INTERACT

Integration of Innovative Technologies of Positive Energy Districts into a Holistic Architecture

D 4.3 Market structure and its interfaces with the Energy Community

21st of November 2022

Federal Ministry
Republic of Austria
Climate Action, Environment, Energy, Mobility, Innovation and Technology

Leader: TU Wien

Dissemination Level

PU	Public	X

History

Version	Description	Lead author	Date
V0	Table of Content	TU Wien	17.3.2022
V1	Definition of Market Structure	TU Wien	8.8.2022
V2	Czech Market Structure	LEEF	10.8.2022
V3	Austrian Market Structure	TU Wien	22.8.2022
V4	Nordic Market Structure	Tornet	26.8.2022
V5	Pricing Mechanisms, current status	TU Wien, SON	8.9.2022
V6	Pricing Mechanisms, possibilities	All partners	10.2022
V7	Staggered Pricing Model	TU Wien	3.11.2022
V8	Power Purchase Agreement	SON	4.11.2022
V9	Review and Refinement	LEEF, TU Wien, SON	7.11.2022
V10	Quality Adjustments in Pricing Models	TU Wien	14.11.2022
V11	Conclusion, Executive Summary	SON	17.11.2022
V12	Final Review	All Partners	21.11.2022

Disclaimer

This project has received funding in the framework of the PED Programme, which is implemented by the Joint Programming Initiative Urban Europe and SET Plan Action 3.2. The project is supported by the Austrian Ministry of Climate Action, Environment, Energy, Mobility, Innovation, and Technology (BMK), Technology Agency of the Czech Republic (TAČR) and Viable cities, a research program funded by the Swedish Energy Agency, Formas and Vinnova.

Executive Summary

This deliverable "Market structure and its interfaces with the Energy Community" is analysing the current market structure of electricity markets in Austria, Czech Republic, and Sweden, how Energy Communities currently are situated in relation to this market structure, and proposes a new, holistic market structure which enables their participation. Furthermore, we describe current pricing mechanisms and two adaptations for price-finding in a local energy market: (i) a staggered pricing mechanism based on merit-order principle with levelized costs of electricity, and (ii) power purchase agreements. We also outline how the proposed market structure is mirroring the power system structure, and therefore better reflecting the physical flows of electricity.

Also based on pricing mechanisms developed within this deliverable, we will perform the evaluation of our business cases in D5.3. Further description of the different rights and roles within the proposed market structure and further research regarding the pricing mechanisms to better fit to a broader range of price situations is suggested.

After a short introduction into the document in Chapter 1, we explain in Chapter 2 different market terms and structures. In Chapter 3 we describe in detail the current participants and information rules within the electricity markets in Austria, Czech Republic, and Sweden. As Energy Communities currently are not able to participate, we propose in Chapter 4 a holistic market structure, which is enabling the participation. We also describe pricing mechanisms which would help promoting the further investments into DERs and compare them with the current status. And we outline the link between the power grid structure and the proposed market structure, to easy understand its underlying principles. The deliverable summarizes its conclusions in Chapter 5.

With this deliverable, Work Package 4 – "Design of the LINK-based Energy Community with respect to Stakeholder Needs" is concluded. The information gathered and developed within this document is a vital contribution to the final Deliverable 6.1 – "Roadmap for the implementation of the designed INTERACT energy community in general and for the specific local perspectives" as it integrates the Energy Community with the Electricity Market and shows the still open steps to enable this proposed integration.

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List of Abbreviations and Acronyms

ATV	Average Trading Volume
BEP	Break Even Price
BG	Balance group
BRP	Balance responsible party
CAM	Control area manager
CAO	Control area operator
CAPEX	Capital Expenditure = Investment Cost
CSA	Clearing and settlement agents
DER	Distributed energy resources
DSO	Distribution System Operator
EC	Energy Community
ECDEP	Energy Community Data Exchange Platform
ISR	Imbalance settlement responsible
LCOE	Levelized Cost of Energy
LVG	Low Voltage Grid
MVG	Medium Voltage Grid
NEMO	Nominated electricity market operator
OPEX	Operational Expenditure = Running Costs
OTC	Over-the-counter bilateral trades
PPA	Power Purchase Agreement
REC	Renewable energy community
SO	System operator
TSO	Transmission system operator

Table of Contents

1 Introduction

A market is a place or an opportunity where people buy and sell goods. The market rules are human made to enable fair cooperation between market participants. They are subject to constant changes and adoptions depending on the circumstances. Whereas the product "Electricity" differs qualitatively from the usually traded products, its production and distribution must be subject to the electricity's laws, i.e., nature's laws. In contrast to human-made laws, nature's laws cannot be modified – that's why they are so powerful and explosive. Therefore, when now the structure of the production and consumption of electricity changes, also the market structure should be redesigned. The redesign should follow a standardized and holistic architecture, in line with the holistic architecture of Smart Grids and Energy Communities.

Although the electricity markets are undergoing a radical change, the current re-dispatch process for congestion management is still costly and drives the transmission grid operation to its limits. On the other hand, the electricity producers connected to the distribution grid cannot participate in the market. The DSOs do not participate in the market operation to manage their congestion management. The effective operation of the Distributed Energy Resources (DER) is quite limited. The transformation of the resource mix of fossil fuels to renewables and the rise of distributed resources call for a radical review of the market structures under a holistic view, including the power grid, customer plants, and the market together.

1.1 Purpose of the document

This document aims to outline an electricity market structure that harmonizes with the smart grids and facilitates the energy communities, thus enabling the democratization of the power industry. It wraps up the current electricity market principles in the countries Austria, Czech Republic, and Sweden, and outlines an alternative holistic market structure, where energy communities are participating within the market. Furthermore, the document shows different pricing mechanism available for energy communities, and outlines principles for aligning the electricity market more with the real physical flows of electricity.

1.2 Relation to other project activities

This activity is one of the main pillars of the project enabling viable energy communities and the design of the roadmap. It designs the market to allow the viable implementation of energy communities. It bases on the organizational structures for INTERACT Energy Communities discussed in D4.1 and the current legal situation regarding Energy Communities and Electricity Markets described in D5.1. Based on the described pricing mechanisms the economic evaluation currently performed and then summarized in D5.3 is made.

1.3 Structure of the document

The deliverable is divided in 3 main chapters: after this introduction in Chapter 2 a general description of electricity markets and its terms is made. In chapter 3 we focus on the electricity markets in Austria, Czech Republic, and Sweden, which is part of the Nordic Electricity Market. We show the current relations between the different market players and verify, whether energy communities can participate. In chapter 4 we describe the proposed holistic market structure, which allows a direct participation of energy communities, and outline different pricing mechanisms and discuss how they would promote further investments into DERs. Conclusions are summarized in chapter 5.

2 Electricity market types

Several characteristics determine the nature of the electricity market, such as sales strategy, geographic conditions, and the specifics of the traded commodity "Electricity".

2.1 Distribution Channel

Within the sales strategy, on the level of distribution channels, wholesale and retail market types are well-established in the worldwide trading process.

2.1.1 Wholesale Market / B2B-Market

The wholesale market is the market for the sale of goods to a retailer or intermediaries, also known as Business to Business (B2B) Market. A wholesaler receives large quantities of goods from a manufacturer and distributes them to stores, where they are sold to consumers. A wholesaler can generally extract a better price from the manufacturer because it buys many goods relative to an individual retailer. In theory, this enables the retailer to resell the goods at a better price for the consumer. Due to the specifics of "Electricity" the electricity wholesaler cannot "store" the goods, but the trade is happening for expected future production and demand, with a short time balancing system managing differences.

2.1.2 Retail Market / B2C-Market

The retail market is the market for selling goods or services directly to consumers rather than producers or intermediaries, also known as Business to Consumer (B2C) Market. For example, a retail clothing store sells to people who will (most likely) wear the clothes. It does not include the sale of the clothes to other stores that will resell them. A retailer is a company that sells goods or services to consumers. It acts as a customer in the wholesale market. Retailers do not sell their products to other stores that will resell them.

2.2 Markets for different geographical levels

We can divide markets e.g., in the following three types per geographical levels:

2.2.1 National/International market

The national/international market constitutes the customers who buy the products/services from vendors who sell products that are produced nationally or internationally.

2.2.2 Regional market

The regional market constitutes the customers who buy the products/services mainly from vendors who sell products produced in the region.

2.2.3 Local market

The local market constitutes the customers who buy the products/services mainly from vendors who sell products produced in the local area.

2.3 Specific electricity market categories

The electricity market can be divided into three large categories: the day-a-head market, the intraday market, and the market for other services. More information on the Energy Market and its current relation towards ECs can also be found in our Deliverable D5.1 "Current regulatory framework and differences between the PED-target countries", mainly within the chapters 2 – European Electricity Market and 5 – Energy community and energy market.

2.3.1 Day ahead market (Energy)

The day-a-head market is based on auctioning electricity in an exchange platform. It hosts transactions for selling any buying electric energy one day before the delivery. In the day-a-head market, the Merit Order pricing mechanism is used. Buyers and sellers submit their offers to a market operator, which acts as a central counterpart. A market offer includes a quantity of energy and the price for this energy. In the case of sell offers or buy bids, the price denotes the minimum or maximum price at which the seller is willing to provide or the buyer to consume electricity. To build a cumulative selling curve, all sell offers are ranked in price-increasing order. The cumulative buying curve is carried out similarly by ordering buy bids in price-decreasing order. The intersection between the two curves identifies the market-clearing price and volume. All offers on the left of the clearing volume are accepted, while the offers on the right are rejected. Accepted offers or bids are generally reimbursed at the clearing price, disregarding the offer, or bid price [1].

2.3.2 Intraday market (Flexibility)

The intraday market is an essential instrument that allows market participants to react flexibly in considering unexpected changes in generation, consumption, and grid outages. It works closely with the day ahead and ancillary markets (see below chapter 2.3.3) to help a secure grid operation. You can trade closer to the physical delivery within the intraday markets. It is a continuous market, with trading occurring daily around the clock until one hour before delivery and, in some cases, right up until delivery. Prices are set based on a first-come, first-served principle, where the best prices come first – the highest buy price and lowest sell price.

2.3.3 Other services

"Other services" includes the ancillary service market, capacity market, etc. The ancillary services market aims to enable market participants to act efficiently in the short term (e.g., demand response, power reserve, etc.) and to guide long-term investment decisions. It uses short-term information to form prices that reflect the location-based marginal value of specific energy services. The capacity market facilitates long-term decisions to ensure sufficient capacity to operate the grid reliably in the future: It uses an auction to procure the required power capacity.

3 Status quo of Electricity Markets in Austria, the Czech Republic and Sweden

3.1 Electricity market in Austria

The main legal source for Austrian energy policy is the Federal Electricity Management and Organization Act 2010[2]. It provides regulations for an equal, fair, consumer-friendly, and transparent energy market. Therefore, it regulates, among other things, the rights and duties of the market participants, especially their obligations to the consumers.

3.1.1 Market's Players

Control area managers (CAMs) The European interconnected grid is subdivided into control areas that control the power flows across it. The interconnected grid consists of several areas, each operating separately. Load meters are installed on every power line that crosses a control area boundary, and the readings are transmitted online to the respective control centres. The control area managers calculate in advance how much electricity will need to cross the control area boundaries to fulfil the supply contracts in place. The power stations within the control areas are operated following these schedules.

