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Euregio Meuse-Rhine
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GRID ASPECTS

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1 Introduction

The 5 regions involved in Blockchain4prosumers have completely different technical but also legal requirements. This deliverable introduces grid aspects by reviewing the possible network service that can be provided by regional peer-to-peer networks and thus lead to network relief. There is an outlook on how further developments on network aspects could look like. It also describes how users and prosumers can behave in a network-compliant way in order to achieve a higher regenerative share. The impact of geographic distribution of prosumers is described.

2 Electricity grid

2.1 Introduction

Electricity grids are systems that transport electricity from power plants to consumers. These grids are essential infrastructure that plays a crucial role in modern society, as they provide the electricity that powers homes, businesses, and various other types of facilities. In this section, we will explore the various components that make up an electricity grid, how these grids are designed and operated, and some of the challenges that grids face in the modern world.

The main component of an electricity grid is the transmission system, which consists of high-voltage power lines that transmit electricity from power plants to substations. These power lines are typically made of aluminum or steel and are supported by towers or poles. The voltage of the electricity transmitted through these lines is typically between 115 kV and 765 kV, which allows for the efficient transmission of electricity over long distances.

Substations are facilities that receive electricity from the transmission system and transform it to a lower voltage for distribution to consumers. The transformation of voltage is necessary because the electricity transmitted through the transmission system is too high to be used directly by most consumers. The voltage of electricity that is distributed to consumers is typically between 4 kV and 35 kV.

Once the electricity reaches a substation, it is then distributed to consumers through a distribution system. The distribution system consists of lower-voltage power lines and transformers that reduce the voltage of the electricity to a level that can be used safely by consumers. These power lines are typically made of copper or aluminum and are supported by poles or underground cables.

The operation of an electricity grid is complex and requires the coordination of various parties, including power plants, transmission companies, distribution companies, and regulatory agencies. Power plants are responsible for generating electricity, which is then transmitted through the transmission system to substations. Transmission companies own and operate the transmission system, while distribution companies own and operate the distribution system. Regulatory agencies oversee the operation of the grid and ensure that it is operated safely and efficiently.

One of the key challenges facing electricity grids today is the integration of renewable energy sources, such as solar and wind power. These sources of energy are intermittent and can be difficult to predict, which makes it challenging to ensure that there is a constant supply of electricity to meet demand. To address this challenge, grids are increasingly incorporating technologies such as energy storage systems and demand response programs, which allow them to store excess energy and reduce demand when necessary.

Another challenge facing electricity grids is the aging of infrastructure. Many power lines and transformers are decades old and are in need of repair or replacement. This presents a significant challenge as it can be expensive and logistically difficult to upgrade infrastructure, particularly in urban areas where there is a high density of consumers.

In addition to these challenges, electricity grids also face the risk of physical and cyber-attacks, which can disrupt the supply of electricity and potentially cause widespread damage. To mitigate these risks, grids are implementing security measures such as encryption, firewalls, and intrusion detection systems.

2.2 Grid components

The electricity grid is made up of a number of components, including:

2.2.1 Power plants

These are facilities that generate electricity, using a variety of methods. There are several different types of power plants, including:

- Thermal power plants: These facilities generate electricity by burning fossil fuels, such as coal, natural gas, or oil, to heat water and produce steam. The steam is then used to turn a turbine, which generates electricity.

- Nuclear power plants: These facilities generate electricity by harnessing the energy released during a nuclear reaction. The heat produced by the reaction is used to produce steam, which drives a turbine to generate electricity.

- Hydroelectric power plants: These facilities generate electricity by harnessing the energy of falling water. Water is captured in a dam and then released through a turbine, which generates electricity.

- Solar power plants: These facilities generate electricity by capturing the energy of the sun using solar panels. The panels convert sunlight into electricity, which can be used to power homes and businesses.

- Wind power plants: These facilities generate electricity by harnessing the energy of the wind. Large wind turbines are used to capture the wind's energy, which is then converted into electricity.

2.2.2 Transmission lines

Transmission lines are high-voltage power lines that carry electricity from the power plants to distribution substations. These lines are typically made of conductive materials such as copper or aluminum, and they are supported by towers or poles.

The voltage of the electricity in the transmission lines is typically much higher than the voltage that is used to power homes and businesses. This allows the electricity to be transmitted over long distances with minimal loss of power. The voltage is reduced at the distribution substations, where the electricity is transformed into a lower voltage that is suitable for distribution to homes and businesses.

