing site in Austria.

4.1.2 Building

This sheet gives us information about the name of all buildings, the number of consumer per building and the rooftop area. The sheet has the following columns:

- **Building:** insert a name for each building (e.g. Building A)
- **Number of consumers:** insert the number of consumers/flats (e.g. three families are living in the building)
- **Rooftop Area:** insert the rooftop area used for installed and/or available for future investments in solar PV or thermal in m² (see sheet "Process", "area-per-cap")

	A	B	C
1	Building	Number of consumers	Rooftop Area
2	Building A	3	60
3	Building B	2	60

4.1.3 Consumer

This sheet gives information about the demand for each consumer and commodity as time-series. The header of the sheet contains two rows:

- **Commodity:** gives information about the demand's commodity (e.g. Electricity, Heat)
- **Building:** gives information about the building (see sheet "Building")
- **Consumer:** name of each consumer (e.g. Flat1)

Insert the load data as time series in 15min or 1h intervals with the corresponding timestamps (e.g. 01/01/2017 00:00, 01/01/2017 00:15)

	A	B	C	D	E	F	G	H	I
1	Commodity	Elec	Elec	Elec	Elec	Elec	Heat	Heat	Heat
2	Building	Building A	Building A	Building A	Building B	Building B	Building A	Building A	Building A
3	Consumer	Flat1	Flat2	Flat3	Flat1	Electric Vehicle	Flat1	Flat2	Flat3
4	DateTime								
5	01/01/2017 00:00	0.09	0.61	0.05	0.09	0.19	0.12	0.12	0.12
6	01/01/2017 00:15	0.44	0.42	0.02	0.44	0.55	0.16	0.16	0.16
7	01/01/2017 00:30	0.19	0.86	0.25	0.19	0.23	0.01	0.01	0.01
8	01/01/2017 00:45	0.33	0.81	0.18	0.33	0.93	0.32	0.32	0.32
9	01/01/2017 01:00	0.34	0.32	0.28	0.34	0.48	0.03	0.03	0.03
10	01/01/2017 01:15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

4.1.4 Process

We describe the processes for each building in this sheet with the following entries:

- **Building:** assigns the processes to a building (see sheet "Building")
- **Process:** insert a name for the process (e.g. Photovoltaics or Heat pump)
- **installed:** insert the installed nominal power of the process currently installed in kW/building, if no process is available, insert "0".
- **inv-cost-p:** insert the specific investment costs in €/kW, if you are not interested in additional investments please do not fill out this field.
- **om-cost-p:** insert the annual operational and maintenance (O&M) costs in €/kW/a.
- **area-per-cap:** insert the area per unit capacity m²/kW. Necessary for renewable roof generation e.g. PV.

	A	B	C	D	E	F
1	Building	Process	installed	inv-cost-p	om-cost-p	area-per-cap
2	Building A	Photovoltaics	5	850	8	6.5789
3	Building A	Electric heater	6	60	1	#N/A
4	Building A	Heat pump	10	1150	1150	#N/A
5	Building B	Photovoltaics	0	850	850	6.5789

4.1.5 Process-Commodity

This sheet gives information about the transformation capabilities (Input → Output) of each process including the efficiency factors.

- **Process:** name of the process (see sheet "Process")
- **Commodity:** in- or output commodity (e.g. Solar, Elec) of each process, connected to "Direction"
- **Direction:** specifies if the commodity is an input (In) or output (Out)

- **Ratio:** defines the efficiency factor. Either a number (e.g. 0.95 for 95 %) or the name of a time series (see sheet “Process-Efficiency”)

	A	B	C	D
1	Process	Commodity	Direction	ratio
2	Photovoltaics	Solar	In	1.00
3	Photovoltaics	Elec	Out	eta PV
4	Electric heater	Elec	In	1.00
5	Electric heater	Heat	Out	0.95
6	Heat pump	Elec	In	1.00
7	Heat pump	Heat	Out	eta HP