Tasks:

- Continuously measure demand within their control areas.
- Transmit these readings to the clearing and settlement agent, which calculates the amount of balancing energy required based on the difference between forecasts and actual supply and demand.
- Bill the clearing and settlement agent for the balancing energy required.

Clearing and settlement agents (CSAs) are individuals or entities with official licenses to operate a settlement agency.

Tasks:

- Calculate the difference between the balance responsible parties' forecasts and actual flows metered by the system operators
- Bill the balance responsible parties for the balancing energy required
- Pay the control area managers for the balancing energy required
- Obtain offers for balancing energy from producers and compile merit order lists based on these bids

Imbalance settlement responsible (ISR) is a natural or legal person or a registered partnership operating a billing agent for imbalance settlement.

The **Transmission System Operators** (TSOs) are responsible for performing the functions of a network operator and for transiting electricity. It takes over the function of CAM.

The Balance Responsible Parties (BRPs) consolidate suppliers and consumers into a virtual group within which supply (procurement schedules, injection) and demand (delivery schedules, withdrawals) are balanced. It requires both a clearing and settlement agent and a balance responsible party to function.

All market players are obliged to join **balance groups** (BG). They supply power to and/or procure it from their balance groups. The purpose of a balance group is to even out supply and demand fluctuations.

The balance responsible parties represent their groups in dealings with other market players.

Tasks:

- Obtain day ahead consumption forecasts from all the suppliers in their balance group
- Send these forecasts to the clearing and settlement agent
- Pay the clearing and settlement agent for the balancing energy
- Bill the suppliers for the balancing energy required

The **Distribution System Operators** (DSOs) are obliged to transport electricity in accordance with the existing contracts between producers and withdrawers, in return for payment of the regulated system charges. They must take any action necessary, under the prevailing technical circumstances, to maintain network stability. In particular, they must make long-term investments to maintain the operability of their networks.

Tasks:

- Conclude system access contracts with their customers
- Transport electricity to their customers
- Meter consumption and attribute it to the individual balance groups
- Transmit consumption data to the clearing and settlement agent.

The **Suppliers** sell electricity to their customers. Since October 2001 system operators have been obliged to grant all suppliers non-discriminatory access to their networks. As a result, all consumers have a choice of suppliers.

Tasks:

- Conclude supply contracts with their customers.
- Notify their balance responsible party of their customers' forecast consumption for the next day
- Bill their customers for the power they consume

Electricity Consumers: Since 1st of October 2001 all consumers — households, small and medium-sized, and large businesses — have been free to choose their suppliers.

Tasks:

- Conclude supply contracts with their suppliers
- Pay their suppliers for the power they consume

A **Producer** is a natural person, legal entity or partnership that generates electricity.

Tasks:

- Conclude contracts with electricity suppliers or OeMAG (the green power clearing and settlement agent)

An **Electricity Wholesaler** is a natural person, legal entity or partnership gainfully selling electricity. An electricity wholesaler performs no transmission or distribution functions either inside or outside of the network in which it operates.

Tasks:

- Conclude contracts with producers.
- Conclude contracts with electricity suppliers and/or other electricity wholesalers or traders

The **Nominated Electricity Market Operator** (NEMO) is responsible for introducing single day-ahead and/or intraday market coupling.

3.1.2 Market structure and information flow

Figure 1 shows the electricity market structure in Austria and the information flow, based on [2],[3],[4],[5].

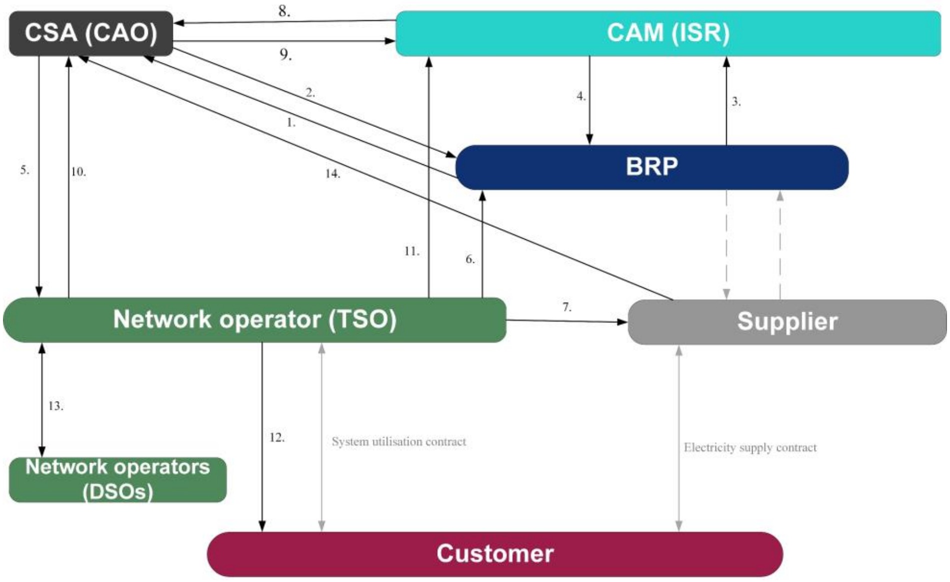


Figure 1: Electricity market structure in Austria and the information flow.

The following information exchange between the market players:

1. BRP sends to CAO:

Everyday: - External schedules, i.e., separate receipt and supply schedules (intraday changes with a lead time of 45 min before each full hour);
- Network-node power station schedules, i.e., separate schedules for production and consumption for pumping (immediately the deviations from the schedules that exceed the thresholds);

- Total net generation, i.e., gross generation minus own consumption (immediately the deviations from the schedules that exceed the thresholds);
- Total consumption of the balance group (BG) for pumping (immediately the deviations from the schedules that exceed the thresholds).

Annually: - Power station maintenance schedules (annual schedules with weekly information, to be updated when changes are made).

2. CAO sends to BRP:

Everyday: - Confirmation of external schedules, i.e., Time Series Confirmation Report (intraday changes to be sent no later than 20 minutes after receipt by the CAO).

3. BRP sends to ISR:

Everyday: - Internal schedules, i.e., separate receipt and supply schedules (intraday changes with a lead time of 15 minutes before each quarter of an hour);
- Schedules for grid losses, transmitted by the network operator in its role as BRP of the dedicated balance group for grid losses.

4. ISR sends to BRP:

After clearing is concluded → Total imbalance caused by the BG.

5. CAO sends to Network operator (SO):

Everyday: - Network-node power station schedules, i.e., separate schedules for production and consumption for pumping (intraday changes immediately).

Annually: - Power station maintenance schedules.

6. Network operator (SO) sends to BRP:

Monthly: - Monthly aggregate time series per supplier (except for local players): separate time series for actual production and actual consumption (in accordance with the clearing interval);
- Monthly aggregate time series per balance group: separate time series for actual production and actual consumption (in accordance with the clearing interval);
- Monthly aggregate time series of the second clearing for the month M-14, for each supplier and balance group, i.e., separate time series for actual production and actual consumption (by the last working day of the month).

7. Network operator (SO) sends to Supplier:

Monthly: - Time series (15-minute intervals) for grid users with load meters (in accordance with the clearing interval);
- Monthly aggregate time series per supplier, i.e., separate time series for actual production and actual consumption (in accordance with the clearing interval);

- Monthly aggregate time series of the second clearing for the month M-14 for each supplier, i.e., separate time series for actual production and actual consumption (by the last working day of the month);
- Actual consumption of non-metered customers (according to the meter reading intervals, normally annually).

8. ISR sends to CAO:

Everyday: - Total of each BG's internal schedules (as time series in 15-min. intervals).

9. CAO sends to ISR:

- Tendered, offered and purchased amounts of balancing capacity (after the result of the tender for balancing capacity);
- Each supplier's balancing capacity call-offs, also as internal schedules (the day after call-off);

Monthly: - Clearing data for imbalance price calculation, e.g., standby capacity costs, costs of called-off bids, costs of compensation programs.

10. SO sends to CAO:

Everyday: - Meter readings from power stations for which network-node schedules had to be submitted: separate values for production and consumption for pumping.

11. Network operator (SO) sends to ISR:

Monthly: - Monthly aggregate time series per balance group: separate time series for actual production and actual consumption (according to the clearing interval);
- Total consumption of the balance group for pumping (according to the clearing interval);
- Monthly aggregate time series per supplier, i.e., separate time series for actual production and actual consumption (according to the clearing interval);
- Time series readings of load meters in 15-minute intervals for each grid's interconnection points (according to the clearing interval);
- Monthly aggregate time series of the second clearing for the month M-14, for each supplier and balance group: separate time series for actual production and actual consumption (by the last working day of the month).

12. Network operator to customer:

Annually: - Actual consumption, to bill the system charges according to the Electricity System Charges Ordinance (according to the meter reading intervals).

13. Network operator (SO, TSO) sends to Network operator (SO, DSOs):

Monthly: - Aggregate monthly time series (in 15-minute intervals) of each grid's interconnection points (by the 5th working day of M+1).

14. Supplier sends to CAO (optional bids for balancing energy or capacity**):**

Weekly: - Primary control;

- Secondary control;

Weekly or daily: - Tertiary control.

3.1.3 Pricing mechanism

As per the definition, small consumers and prosumers do not participate in the market. Suppliers define the price mechanisms. The functioning of the Austrian Electricity market has been described in Deliverable 5.1, Chapter 5.

For **large consumers** who can access trade on the exchange, prices are defined following the rules of the exchange. The minimum order value of the Austrian Exchange is 0,1 MWh/h; trading is possible for each 15min period.

Private persons and small consumers purchase electricity via the electricity supplier, who defines the price. Suppliers compete against each other on the free market, and pricing schemes vary between the suppliers. There are many different electricity suppliers available, as well as comparison websites showing the best current offer for a defined area and consumption. Comparison website (such as stromliste.at [6]) shows about 150 energy suppliers within Austria, which are available within the country in different areas. Also, the Austrian regulator e-control offers its price comparison website called "Tarifkalkulator" [7]. In November 2022, EVN Niederösterreich, the biggest electricity supplier in Austrian demo-site Großschönau offers the following tariffs [8]:

- **Private persons**:

a. Optima Float: monthly, index-based price adaption, 1-year minimum duration, 100% domestic production, 3 EUR/month, 45,78 ct/kWh
b. Optima Float Natur: monthly, index-based price adaption, 100% CO_2-free, 1-year minimum duration, 100% domestic production, 3 EUR/month, 46,26 ct/kWh
c. Optima Flex Natur: 12-month price guarantee, 100% CO_2-free, no minimum duration, 100% domestic production, 3,504 EUR/month, 54,26 ct/kWh

- **Enterprises**: Individual offers only. Available: floating tariffs with monthly price adaption, fixed tariffs, CO_2-free electricity

- **Municipalities**: Individual offers only. Available: floating tariffs with monthly price adaption, fixed tariffs, CO_2-free electricity

For **produced electricity,** the same rules apply to consumed electricity. Large producers can access the exchange and sell via the exchange. Small producers need to sell to an electricity supplier, who purchases the electricity. They are again competing in the market, and price offers can differ from company to company. Each producer has two contracts, one for sold electricity and one for purchased electricity. The contract partners may be the same but do not have to be the same. For produced electricity in Austria, a market price exists, which is quarterly updated by the regulator e-control. This market price is usually the reference price for energy suppliers. Currently, EVN Niederösterreich, the biggest electricity supplier in the area of Austrian demo-site Großschönau offers private persons to pay a fixed price up to the amount of energy consumed fixed for the given period. For energy excess, the market price of the e-control must be used, which should not exceed the price of the consumed energy set on the contract.