Transmission lines are typically owned and operated by utilities or other large energy companies. They are an important part of the electricity grid, as they allow electricity to be delivered from the power plants to the end users.

Distribution substations:

Distribution substations are facilities that take the high-voltage electricity from the transmission lines and transform it into lower-voltage electricity that is suitable for distribution to homes and businesses.

The process of transforming the electricity is accomplished using transformers, which are devices that use electromagnetic induction to change the voltage of the electricity. The voltage is typically reduced by a factor of 10 or more at the distribution substation, making it safe and suitable for use in homes and businesses.

Distribution substations also include other equipment such as switches, circuit breakers, and protective devices, which are used to control the flow of electricity and protect the grid from damage.

Distribution substations are typically owned and operated by utilities or other large energy companies. They are an important part of the electricity grid, as they allow electricity to be delivered from the power plants to the end users in a safe and reliable manner.

2.2.3 Distribution lines

These are the power lines that carry electricity from the distribution substations to homes and businesses.
The voltage of the electricity in distribution lines is typically lower than the voltage in transmission lines, as it has already been reduced at the distribution substation. This lower voltage is safer for use in homes and businesses, and it allows the electricity to be distributed more efficiently over shorter distances.

Distribution lines are an important part of the electricity grid, as they deliver electricity from the power plants to the end users. Distribution lines are typically owned and operated by utilities or other large energy companies. They are usually designed to be highly reliable, with backup systems in place to ensure that the electricity supply is not disrupted in the event of a malfunction. However, these lines can sometimes be damaged by storms, accidents, or other events, which can cause power outages. In these cases, utilities and other energy companies may work to repair the damage and restore power as quickly as possible.

The design and operation of distribution lines are governed by a variety of regulations and standards, which are intended to ensure the safety and reliability of the electricity grid. These regulations and standards may vary from one jurisdiction to another, but they generally include requirements for the construction, testing, and maintenance of distribution lines.

2.2.4 Metering and billing equipment:

Metering and billing equipment refers to devices and systems that are used to measure the consumption of a resource, such as electricity, natural gas, water, or steam, and to generate bills for customers based on their usage. These devices typically include meters, which measure the quantity of the resource being consumed, and billing systems, which process the meter readings and generate bills for customers.

Metering equipment can be used in various settings, including residential, commercial, and industrial properties. In residential properties, meters are often installed at the point where utility service enters the building and are used to measure the consumption of electricity, natural gas, or water. In commercial and industrial settings, meters may be used to measure the consumption of various resources, such as steam, chilled water, or compressed air.

Billing systems can be manual or automated. Manual billing systems typically involve manual meter readings and the generation of bills based on those readings. Automated billing systems use technology, such as computerized meter reading systems, to automatically collect meter readings and generate bills.

Metering and billing equipment is used by utility companies and other organizations to accurately measure and bill for the consumption of various resources. It helps ensure that customers are billed accurately for the resources they consume and helps utilities manage their operations and revenue streams.

2.2.5 Power transformers

These devices are used to transform electricity from one voltage level to another, allowing it to be transmitted over long distances or used by different types of equipment.

2.2.6 Protective devices

These include fuses, circuit breakers, and other devices that are used to protect the grid and its components from damage due to overloading, short circuits, and other types of electrical problems.

2.2.7 Control systems

These are computer systems that monitor and control the flow of electricity through the grid, ensuring that the electricity is delivered to the right place at the right time.

2.3 Functionalities

Electricity grids have a number of different functionalities that are designed to ensure that electricity is transmitted, distributed, and stored efficiently. These functionalities include:

2.3.1 Demand

The demand for electricity can vary significantly over the course of a day, with demand being highest during the daytime when people are awake and using electricity for things like lighting and appliances. Electricity grids are designed to meet this fluctuating demand by using a combination of generation, transmission, and storage facilities.

2.3.2 Voltage

Voltage is a measure of the electrical potential difference between two points in an electrical circuit. In order for electricity to be transmitted effectively through an electricity grid, the voltage of the electricity must be kept at a consistent level achieved through the use of substations, which can transform the voltage of the electricity as it is transmitted through the grid.

2.3.3 Frequency

Frequency is a measure of the number of cycles of alternating current (AC) per second in an electrical circuit. In order for electricity to be used effectively, the frequency must be kept at a consistent level. This is typically achieved through the use of generators and other control systems that are designed to maintain a constant frequency.