4.1.6 Process-Efficiency

The transformation of some processes is time-variable, e.g. due to solar radiation in case of photovoltaics. If this is specified in the sheet “Process-Commodity” as text the same text (e.g. eta PV) has to be in this sheet as time series with the corresponding timestamps (e.g. 01/01/2017 00:00, 01/01/2017 00:15)

	A	B	C
1	t	eta PV	eta HP
2	01.01.2017 00:00	0	2.875375222
3	01.01.2017 00:15	0	2.858619946
4	01.01.2017 00:30	0	2.84186467
5	01.01.2017 00:45	0	2.825109394
6	01.01.2017 01:00	0	2.808354117
7	01.01.2017 01:15	0	2.825109394
8	01.01.2017 01:30	0	2.84186467
9	01.01.2017 01:45	0	2.858619946

4.1.7 Storage

We describe storages for each building in this sheet with the following entries:

- **Building:** assigns the storages to a building (see sheet “Building”)
- **Storage:** insert a name for the storage (e.g. Battery)
- **Commodity:** insert the commodity to be stored (e.g. Elec in the case of a battery)
- **installed-p:** insert the installed nominal power of the storage currently installed in kW/building, if no storage is available, insert “0”.
- **installed-c:** insert the installed nominal storage capacity of the storage currently installed in kWh/building, if no storage is available, insert “0”.
- **eta-in:** defines the input efficiency factor. Insert a number (e.g. 0.95 for 95 %).

- **eta-out:** defines the output efficiency factor. Insert a number (e.g. 0.95 for 95 %).
- **inv-cost-c:** insert the specific investment costs in €/kWh
- **om-cost-p:** insert the annual operational and maintenance (O&M) costs in €/kWh/a.

	A	B	C	D	E	F	G	H	I
1	Building	Storage	Commodity	installed-p	installed-c	eta-in	eta-out	inv-cost-c	om-cost-c
2	Building A	Battery	Elec	0	0	0,95	0,95	500	8
3	Building A	Thermal Storage	Heat	0	0	0,95	0,95	100	1
4	Building B	Battery	Elec	0	0	0,95	0,95	500	8

5 Summary and Conclusions

The objective of this report was to propose and evaluate improvements to existing prosumers. We learned that improvements are possible, where we differentiate between two concepts, investment, and operational concepts. As stated, significant changes in the electricity market design can be expected with the implementation of the CE4AE-Package. This document illustrates that the proposed concepts are designed in a way to addresses the future market design. In total, we see five concepts: (a) individual Investment, (b) joint investment, (c) single metering point, (d) virtual metering and (e) energy communities. While the first two concepts are investment concepts, the latter ones are operational concepts. For operational concepts, the security of the investment is an essential parameter. Although potential prosumer is not only entirely motivated by monetary motives, an economic concept increases the probability of a favorable investment decision.

Furthermore, the document gives an outlook in the simulation and testing part of the PVP4Grid project. It describes the setup of the simulation use cases to give an insight into the connection of the current use cases of (Lettner et al., 2018) and improved PVP concepts. Finally, each country will specify its settings for the real-life tests. To handle all the different use cases, we provide a spreadsheet, which is used as model input.

The conclusions of this deliverable are currently on a qualitative level:

- As the legislation in Europe will change with the decision of implementing the *Clean Energy for All Europeans* package, new concepts for consumer, prosumers and generators are needed.

- New investment models, allowing community participation, may increase the local welfare of PV prosumers.
- Although investments may be driven by different motivations, community concepts help to share energy on a local level (e.g. in apartment houses or urban districts).
- The coupling of different technologies and the possibility of local trading (e.g., by energy communities), may increase the flexibility of the local system.
- Innovative concepts help to match supply and demand better and thus increase the degree of self-consumption (also by the substitution of fossil fuels (e.g., oil, gas, and petrol)).

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