3.1.4 Electricity market and the Renewable Energy Communities

Regulatory framework in relation to Renewable energy communities has been described in Deliverable D5.1., regarding participation possibilities in chapter 5, and regarding incentives in chapter 6.3.1.

With regards to the participation in the electricity market, the EC is creating an additional object which is added to the possibilities of the EC members. Depending on the individual contractual agreements within the EC, the members either must or can take the provided electricity from the EC, and only the rest will be provided by the current electricity supplier. The same is valid for production, where the produced electricity surplus (production exceeding own demand) must or can be first sold to the EC before it will be sold to the electricity supplier. More details regarding contractual possibilities will be given in D5.3 "Required contracting models and economic evaluation of the solution".

The main benefit for the EC members is given by law, as the grid fees are reduced by certain percentages, depending on the grid level. Table 1 below shows again examples of savings for Lower Austria, the region of our Austrian demo site, based on [9].

Table 1: Calculation examples of savings in the part of fees - Lower Austria

	Example 1 – Local REC on LVG	Example 2 – Regional REC on LVG	Example 3 – Regional REC on MVG:
Grid Fee Standard Usage	4.45 Cent/kWh (Level 7)	4.45 Cent/kWh (Level 7)	0.87 Cent/kWh (Level 5)
Grid Fee REC	1.91 Cent/kWh (Level 7)	3.2 Cent/kWh (Level 7)	0.31 Cent/kWh (Level 5)
Savings on the part of the fees	57%	28%	64%

To minimize the risk for producers of renewable energy, another supporting mechanism was added by the Austrian government, a so-called market premium. This tool shall support producers in times of low energy prices and shall add a premium to the current market price. This tool is switching the support for DERs from fundings of investments to hatching operations and increases the financial security for lager investments[10].

The Austrian Energy Act defines this market premium also for RECs in EAG §80: next to the investment-based funding of installations, RECs may receive for maximally 50% of the produced and not consumed electricity within a REC a market premium[11].

To support the creation of Energy Communities in Austria, a special website was created by the Austrian government, bundling all information towards this topic: www.energiegemeinschaften.gv.at.

3.2 Electricity market in Czech Republic

3.2.1 Market Players

The Czech electricity market and its players have similar structure as described in previous section dedicated to Austria. Figure 2 below shows the main participants and their interaction. More detail to regulatory framework is describe in Deliverable D.5.1. Legally they are defined in Energy Act No. 458/2000, there are following electricity market players:

- transmission system operator,
- distribution system operators,
- market operator,
- electricity traders,
- electricity producers (Suppliers),
- customers.

There is one transmission system operator (ČEPS, a.s.), three main distribution system operators (PREdistribuce, a.s., ČEZ Distribuce a.s. and E.GD a.s.). There is one market operator (OTE, a.s.) that operates short term market.

3.2.2 Market structure

The main task of OTE is to organize the short-term electricity and gas market and to ensure the balance between supply and demand. In addition, OTE also has a statistical function and is the central information point for the electricity and gas market. It produces monthly and annual reports and balances and prepares detailed annual reports each year.

Grid operators transmit to OTE each day the actual values electricity deliveries and withdrawals at the transfer points of individual electricity generating plants equipped with continuous metering and the amount of electricity procured by it to resolve imbalance conditions.

Market participants responsible for their imbalances ("subject to settlement") on energy market provide data to OTE on a regular basis. The evaluation interval is one hour until June 2024. From July 2024 the evaluation interval shall be fifteen minutes.

Large customers with subject to settlement have continuous metering and report to OTE their production diagrams. Small customers still have the metering with annual frequency of measurement. The roll-out of implementation of smart meters should start in June 2024 for customers with annual consumption > 6 MWh.

Electricity Producers can participate on ancillary services if they have minimum 1 MW power certified for providing a certain type of ancillary service, large suppliers report to OTE every day, small suppliers on the monthly basis. Since 2021 there is also possible to provide ancillary services in aggregation of smaller sources with < 1MW power. The aggregator becomes responsible for the deviation for the members of the aggregation portfolio.

Further legislative changes are still needed to accelerate the development of flexibility and opening of energy market to direct participation of active customers (i.e. prosumers).

Figure 2 illustrated the relationships among the market players. The exchange of information is like other analysed countries as whole European Energy Market is moving towards harmonization.

1. BRP sends to ISR:

- External schedules, i.e., separate receipt and supply schedules
- Network-node power station schedules, i.e., separate schedules for production and consumption
- Total net generation
- Total consumption of the balance group (BG)
- Power station maintenance schedules (large customers)

2. ISR sends to BRP:

- Confirmation of external schedules
- Total imbalance caused by the BG.

3. Network operator (DSO) sends to BRP:

- Aggregate time series per MGA: separate time series for actual production and actual consumption

4. Network operator (DSO) sends to Trader:

- Time series for grid users with load meters (in accordance with the clearing interval);
- Monthly aggregate time series per supplier, i.e., separate time series for actual production and actual consumption
- Actual consumption of non-metered customers (according to the meter reading intervals, for small customers normally annually).

5. CAO sends to ISR:

- Tendered, offered, and purchased amounts of balancing capacity

6. Network operator (DSO) sends to ISR:

- Monthly aggregate time series per balance group: separate time series for actual production and actual consumption (according to the clearing interval);

7. Network operator DSO send to customer:

- Actual consumption, Bill for transferred electricity

8. Trader/producer with Balance agreement (BRP) sends to EEX/PXE (Market)

- Selling/Buying bid for day ahead market/intraday market

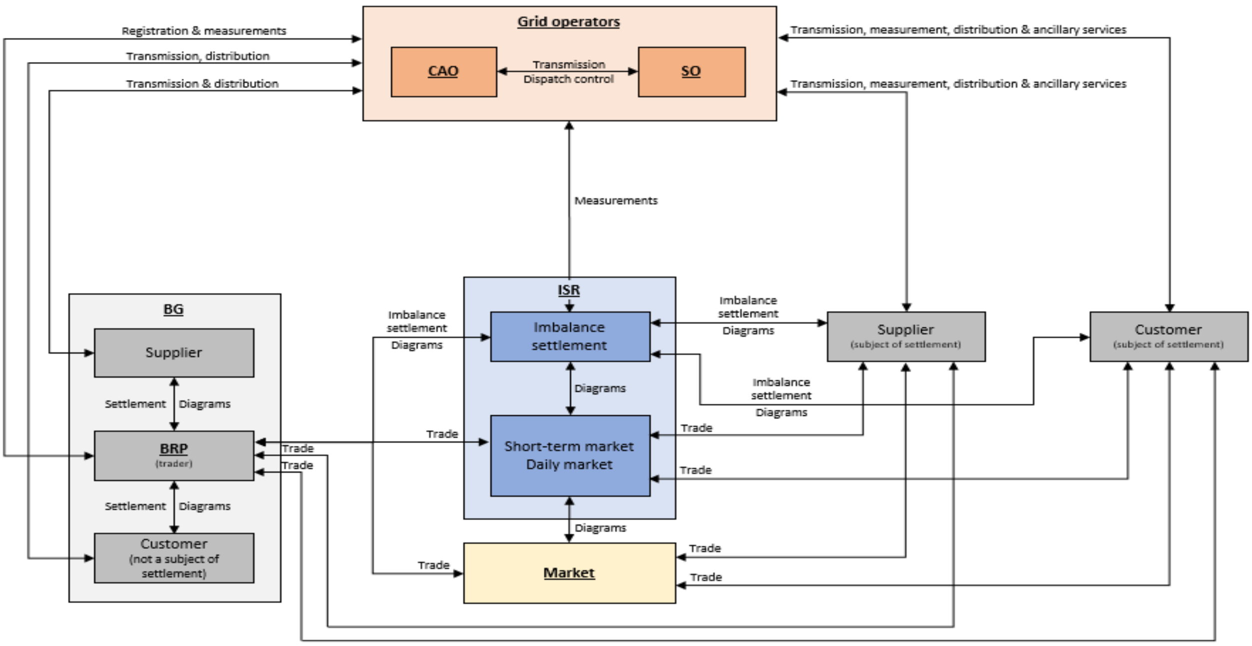


Figure 2: Electricity market structure in the Czech Republic

3.2.3 Pricing mechanism

In the wholesale level in the Czech Republic, electricity is traded via EEX (European Energy Exchange), through bilateral [OTC] contracts, and in spot markets organized by the market operator. For large customers pricing mechanism depends on business agreement and they can have form of long-term contracts or spot-based pricing mechanism (not so frequent). Various types of contracts ranging from long-term fixed to spot-market linked exist also for small customers.

3.2.4 Electricity market and the Renewable Energy Communities

The regulatory framework to Renewable energy communities has been described in Deliverable D.5.1. The existence of Renewable Energy Communities is still not defined in the Czech energy legislation.

3.3 Nordic market

Sweden is a part of the Nordic electricity market, which also covers Norway, Finland, Denmark, Lithuania, Latvia and Estonia.

3.3.1 Market structure

There is a common Nordic market for electricity but is divided into several different market areas, with own system prices.

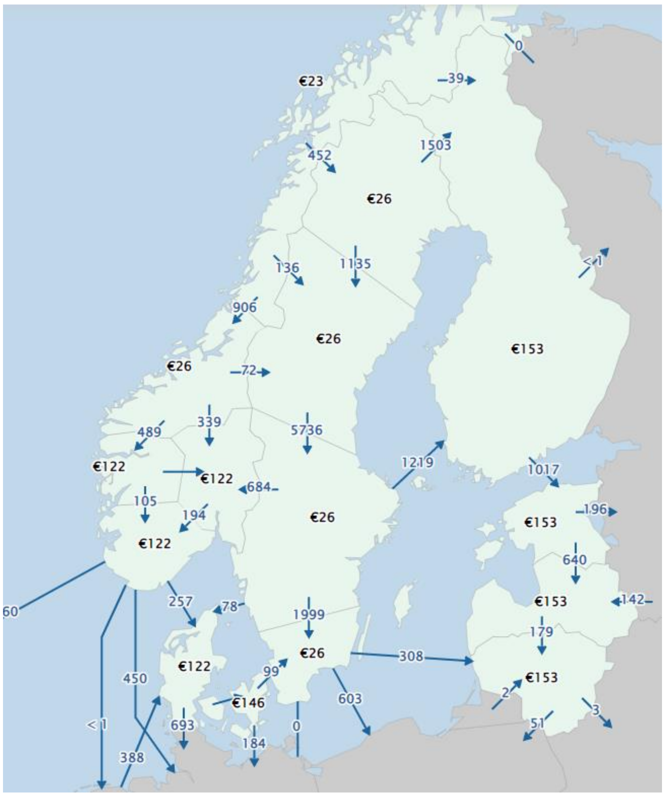


Figure 3: Overview of the Nordic electricity market

The Nordic electricity market has a similar structure and key players as described in previous Sections dedicated to Austria and the Czech Republic. Figure 3 shows the main participants and their interaction. The main difference is that the Nordic electricity market organizes four different CAO which is also the TSOs in their respective country. In addition to this Nordpool who is the NEMO for the Nordic market is also an actor on the market. In the market there is also the eSett which serves as a common imbalance settlement responsible for all four Nordic countries

The main actors are therefore

- CAOs (Energinet, Fingrid, Statnett and Svenska Kraftnät)
- transmission system operator: (Energinet, Fingrid, Statnett and Svenska Kraftnät)
- eSett (ISR)
- distribution system operators,
- market operator: Nordpool
- electricity traders,
- electricity producers (Suppliers),
- customers.