2.3.4 Capacity and firm capacity

The capacity of an electricity grid refers to the maximum amount of electricity that the grid is able to transmit and distribute at any given time. Firm capacity refers to the portion of the grid's capacity that is available at all times, regardless of demand. This is typically made up of reliable sources of electricity, such as fossil fuel power plants.

2.3.5 Production

Electricity grids are designed to produce electricity in a way that meets the demand of the end-users as efficiently as possible. This can be achieved through the use of a variety of generation technologies, including fossil fuel power plants, renewable energy sources, and storage facilities.

2.3.6 Handling failure

Electricity grids are designed to be reliable, but there are times when failures or disruptions can occur. There are a number of different ways in which electricity grids can handle these failures, including:

Brownout A brownout is a temporary reduction in the voltage of electricity that is supplied to a particular area. This can be caused by a number of factors, including high demand, equipment failures, or problems with transmission lines.	**Blackout** A blackout is a complete loss of electricity in a particular area. This can be caused by a variety of factors, including equipment failures, severe weather events, or problems with transmission lines.
Load shedding Load shedding is a process in which some customers are temporarily disconnected from the grid in order to reduce the overall demand for electricity. This is typically done as a last resort in order to prevent a more widespread blackout.	**Black start** A black start is the process of restoring electricity to a grid that has experienced a widespread blackout. This typically involves starting up a small number of generators and then gradually restoring power to the rest of the grid.

3 HEAT NETWORKS

3.1 Definition

A district heating system is a centrally produced heat distribution system that serves several users. It includes one or more heat production units, a primary distribution network in which heat is transported by a heat transfer fluid, and a set of exchange substations, from which buildings are served by a secondary distribution network.

Any heat network has the following main components:

- The heat production unit which can be, for example, a household waste incineration plant (UIOM), a boiler room supplied by a fuel (oil, gas, wood...), a deep geothermal plant, etc. Generally, a network includes a main unit that operates continuously and a back-up unit used as a reinforcement during peak hours, or as a replacement when necessary.

- The primary distribution network consists of pipes in which heat is transported by a heat transfer fluid (steam or hot water). An outgoing circuit (red) transports the hot fluid from the production unit. A return circuit (blue) brings back the fluid, which has lost its calories, to the exchange substation. The fluid is then heated again by the central heating plant and returned to the circuit. The design of the network aims at ensuring a thermal density (number of buildings connected per kilometer of pipe laid) as high as possible, in order to allow the economic viability of the network (investment cost strongly linked to the pipe length; revenue linked to the number of users).

- The exchange substations, located at the foot of the building, allow the transfer of heat through an exchanger between the primary distribution network and the secondary distribution network that serves a building or a small group of buildings. The secondary network is not part of the heat network in the legal sense, because it is not managed by the heat network manager but by the building manager.

3.2 Components

3.2.1 - The heat production unit

The heat is produced in robust and reliable installations, permanently monitored and maintained by professionals. It can be generated from various energy sources:

Conventional (fossil) energies such as gas or oil that produce heat through combustion; these energies are high emitters of greenhouse gases. They are well suited to supplying heat during peak periods.

Renewable energies: biomass (wood, agricultural residues, energy crops...) which produces heat by combustion in a specific boiler room, deep geothermal energy which allows the recovery of heat (via an exchanger) from deep aquifers (from 1500m depth).

With the reduced consumption of new buildings, other sources of heat become exploitable by the networks, such as shallow geothermal energy or heat taken from wastewater; these systems use heat pumps that extract energy from the source and transfer it to the network.

The flue gas facilities are equipped with sophisticated and controlled treatment systems, which greatly reduce their impact on air quality compared to individual systems. Some heat production units also operate as cogeneration units, allowing them to simultaneously produce electricity and the heat needed for the heating network.

3.2.2 - The primary distribution network

The primary distribution network is a loop that carries the heat transfer fluid from the heat production unit to the exchange substation. Three types of fluids are used:

The **hot water network** has a temperature between 60° and 110°C. It is generally intended for groups of residential or office buildings, or hospitals and industrial establishments that do not consume steam.

The **superheated water network** has a temperature between 110°C and 180°C. It is mainly used in large-scale networks that supply buildings requiring high temperatures (laundries, slaughterhouses, textile industries, etc.).

The **steam network** has a temperature of 200°C to 300°C. Its use is increasingly limited. It is mainly used to supply industrial heat, but Paris uses it for its heating network (CPCU network).