There is only one TSO per country but over 170 DSOs where some are large energy companies and other are local community owned grids.

The market operator is Nordpool which is responsible for organizing the day ahead market and the intraday market. All traders or producers with a balancing agreement with the national CAO are allowed to put in selling or buying bid on Nord pool. The national TSOs reports available transmission capacities over the borders between market areas to Nordpool. The buying and selling bid in combination with the transmission capacity sets the system price for that market area

Grid operators transmit to eSett each day the actual values electricity deliveries and withdrawals at the transfer points of energy traders per MGA (Metering Grid Area)

Market participants are responsible for their imbalances either via a direct balance agreement with the CAO the imbalances are met by the national TSOs and reported to eSett for financial settlement.

Market actors with a capacity to increase production or reduce consumption with > 0,1 MW can be part of the ancillary service market.

A market actor not shown in Figure 4 below is the aggregators which is a rather new actor on the Nordic market. The aggregators serve as a way for smaller actors to be part of the flexibility market by allowing the aggregator to control some part of a household or industry consumption or production. Adding up several contributions in an area makes it possible to take part in the ancillary service market. The aggregators typically operate in collaboration with a DSO and an Energy trader.

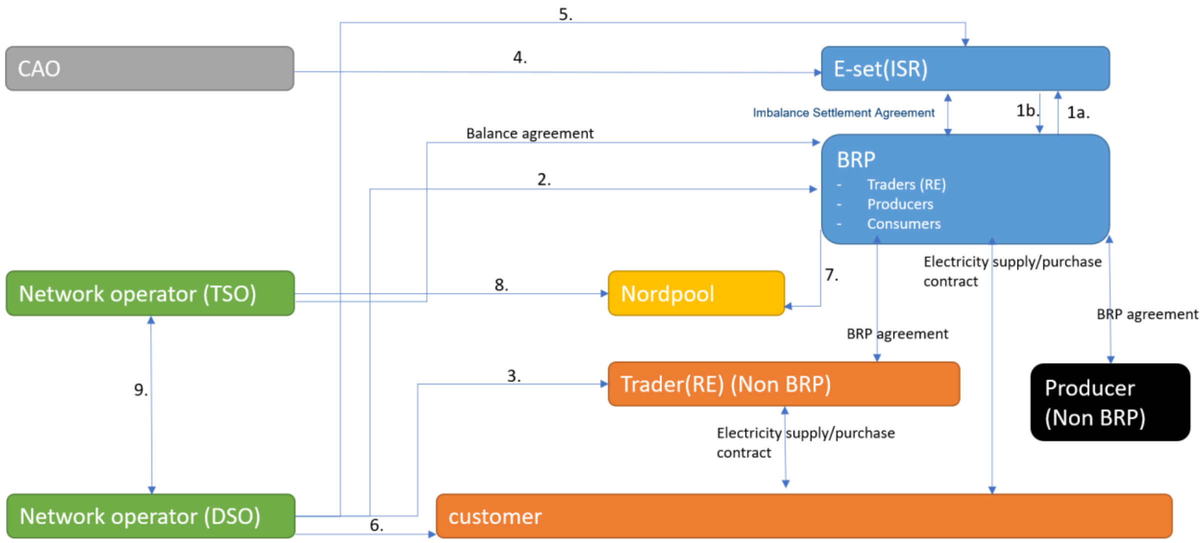


Figure 4: Structure of the Nordic electricity market

The following information exchange between the market players exists [12]:

1a.BRP sends to ISR:

- External schedules, i.e., separate receipt and supply schedules
- Network-node power station schedules, i.e., separate schedules for production and consumption
- Total net generation
- Total consumption of the balance group (BG)
- Information on bilateral trade
- Power station maintenance schedules

1b.ISR sends to BRP:

- Confirmation of external schedules, i.e., Time Series Confirmation Report
- Total imbalance caused by the BG.

2. Network operator (DSO) sends to BRP:

- Aggregate time series per supplier separate time series for actual production and actual consumption per MGA;
- Aggregate time series per MGA: separate time series for actual production and actual consumption

3. Network operator (DSO) sends to Trader:

- Time series (15-minute intervals) for grid users with load meters (in accordance with the clearing interval);
- Monthly aggregate time series per supplier, i.e., separate time series for actual production and actual consumption
- Actual consumption of non-metered customers (according to the meter reading intervals, normally annually).

4. CAO sends to ISR:

- Tendered, offered, and purchased amounts of balancing capacity
- Each supplier's balancing capacity call-offs, also as internal schedules
- Clearing data for imbalance price calculation, e.g., standby capacity costs, costs of called-off bids, costs of compensation programs.

5. Network operator (DSO) sends to ISR:

- Monthly aggregate time series per balance group: separate time series for actual production and actual consumption (according to the clearing interval);
- Monthly aggregate time series per BRP, i.e., separate time series for actual production and actual consumption (according to the clearing interval);

6. Network operator DSO send to customer:

- Actual consumption, Bill for transferred electricity

7. Trader/producer with Balance agreement (BRP) sends to Nordpool:

- Selling bid for day ahead market/intraday market
- Buying bid for day ahead market/intraday market

8. TSO sends to Nordpool:

- Transfer capacity for coming trading period

9. Network operator (SO, TSO) sends to Network operator (SO, DSOs):

- Aggregate monthly time series of each grid's interconnection points

3.3.2 Pricing mechanism

Large consumers have the possibility to secure their electricity prices by dealing with financial instruments on Nasdaq OMX commodities. This is typically done in part by large energy intensive industry.

For **smaller consumers** there are three main types of agreements

- **Flat rate fixed price**
  These agreements typically run for 1,2 or three years with a fixed price per kWh the price of a one-year fixed price is currently appr. 50 ct/kWh.
- **Flexible price monthly price**
  With this agreement you pay the same price per kwh for an entire month. The monthly price is set based on a generic consumption profile in combination with the spot price on Nordpool. Currently 28 ct/kwh
- **Hourly rates**
  With this agreement a consumer buys electricity at current spot price on Nordpool. This means that there can be significant differences in price depending on when you consume the electricity during the day or night. Prices can differ from 1 euro/kwh to 1 ct/kWh within a couple of hours.

Different energy providers have different business models. Some add a fixed fee of 30 to 40 euro/year to the running costs. Other adds a few öre (0,1 cents) per kWh.

Electricity producers with an own Balance agreement with the TSO can sell direct to Nordpool. Smaller producers typically sell to an electricity supplier which in turn hold a balance agreement. When selling to an energy provider you get paid according to the agreement with the supplier. This price is close to current spot price on Nordpool typically +-5 öre (0,005 cents) per kwh. In addition to these micro producers are entitled to a tax reduction of 60 öre (0,06 Cents) per kWh supplied to the grid.

3.4 Assessment of market structures

The market of all three countries studied in this paper converges to a similar structure, having developed under the common EU legislation. Figure 5 gives an overview of the power industry's current pricing mechanisms. Big electricity producers and consumers and energy suppliers are the electricity market players. Different energy suppliers determine on their own the selling and buying of electricity prices to smaller customers and producers. They usually act through various contracting forms.

Small customers, such as residential ones, and small distributed producers, are not considered market players and consequently cannot participate in the trading process: They can only choose between different energy suppliers.

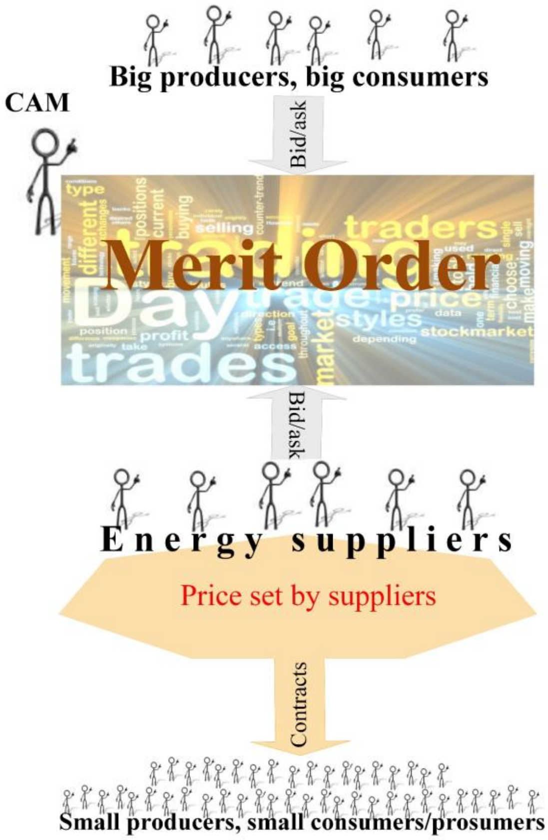


Figure 5: Overview of the pricing mechanisms used currently in the power industry.

4 INTERACT market structure promoting Energy Communities

Since 2019, EU Commission has given the directive to organize [13] a "… competitive electricity markets across country borders, to deliver real choice for all Union final customers, be they citizens or businesses, new business opportunities, competitive prices, efficient investment signals and higher standards of service, and to contribute to the security of supply and sustainability …". At the same time, it underlines the need to adapt the Union Market Rules to the new market reality, putting forward the Commission's vision for a retail market that better serves energy consumers and linking wholesale and retail markets.

The INTERACT project proposes a market structure in line with the EU Commission directives, providing consumers with reliable, environmentally friendly electricity at the lowest possible cost and promoting energy communities and sector coupling. It pursued two main objectives in the design.

The first objective is operation efficiency, making the best use of existing resources. Splitting markets at the national/international, regional, and local levels significantly reduces the current complexity due to the variety and economics of the resources, their uncertainties, and the power system constraints. Furthermore, an efficient welfare-maximizing outcome is achieved by optimizing each market area and the area's coordination.

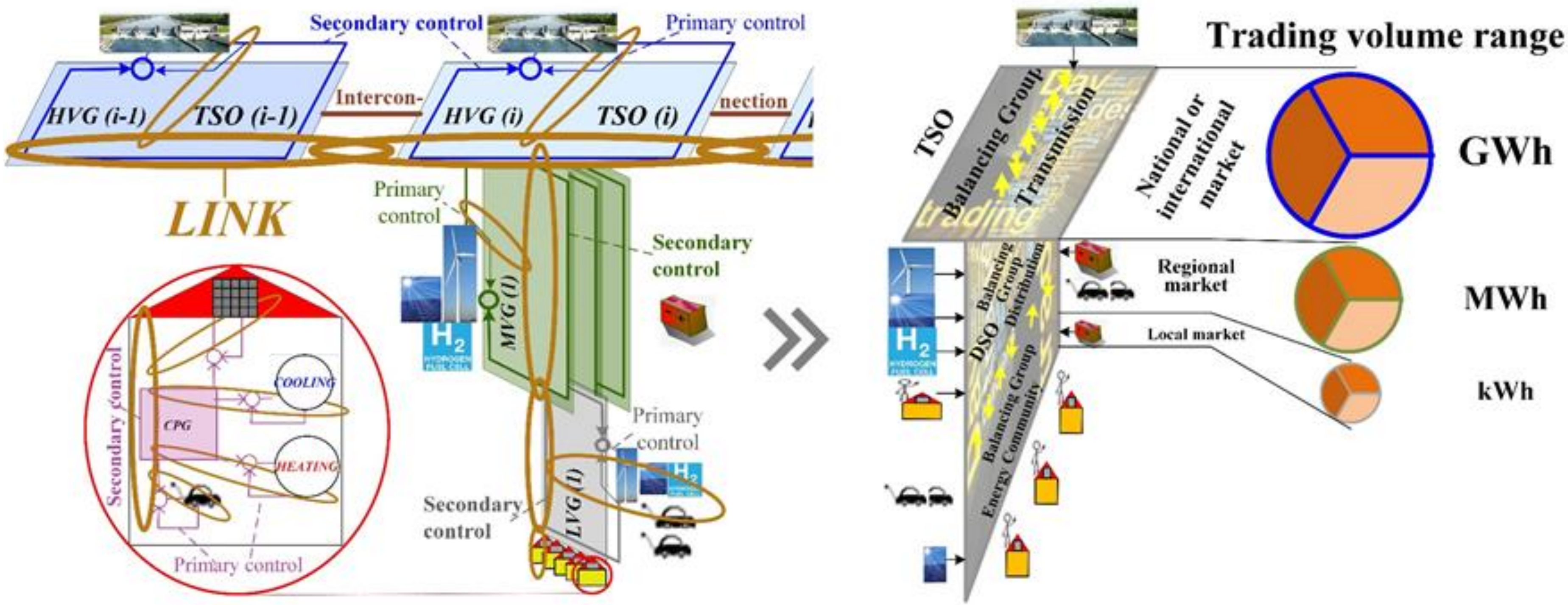
The second objective is stimulating capital investment by providing appropriate incentives for its efficient use. Efficient capital investments are usually prompted by suitable price mechanisms, e.g., spot prices. But electricity is not an ordinary commodity; a unique property, reliability characterizes it. It requires a power reserve to meet demand when supply and demand uncertainties would otherwise create electricity shortages. Intelligent pricing mechanisms should be developed to take this feature into account. A capacity market could also coordinate investments.

The INTERACT-market structure is quite simple because it derives from the fractal structure of Smart Grids. It promotes the direct and equal participation of all stakeholders in the market regardless of the size of their units, making it fair.

4.1 Holistic market vision

LINK-solution proposes a fractal market structure promoting Smart Grids and especially energy communities on a large scale [14].

Figure 6 shows the fractal structure of the power industry in *LINK*-Solution, which automates various processes and information exchange related to market and system operation. The "Energy supply chain net," Figure 6a, is the holistic technical model of Smart Grids, being the fundament of the *LINK* fractal structure. It has a T-arrangement, where the very high and High Voltage Grids (HVG) are set on the horizontal axis, while the Medium and Low Voltage Grids (MVG and LVG) and Customer Plants (CP) are placed on the vertical axis. The INTERACT-market design, Figure 6b, has the same T-arrangement as the Smart Grids enabling their harmonization. It increases the space granularity [15] of the electricity market, establishing



(a) (b) (c)

Figure 6: Overview of the fractal structure of the power industry in LINK-Solution: (a) Energy supply chain net holistic model; (b) LINK-market structure; (c) Fractal range of the trading volume.

different market categories such as the national/international markets in the transmission area, regional markets in the distribution area, and the local markets in customer plants EC-area.

The local market consists of customers (prosumers and consumers) and Distributed Energy Resources trading energy and services in the vicinity of power production based on environmental, socio-economic, and technical criteria (e.g., CO_2 reduction, welfare maximization, power system reliability, etc.). Transmission System Operators (TSO) and Distribution System Operators (DSO) take over the role of whole market players for the transmission and distribution wholesale markets, respectively. The INTERACT Energy Community takes over the role of the local retail market player.

Figure 6c shows the power market set-up conforming to the fractal principle: Similar market patterns and shapes repeated in ever-smaller sizes. The trading volume defines the market size. It refers to the total energy traded during a specific period. The Average Trading Volume (*ATV*) calculates by dividing the total energy trading volume (E_{Tr}) over a period by the length of the period (h). The result is the average trading volume per unit of time, typically per day.

$$ATV = \frac{E_{Tr}(Period)\cdot 24}{Period} \text{ [GWh/day], [MWh/day], [kWh/day]} \quad (1)$$

The ATV for the national market ranges to GWh, for the regional one goes to MWh, while for the local one, it ranges to kWh.

4.1.1 International/national wholesale market

The International/national market is a wholesale market with a trading volume range of some GWh per day facilitated by the TSO. The latter provides an electricity-trading platform to sell and buy electricity and flexibilities in their operating area.

4.1.2 Regional wholesale market

The regional market is a wholesale market with a trading volume range of some MWh per day facilitated by the DSO. The latter provides an electricity-trading platform to sell and buy electricity and flexibilities in their operating area.

4.1.3 Local retail market facilitated by INTERACT Energy Community

The INTERACT Energy Community facilitates the local retail market. It has a trading volume range of some hundred kWh per day. The INTERACT Energy Community provides an electricity-trading platform to sell and buy electricity, flexibilities, and other services in its area. All community members benefit from directly participating in the local retail market by adjusting their consumption according to market signals. In return, they benefit from lower electricity prices or other incentives.

All EC members, be customers (prosumers and consumers), electricity producers, or storage, participate in the local retail market. They firstly buy the products/services near where they are produced, thus globally reducing losses on the power grid. The local market defines by the area in which its members operate. The energy community has a double role as the local market facilitator taking care of power balancing in its area and market participant in buying and selling in the regional wholesale market.

4.2 INTERACT-market

INTERACT project has redesigned the market to conform to the holistic market model. The following treats the market fractal structure with the corresponding pricing mechanism and the design of the technical Link-Grid control areas to harmonize with the market structure.

4.2.1 Market's fractal structure

Figure 7 shows the electricity market structure derived from the fractal *LINK*-structure. Production and storage facilities are available in all Smart Grid fractal levels.

Their operators participate in all three market categories: day ahead, intraday, and other services. Producers supply energy and ask in the day-ahead market, ask and bid in the intraday market, and bid for other services. Storage supply or consume energy, and their operators ask and bid in all market segments.

Markets have two peculiar additional participants: the prosumers and consumers. Prosumers behave in the market similarly to storage operators because they can supply or consume energy, i.e., they ask and bid in all market segments (prosumers are treated as black boxes in the *LINK-S*olution). While consumers only consume energy and bid in the day-ahead and intraday market and ask for other services.

Each market category is defined as a pricing area, as the largest geographical area within each market participant trades without capacity allocation. I.e., a Link-Grid area where congestions at the boundaries are controllable through the *LINK*-Control strategy. These areas are defined by the regulator and the TSO, DSO, and INTERACT-EC.

4.2.2 Pricing mechanism

The pricing mechanism refers to the process where forces of demand and supply determine the prices of commodities and the changes therein. It is the buyers and sellers who determine the price of an item. The merit Order mechanism has long been established in the electricity market. Figure 8 shows an overview of the pricing mechanisms used in different fractal structures of the market. Based on the main fractal principle of repeating the same shape and features in various structure sizes, the Merit Order mechanism is used in the international, regional, and local markets.

The Merit Order mechanism enables the free play of demand and supply market forces. In trouble, political and economic conditions may create severe social problems: Other pricing mechanisms are needed to make goods affordable for the broad population.

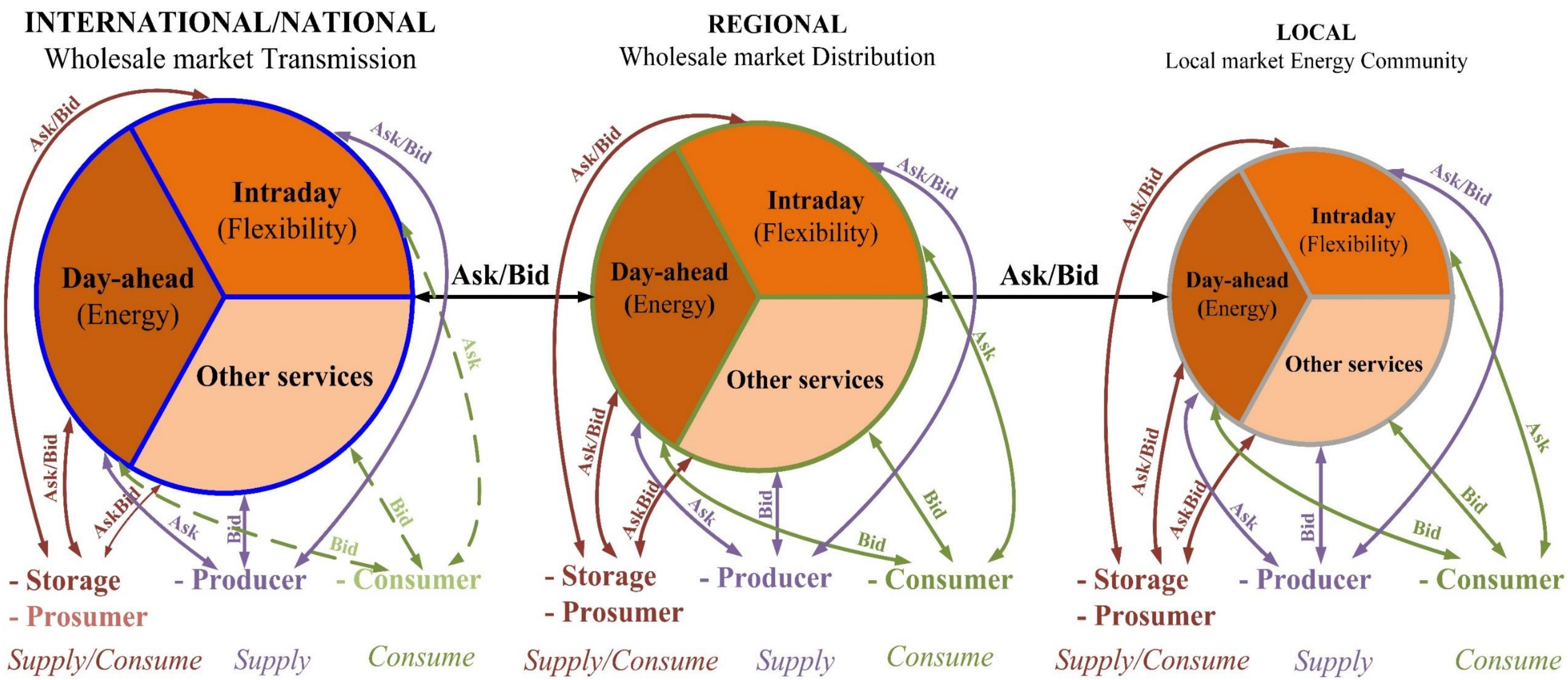


Figure 7: Overview of the electricity market structure derived from the fractal *LINK*-structure.

The new market structure allows all consumers and producers, regardless of size, to democratically decide on the price mechanism that can be applied in each period. For the first time, small customers and producers can actively participate in the local market design as described below.