3.2.3 - Piping and the different types of installation

The pipes are generally made up of a double envelope system: an external steel sheath (up to 800 mm in diameter) inside which is another steel sheath carrying the heat transfer fluid surrounded by a layer of insulation (rock wool, polyurethane foam, etc.).

The installation can be done in a buried channel, which allows a mechanical protection and minimizes the effects due to humidity by ventilation of these channels. It can also be done in a trench, which is a less expensive solution, but requires that the ducts be surrounded by a protective film against humidity and that they be installed at a sufficient depth to absorb the stresses of the surface.

The cost of installing one meter of network is around 1000 to 2000€. This cost depends of course on many factors related to each project.

3.2.4 - Exchange substations

Generally located at the foot of the building, the exchange substation consists of a heat exchanger that allows the transfer of heat between the two circuits. The substation also includes a heat transfer meter that allows to know the energy consumption of the building, necessary data for the billing.

3.3 Application domains

Heating networks are, most of the time, set up by local authorities on their territories in order to heat public and private buildings from a collective boiler room, make it possible to mobilize important sources of renewable energy that are difficult to access or exploit, especially in urban areas (wood energy, geothermal energy, recovered heat, etc.).

3.4 Advantages and constrains

Designed as a modern tool to ensure the transition to sustainable heating and cooling systems in cities - thanks to energy efficiency and the increasing use of renewable and recovered energy - the heat network has many advantages.

The heat network provides a reliable, economical and ecological answer:

1. More reliable energy: connected to the heating network, buildings are directly supplied with heating, hot water or air conditioning and benefit from a perfectly reliable delivery guarantee all year round. No gas, no fuel stocks, no boilers in the building, no smoke, no dust, no odors... It's a guarantee of comfort, without danger for the occupants and the environment.

2. A more competitive energy: the installation, maintenance and renewal of the equipment being centralized, the heating network is a heating solution that offers a very competitive rate. The cost to the user is 25 to 55% lower than other heating methods and less sensitive to price fluctuations because of the use of renewable energy.

3. Cleaner energy: thanks to better use of the energy from the treatment of household waste (eg. Belgium Herstal Uvelia project).

4 Microgrids

4.1 Concept

Electricity microgrids are growing rapidly around the world. This increase is mainly due to the desire to bring electricity production closer to consumption, to limit investments in transmission and distribution networks and to reduce losses. This is now made possible by the multiplication of decentralized energy production facilities, whether solar or wind, and the development of storage devices. Other reasons are also contributing to this boom in microgrid projects, particularly in the United States and Asia, the leaders in terms of the number of projects worldwide, such as the desire to increase the resilience of the electricity system by using the islanding capacity offered by microgrids. These microgrids are a model for optimizing the power grid.

Microgrids are small-scale electrical networks designed to provide a reliable supply of electricity to a small number of consumers. They combine multiple local and diffuse production facilities (micro-turbines, fuel cells, small diesel generators, photovoltaic panels, mini wind turbines, small hydro), consumption facilities, storage facilities and supervision and demand management tools. They can be connected directly to a distribution network or operate disconnected from the network (islanding). This concept, which is likely to concern different scales of the territory (building, district, industrial or small-scale area, village, etc.) is being extended to heat and natural gas networks, and can thus be thought of in a multi-fluid way.

The concept of microgrids is not new, since the first networks, dating from the end of the 19th century, were isolated and then gradually aggregated to create the current national networks, taking advantage of the economies of scale associated with large networks. Microgrids have been able to evolve and the deployment of Smart grids has broadened their scope. The primary mission of microgrids is electrification, which is why they are seen as an opportunity for the development of certain emerging countries, particularly in Africa. While they continue to fulfill this role today, the energy transition has also made them a vector for the development of decentralized energy production.

4.2 Typology

Electric microgrid projects can be classified according to their size, but also their usefulness (reliability, resilience and efficiency of networks, difficulty in accessing energy, degraded weather conditions, emergence of eco-neighborhoods, multi-energy thinking, energy savings, etc.) into 5 main categories:

Microgrids in commercial, craft or industrial zones:
These zones, which consume a lot of electricity, bring together companies and industries with diverse activities, whose energy needs are not all identical. The aim is to optimize energy management in these areas, in particular to make them more neutral with respect to the distribution network.

University campus microgrids:

The challenge is to improve the energy management of campuses in a context where they must adopt a sustainable development approach, as provided for in Article 55 of the "Grenelle 1" law of 3 August 2009.