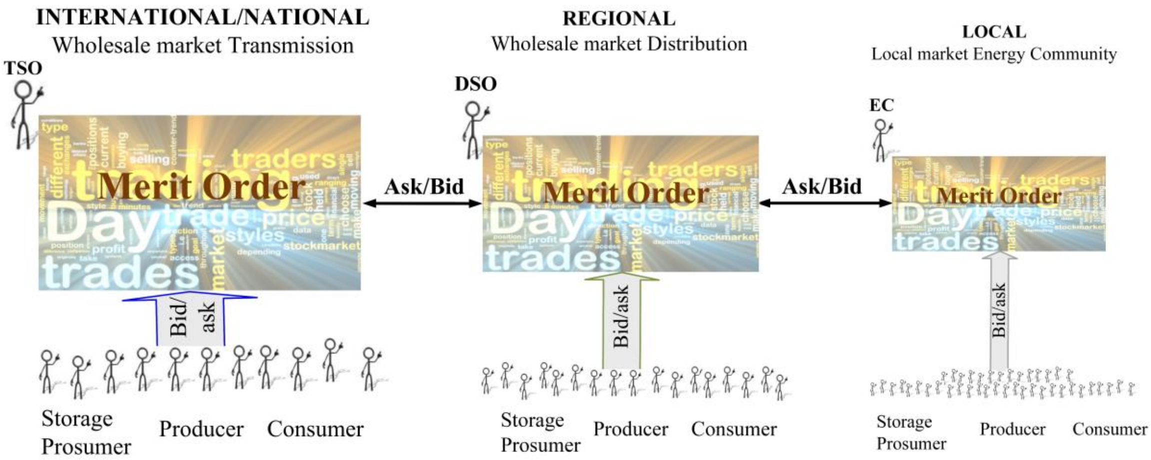


Figure 8: Overview of the pricing mechanisms used in different fractal structures of the market.

INTERACT EC, as a facilitator of the local retail market, has a portfolio of pricing mechanisms. The EC entity democratically decides which pricing mechanisms from its portfolio to use for a given period. It involves its members, the executive board and eventually the supervising board. EC should formally inform the controlling body, e.g., the energy authority, of any change in the pricing mechanism and the application period. It has the following portfolio of pricing mechanisms, which may be applied in different circumstances: Merit Order based on arbitrary price offers, Merit Order based on the Levelized Cost of Energy (LCOE) price offers, and Power Purchase Agreements.

4.2.2.1 Local retail market: Merit Order based on arbitrary price offers

EC members use the Merit Order based on unregulated price offers of the producers, prosumers, and consumers. With standard market behaviour, this leads to bits based on marginal prices, to maximize the chances of receiving the order, which is then valued not on the bidding price, but based on the Merit Order system. Participants can switch to another pricing mechanism depending on the actual conditions.

4.2.2.2 Local retail market: Merit Order based on LCOE price offers

This pricing mechanism uses the Levelized Cost of Energy (LCOE) instead of the unregulated price offers. We use a fictitious REC for calculations to show the pricing mechanism on real values. The values are partially based on the Austrian demo site, where missing data was added randomly (i.e., installation year of PV, etc.). It is therefore assumed that the fictitious EC has 142 members, of which 12 are prosumers with installed PV facilities, and the rest are consumers. After calculating the PV production price, the actual and the proposed pricing mechanisms are discussed.

The Levelized Cost of Energy (LCOE) of an energy-generating facility is the cost of building and operating the asset per unit of total electricity generated over an assumed lifetime[16]. The average production kWh cost purchased through a PV depends on the size of the facility, type of equipment and local incentives. It may be calculated based on (2) as follows:

$$LCOE^{PV}(i) = \frac{NPV(i)}{TES^{PV}(i)}, \tag{2}$$

Where $LCOE^{PV}(i)$ – average electricity production price of the PV facility of prosumer *i*;

NPV – Net present value of the PV facility.

TES^{PV} – Total Energy Supplied by the PV over its lifetime.

TES^{PV} strongly depends on the PV installed capacity, P_{Inst}^{PV}. Like all technical systems, they are delivered with a warranty period T_{Warr}. During this warranty period, which can be 22 to 25 years, the production performance of the system may change. This effect is considered by μ, the average electric power efficiency of the PV panel over the lifetime. As is well known, the PV production curve is not constant over the day but resembles a half-sine curve, as shown in Figure 9. The daily energy produced may be calculated using the average value of the half-sine of 0,637 and the daily sun-shining hours (lined area in Figure 9).

Since there are cloudy and hazy days throughout the year, the sun does not shine all year long. Consequently, PV systems do not produce. Therefore, the average hours of sunshine per day over a year, N_{hour}^{Sun}, are used to calculate the TES^{PV} (3).

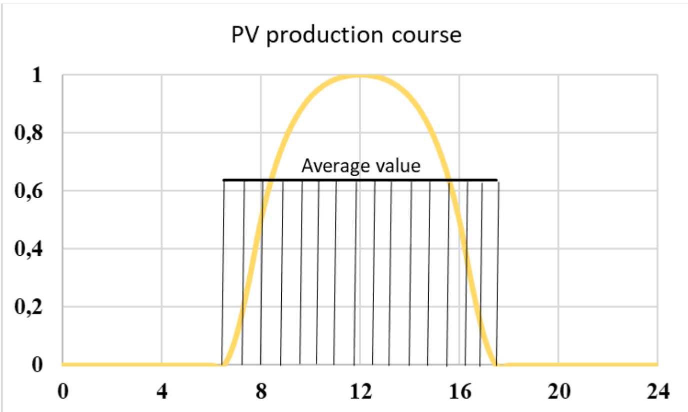


Figure 9: PV production course over the day

$$TES^{PV}(i) = 0{,}637 \cdot \mu \cdot P_{Inst}^{PV}(i) \cdot N_{hour}^{Sun} \cdot 365 \cdot T_{Warr}(i) \tag{3}$$

where: P_{Inst}^{PV} – Installed PV capacity [kWp];

T_{Warr} – Warranty period of PV panel [Years];

μ – Average electric power efficiency of the PV panel over the lifetime [%];

N_{hour}^{Sun} – Average hours of sunshine per day over a year.

- **Current scheme for purchasing and selling electricity**

Figure 10 shows the current scheme for buying and selling electricity. The considered customer plants consist of a mix of prosumers and consumers. Twelve prosumers are considered with various installed sizes, from 4.23 to 72.03 kWp, of PV facilities in different years, from 2010 to 2021, see Table 2. The PVs production costs are obtained by applying eq. (3) with 90% efficiency over the 22 years of PV facility lifespan. The average hours of sunshine per day over one year are estimated at 5.5 hours. Calculation results are shown in Table 2

Table 2: Installation costs of the PV facilities owned by energy community members

EC Memb.	PV prod. year	Inst. Cost [EUR/kW]	Size [kW]	Net Cost [EUR]	Total Ener.Supply [kWh]	Price Cent/kWh
1	2010	3 634	4.23	15 373,37	107 102.73	14,35
2	2011	2 952	8.00	23 612,77	202 558.36	11,66
3	2012	2 433	9.90	24 089,51	250 665.97	9,61
4	2013	2 065	9.60	19 826,63	243 070.03	8,16
5	2014	1 868	5.4	10 088,09	136 726.89	7,38
6	2015	1 702	5.39	9 173,16	136 473.69	6,72
7	2016	1 552	10.30	15 985,56	260 793.88	6,13
8	2017	1 315	72.03	94 749,77	1 823 784.80	5,20
9	2018	1 074	6.00	6 443,46	151 918.77	4,24
10	2019	934	25	23 362,41	632 994.86	3,69
11	2020	803	39.9	32 045,64	1 010 259.80	3,17
12	2021	725	47.79	34 648,80	1 210 032.98	2,86

The **Break-Even-Price** $BEP_{Prod.Costs}^{Pros.}$ that each prosumer should earn in one-hour power delivery to cover the installation costs is presented by the green area (Figure 8 below) and calculated by

$$BEP_{Prod.Costs}^{Pros.}(i) = P_{Inj.}^{Pros.}(i) \cdot LCOI^{PV}(i); \quad (4)$$

Where $P_{Inj.}^{Pros.}(i)$ – the power surplus of prosumer *i*.

While the Break-Even-Price (BEP) for all prosumers is EUR 10.56 and is calculated using eq. (5).

$$BEP^{AllPros.} = \sum_{i=1}^{n}(P_{Inj.}^{Pros.}(i) \cdot LCOI^{PV}(i))\,; \tag{5}$$

The graph shows results at noon when all PVs supply their maximal capacity; the load for every customer plant, be it prosumer or consumer, is assumed to be equal to 2 kW.

Typically, a prosumer may cover or not the own native load so that it may inject or consume electricity $P_{LoadInj}^{Pros.}$ as in

$$P_{LoadInj}^{Pros.}(i) = P_{PV}^{Pros.}(i) - P_{Nat.Load}^{Pros.}(i). \tag{6}$$

When $P_{LoadInj}^{Pros.}(i) > 0$ → the prosumer covers his own electricity needs and may sell the surplus.

When $P_{LoadInj}^{Pros.}(i) < 0$ → the prosumer does not cover his own electricity needs and must buy the electricity needed.

In the calculated case, all prosumers cover their own electricity needs and have a surplus available for sale calculated as follows

$$P_{LoadInj}^{Pros.}(i) = P_{PV}^{Pros.}(i) - P_{Nat.Load}^{Pros.}(i) > 0. \tag{7}$$

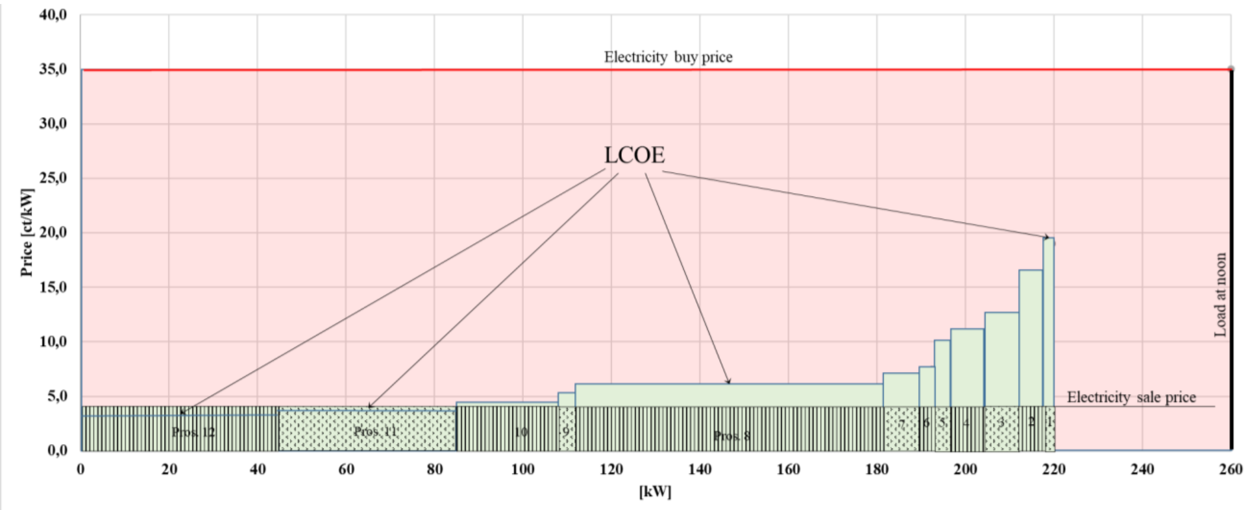


Figure 10: The current scheme for purchasing and selling electricity to customer plants consisting of prosumers and consumers.