Microgrids supplying isolated areas not connected to the electricity grids or temporarily cut off from the grid due to unforeseen events (bad weather, for example): The deployment of microgrids enables them to exploit local renewable energy resources and no longer depend solely on polluting and costly diesel generators.

Eco-neighborhoods:
These operate more or less on the same model as microgrids in commercial or industrial areas, but on the scale of urban residential and/or service areas.

Microgrids in "living bases" (military camps or hospitals, for example):
With its own production and storage resources and its own distribution infrastructure, the microgrid guarantees energy autonomy, providing electricity during periods of power cuts on the distribution network, which is an essential asset for military bases or hospitals, which cannot let power cuts prevent them from carrying out their missions.

4.3 Advantages

The benefits of deploying microgrids are numerous:

From a technical standpoint microgrids facilitate optimized management of renewable electricity generation at the local level, among other things. They can provide an auxiliary service to the public distribution network, helping it to maintain stable voltage and "lightening" it when it is cut off from the distribution network.

From an economic point of view depending on its size, the microgrid can play the role of a capacity aggregator. Microgrids also make it possible to defer network investments, as the proximity between production and consumption makes it possible to optimize the routing of energy. They also reduce the volume of technical losses.

From a societal point of view a microgrid provides answers to the evolution of the basic energy needs of a territory. in particular by guaranteeing a safer and more reliable network in the event of an incident. Because it is a local project, it also facilitates the creation of initiatives and new partnerships between local players. The development of microgrids also responds to consumers' appetite for short circuits, especially since the Smart Grids functions that can be attached to them considerably strengthen the role of the consumer.

From an environmental point of view microgrids facilitate the integration of renewable energies into the grids, thus avoiding the installation of thermal power plants in "fragile" areas.

In addition, as the infrastructure required for smart grids is complex to set up and can take several years, microgrids can be considered a simpler alternative to implement. By replicating on a small scale many of the issues related to the deployment of smart grids and the integration of renewable energies into the grid, they are demonstrators of what larger smart grid deployments could be.

4.4 Technical aspects

A microgrid is usually composed of one or more generators (variable renewable power generation facilities, but also conventional generation facilities), energy storage facilities, load balancing facilities, compensation systems and information systems. All of these technologies must also allow the microgrid to disconnect from the main grid to become islanded - that is, to operate independently of the main grid.

The development and operation of microgrids involves several technical and technological challenges:

The stability of the microgrid must be ensured in all circumstances, when the microgrid is connected to the main grid or when it is disconnected from it, when it connects and disconnects. Moving from interconnection to islanding can induce significant power supply-demand imbalances and, therefore, frequency and voltage control difficulties.

Maintaining stability and power quality in islanded mode requires elaborate control strategies that take into account all the parameters of generation, consumption and energy storage. A microgrid controller allows the connection to the smart grid and ensures the control of voltage, energy flow, load sharing or load shedding, and takes into account the constraints of the public grid transmitted by a communication bus.

It is also necessary to ensure the protection of the microgrid in case of failures or disturbances of various origins on the main grid. In case of a fault, the microgrid must be quickly decoupled from the main grid to protect its own loads. If the fault is attributable to the microgrid, protection functions must be able to detect short-circuit currents, due to the power electronics of the microgenerators, in order to isolate the critical part of the microgrid. The specific design and operation of microgrids requires a study of the various aspects of low voltage grid protection.

The impacts of the microgrid on the operation of the power system and the services, including system services, that the microgrid can provide (improved reliability, reduction of power system losses, impact of microgrids on future transmission and distribution infrastructure replacement and expansion strategies, at the regional, national and European levels) must be determined.

4.5 Economical aspects

The European energy system is based on an economic model organized around centralized electricity production. This configuration is gradually being challenged by the growth of decentralized renewable electricity production facilities. At the same time, the development of the public power transmission system could be limited in the future, because local opposition to new overhead structures of the public power transmission system - such as towers considered unsightly - would be increasingly strong, and burying these structures would increase their construction cost while delaying their commissioning.

In this respect, some people believe that tomorrow's electricity system could gradually move away from the current centralized model to a proximity model, with a growing number of microgrids allowing electricity to be produced and then consumed locally. The development of microgrids could thus be a complement to the traditional model so that consumers continue to benefit from clean, reliable and cheap energy.