All prosumers together have a power surplus of 220 kW to sell. Depending on the legislation of each country, prosumers may be allowed or not to inject into the LV grid. If they are allowed, the sale price strongly depends on the connection point on the grid: until recently, the selling price, $Price_{Sale}^{PV}$, was marginal, and, in many cases, it might have been negative. That means the prosumer partially paid to inject into the grid.

The actual sale price $Price_{Sale}^{PV}$ is calculated from dedicated internet platforms. For this calculation we assume a price of 4 ct/kWh. The revenue of each prosumer is then calculated by

$$Rev._{Sale}^{Pros.}(i) = Price_{Sale}^{PV} \cdot P_{Inj}^{Pros.}(i). \tag{8}$$

The green-lined areas present the monetary amount each prosumer earns in one-hour power delivery calculated by (8).

The total revenue of all prosumers together is EUR 8.78, resulting from the following eq.

$$Rev._{Sale}^{AllPros.} = Price_{Sale}^{PV} \cdot \sum_i^n P_{Inj}^{Pros.}(i). \tag{9}$$

The electricity of 260 kW to cover the needs of all *m* consumers is purchased at the selling price of 35 cents/kWh set in the platform. The red area in the Figure 10 represents the expense of all *m* consumers reaching EUR 91.00, Table 3, calculated by

$$Exp._{Sale}^{AllCons.} = Price_{Sale}^{PV} \cdot \sum_{j=1}^m P_{Load}^{Cons.}(j). \tag{10}$$

Table 3: Financial situation of the EC when using the described scheme for purchasing and selling electricity

	$BEP^{AllPros.}$ [EUR]	$Rev._{Sale}^{AllPros.}$ [EUR]	$Exp._{Elec.}^{EC.}$ [EUR]	$Exp._{Elec.}^{AllCon.}$ [EUR]
EC in Total	10.56	8.80	91.00	91.00

This example shows that **the current pricing scheme does not promote larger PV installations** because the EUR 8.80 revenue does not cover the EUR 10.56 needed to break even. Covering self-consumption remains as the main investment motive.

- **Merit-Order based on LCOE**

Electricity bills are subject to ever-changing tariffs, which depend on the prices of primary resources and the global relationship between the supply and demand for energy. As observed during the Ukrainian war, in certain situations, tariffs no longer correspond to the electricity production price but are incredibly high, causing significant economic and social problems. The goal of this pricing mechanism is not only the promotion of investments in distributed generation in the EC area but also to achieve a fair electricity price there.

Figure 11 shows the Staggered pricing model in the INTERACT local market: Prosumers and consumers buy and sell in the local market, while the Energy Community buys on the regional market to cover the energy needs of its members. In the case of a power surplus within the energy community area, the Energy Community bids it on the regional market it participates in. Since only renewable energy sources are eligible under INTERACT EC, the price of primary resources does not play any role in pricing on the local market. This fact prevents speculation and weakens the impact of the global relationship between the supply and demand for energy. The pricing mechanism has two components; the one used for trading within the EC members and the regional market or market price used for trading the energy not balanced within the energy community area.

Figure 11: A staggered pricing model in the INTERACT local market: Energy Community buys electricity on the regional market.

The PV surplus is cumulatively set in the X-axis: Only prosumers and distributed energy resource operators participate in the merit order process. The total load of the consumers in the energy community is 260 kW, of which prosumers can supply 220 kW to the energy community members, based on eq. (11). The local Merit-Order principle determines the electricity sale price between the EC members. The $Price^{PV}_{Sale}(1) = 14.35\ Cents/kWh$ is determined by the prosumer "1", who had the most expensive investment costs. All prosumers together will earn EUR 31.51, reflecting a larger value than the price needed to break even, see Table 4.

$$Rev._{Sale}^{AllPros.} = Price^{PV}_{Sale}(1) \cdot \sum_{i=1}^{n} P^{Pros..}_{LoadInj}(i), \tag{11}$$

Table 4: Financial situation of the EC when using a staggered pricing scheme for purchasing and selling electricity

	$BEP^{AllPros.}$ [EUR]	$Rev._{Sale}^{AllPros.}$ [EUR]	$Exp._{Elec}^{EC.}$ [EUR]	$Exp._{Elec.}^{Cons..}$ [EUR]
EC in Total	10.56	31.51	14.00	45.51

The remainder of the 40 kW are calculated by

$$P^{EC.}_{Load} = \sum_{i=1}^{n} P^{Pros..}_{Load}(i) + \sum_{j=1}^{m} P^{Cons..}_{Load}(j), \tag{12}$$

Where *n* – the number of energy community members acting like prosumers,

m – the number of energy community members acting like consumers, must be purchased outside the energy community. In our case, prosumers cover their own electricity needs, $\sum_{i=1}^{n} P_{Load}^{Pros.}(i) = 0$.

This power amount is bought in the regional market with $Price_{Buy}^{Elec.} = 35\ Cents/kWh$.

$$Exp._{Elec.}^{EC.} = P_{Load}^{EC.} \cdot Price_{Buy}^{Elec.}, \tag{13}$$

EC expenditure, in this case, results in EUR 14.00. Consumers must settle with two suppliers, the EC and the EC members, the latter being prosumers, producers, or storage owners. Their total consumer spending is EUR 45.51, about 50% less than their spending with the current pricing mechanism. Figure 12 shows the revenues per each prosumer and customer's expenses in total at present and the INTERACT-EC Merit Order pricing mechanism based on LCOE. All prosumers cover their investments and make a profit that encourages consumers to invest, e.g., in further PV systems.

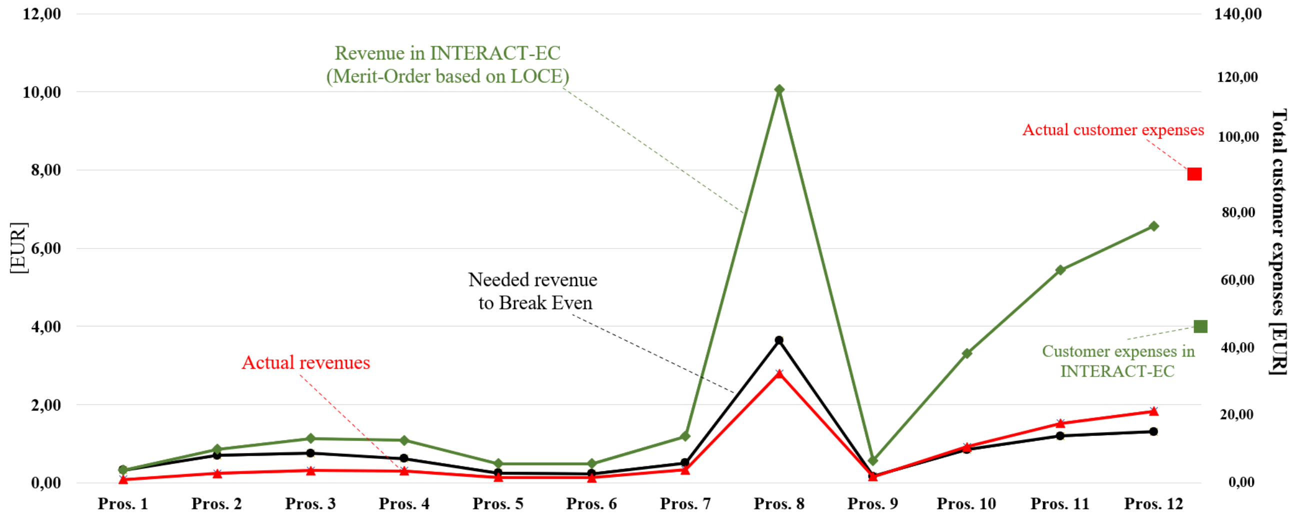


Figure 12: Overview of prosumers' revenues and customers' expenses in the current and INTERACT-EC Merit Order pricing mechanism based on LCOE.

4.2.2.3 Local retail market: Power Purchase Agreement

The pricing model Power Purchase Agreement (PPA) reflects a basic agreement between the producer and the consumer to use the production facility over its lifetime together at predefined conditions, securing the investment for the producer and securing the supply at defined prices for the consumer. The agreed price should be based on a cost-plus approach, taking into consideration CAPEX and OPEX of the production facility. As the partnership is agreed over a predefined lifetime of the investment, risk is reduced, and prices for the consumer should be lower than otherwise, are kept stable and predictable.

Continuing with the fictitious EC from above, each prosumer agrees on a Producer Consumer Partnership latest when joining the EC. We assume, that each prosumer agreed on a PPA at the time when the investment decision was taken, to reduce the risk of a not profitable investment. The EC on the other hand will assess, whether enough consumers are within the community to use another source of electricity, and in case this is given, agrees to a PPA to fix electricity prices over a longer time.

Table 5 below shows again the list of prosumers. To motivate the producer to invest into the facility, not only the investment costs have to be returned over time, but an entrepreneurial margin needs to be achieved. In the calculation below, within the PPA, counterparties agree on 5% profit on the investment per year for the producer, without taking any interest or compound interest into consideration.

Table 5: Installation costs of the PV facilities owned by energy community members

EC Memb.	Inst. Cost [EUR/kW]	Size [kW]	Net Cost [EUR]	5% Profit Margin [EUR]	Yearly Production [kWh]	PPA Price [Cent/kWh]
1	3 634	4.23	15 373,37	768.67	4 868	30.14
2	2 952	8.00	23 612,77	1180.64	9 207	24.48
3	2 433	9.90	24 089,51	1204.48	11 394	20.18
4	2 065	9.60	19 826,63	991.33	11 049	17.13
5	1 868	5.4	10 088,09	504.40	6 215	15.49
6	1 702	5.39	9 173,16	458.66	6 203	14.12
7	1 552	10.30	15 985,56	799.28	11 854	12.87
8	1 315	72.03	94 749,77	4737.49	82 899	10.91
9	1 074	6.00	6 443,46	322.17	6 905	8.91
10	934	25	23 362,41	1168.12	28 772	7.75
11	803	39.9	32 045,64	1602.28	45 921	6.66
12	725	47.79	34 648,80	1732.44	55 001	6.01

With the PPA pricing model, both customers as well as producers have long-term security over the pricing. In terms of falling investment costs, prices for consumers will decrease with newly added producers. Producers already invested at higher costs, still have the guarantee of not getting into the negative values, which might have prevented them from investing in the first place. A PPA pricing model therefore might be appropriate in emerging industries, where investment costs are falling over time and investment sizes are rising over time.

Figure below 13 shows the PPA pricing model for the 12 prosumers: each prosumer has a fixed price over the lifetime of its investment. The average price for the consumers depends on the prices and sizes of all prosumers included in the EC.

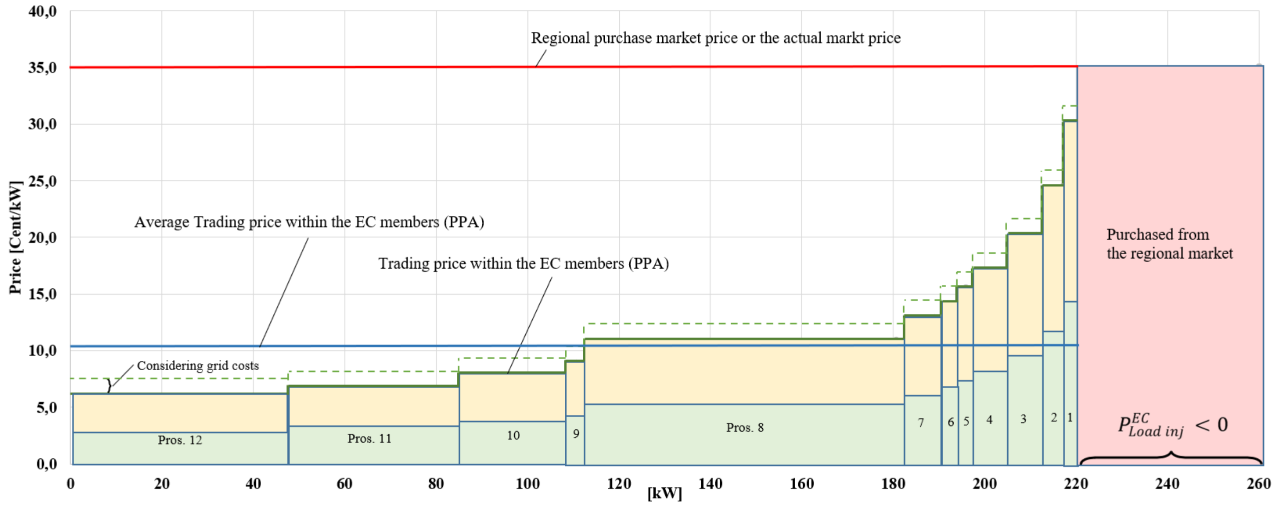


Figure 13: The PPA pricing model in the INTERACT local market: Each Prosumer has a fixed price over the lifetime of its facility.

The individual revenues of each prosumer and the total customer expenses for the current pricing scheme, the INTERACT-EC staggered pricing model and the INTERACT-EC PPA pricing model are shown below in Figure 14. As the prosumers are sorted by investment costs per kWh from 1 to 12, it is visible that for early development stages of the industry, the PPA pricing model offers higher prices to the prosumers, whereas over time, when the investment costs are getting lower, the prices of the prosumers are reduced. Nevertheless, in all cases the prices are above the needed revenue to break even, which is the basic target of a PPA.

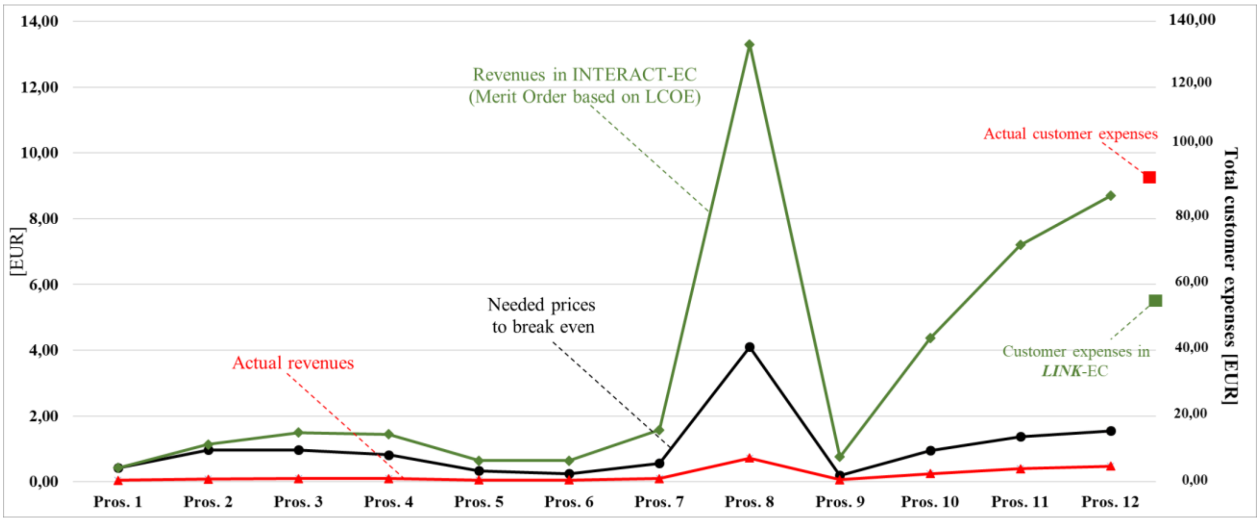


Figure 14 : Overview of prosumers' revenues and customers' expenses in the current, the INTERACT-EC staggered and the INTERACT-EC PPA pricing mechanism

Of course, the examples here show only one situation of one virtual Energy Community. The situation can get more complex, for example when local supply is exceeding local demand. Furthermore, in all shown cases the regional price is higher than the local price, which is favourable for consumers, but not for producers, who might earn more money when participating directly in the regional market. Further research and also insights into currently existing Energy Communities is needed in order to develop more pricing mechanisms, which are optimized in accordance with local structures and local motives for the development of the individual local energy communities.

4.3 Harmonized INTERACT-market structure with the power grid

The holistic market model derived from the technical one consists of coupled market areas at the horizontal and vertical axes and is operated by the TSO and DSO. They interact directly with the whole market to ensure a congestion-free transmission and distribution grid operation. A detailed market structure that fits the *LINK*-holistic architecture is presented below.

The market structure should take into account the technical behaviour of the Smart Grids and support their safe, reliable, and resilient operation while at the same time attracting the demand response bids. Figure 15 illustrates the harmonization and coordination of the market structure with the grid link arrangement. The implementation of the local retail markets requires Balancing Group Areas (BGA) within the whole market. The day-ahead market harmonizes with the Grid- Links as follows:

- BGA is a geographical area consisting of one or more Grid-Links with standard market rules and has the same price for imbalance in the day-a-head market. In general, a TSO grid includes one grid link, while the grid of a DSO may include several grid links. Additionally, all grid links included in one BGA should be operated by one DSO (not by several DSOs).

The geographic boundaries of BGA may vary considerably and are defined by the external boundaries of Grid-Links contained in the BGA. Grid links may have two types of boundaries: external and internal. The external ones exist between different links with other owners or operators, i.e., between TSO and DSO. They are subject to data security and privacy because of the data exchanges between two different companies. In contrast, the internal interfaces are set between various links with the same owner or operator, e.g., the same DSO.

- All electricity producers, storages, and customer plants electrically connected to the Grid-Links belonging to the BGA participate in the same balancing group.

The Grid-Link operators (e.g., a TSO, DSO, or EC) act as neutral market facilitators responsible for controlling and independently balancing power flow fluctuations in their area.

Moreover, each Grid-Link operator provides ancillary services to the neighbouring Grid-Link areas to ensure the reliability of the electricity supply.

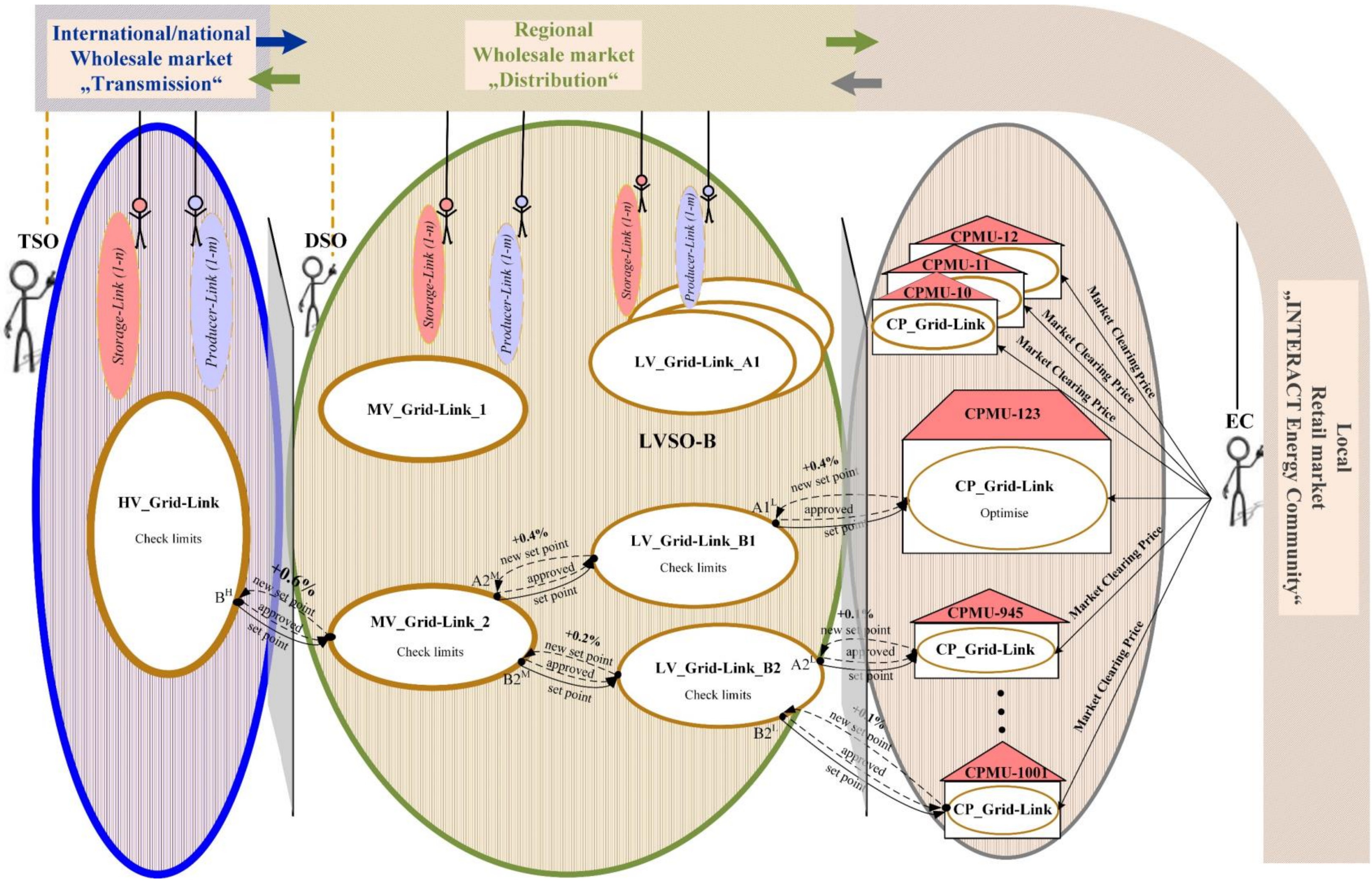


Figure 15: Harmonization of the market structure with the grid link

5 Conclusions

The analysis of the current electricity market structure shows, that Energy Communities as well as other smaller entities are at the moment not able to participate. This market structure was created when the electricity system was more unidirectional, and smaller entities only consumed electricity. With an increasing number of DERs, and local entities also producing electricity and being able to provide further supporting services to the grid, this market structure does not seem adequate anymore.

Therefore, we propose a different market structure, more in line with the physical flows of electricity, and supporting and automated and fair participation within the market at different market levels. In line with the fractal structure of the power grid itself, also the market structure is structured in a fractal way: a national/international market, a regional market, and a local market, where each lower level participates in the level above.

We show two different potential pricing mechanisms: a local merit-order based staggered pricing system using levelized costs of electricity, and power purchase agreements, and compare both pricing mechanisms with current market prices. In the example situation described, both pricing mechanism are lowering the total costs of energy for the local market, and are promoting the investment into further DERs.

Further research is needed in this field, as different market situations might lead to unfavourable situations for the different types of EC members. Also, the detailed organisation of the proposed holistic energy market, with a description of all rules and responsibilities, would need to be developed as a next step for its realization.

In any case, we see the generation of a holistic market structure, enabling the participation of Energy Communities directly in the energy market as important step forward.

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