By allowing locally produced electricity to be consumed locally, the development of microgrids, at different scales of the territory, allows:

- increase reliability and energy security (assurance of energy supply even during consumption peaks or blackouts);
- reduce network transits and therefore allow savings in network costs, both in the short term (in terms of network losses) and in the longer term (in terms of network investments);
- to achieve savings in electricity supply costs (shifting loads to when electricity is cheaper to produce, optimizing electricity supply according to energy prices on the markets and in the microgrid);
- to obtain environmental benefits (reduction of fossil fuel consumption, reduction of thermal losses, etc.).

It should be noted that if the locally produced electricity is not consumed locally, it is then injected into the upstream network which becomes a feeder network that may then require reinforcements.

4.6 Regulation

All the investment costs in the public transmission and distribution networks, as well as the related operating expenses, are borne by consumers and producers and are passed on to their energy bills, depending on the physical energy flows they generate. However, in the case of the microgrid connected to the public electricity networks, as in the case of self-consumption, the use of the upstream networks is reduced during the consumption of the "local" production. This observation could lead some consumers to ask for a reduction in their contribution to the coverage of network costs, which could open a debate on the financing of investments in the national electricity distribution and transmission network.

However, this reasoning does not take into account the many advantages of connecting to public grids, particularly in terms of security of supply, safety and quality of supply. Microgrids can be considered as complementary tools to public electricity networks as a new solution to the above-mentioned issues.

Microgrids could be a useful tool for organizing and managing energy production, distribution and consumption at the local level. Their development is related to the concepts of "local energy communities" and "renewable energy communities", introduced by the European Union in the 4th Energy Package, which is currently being transposed into different EU National law.

Finally, microgrids are inseparable from self-consumption, especially collective, which is gradually developing in France. Self-consumption, which the law now defines as the fact of consuming oneself "and on the same site all or part of the electricity produced by its installation, the part of the electricity produced that is consumed is either instantaneous or after a period of storage", participates in a better integration of decentralized production to the networks.

4.7 Why developing microgrids?

4.7.1 Provide electricity to isolated areas

The development of microgrids makes it possible to sustainably electrify the most isolated, hard-to-reach areas located far from electricity distribution networks. One example is the Princess Elisabeth Antarctica scientific research station, located in Antarctica in particularly difficult conditions, which is not connected to an electricity grid. The station's electricity is produced by solar panels (379.5 m^2) and wind turbines (9 wind turbines of 6 kW each), then stored in lead batteries with a capacity of 6,000 Ah. Heating is provided by solar thermal panels (22 m^2) and two diesel generators (44 kWh) are available as backup. The energy needs of the Princess Elisabeth Antarctica Station are barely 20% of those of a standard Antarctic station of comparable size. Each energy request is analyzed, processed and submitted for approval. The objective is to maintain the balance between what is produced and what is consumed in electricity, by ballasting and unballasting the electrical circuits. All the intelligence of the management of the polar station is centralized in a programmable logic controller. The production of energy and all the techniques used in the polar station (water treatment, HVAC, ventilation system) operate thanks to this management unit.

4.7.2 Help to reinforce grid fragility

Microgrids capable of operating in total autonomy can also be a viable response to the fragility of certain urban networks. This is a particular type of microgrid, which is not the most widespread at present: microgrids with an "islanding" mode. These grids can disconnect from the main grid and independently distribute electricity to consumers in the area. This solution is increasingly being adopted in the United States, where these microgrids are seen as a way to ensure security of supply in areas that are too often plagued by grid failures, leading to power outages. Highly centralized grids can be vulnerable to extreme weather events, in particular. In areas exposed to severe storms, for example, such microgrids could continue to supply electricity even when the main grid has been damaged. This would limit the number of consumers affected by the grid failure.

Hurricane Sandy, which hit the Northeastern United States in 2012, put microgrids in the spotlight. While the power grids failed in almost all of the affected areas, a few neighborhoods continued to receive power. College campuses, in particular, are good places to experiment with microgrids. The campus microgrid at Princeton University in New Jersey, for example, includes a gas turbine and a photovoltaic system, with a total generating capacity of 15 MW.

In normal times, if campus demand for electricity is high or electricity prices are low, the microgrid uses electricity from the public grid; conversely, if campus demand is low, the microgrid can even help power the utility grid. In times of crisis, Princeton University's microgrid can disconnect from the grid and supply the entire campus with electricity on its own. On October 29, 2012, as Hurricane Sandy hit the region causing power grid failure and blackouts, the microgrid operated in islanding mode and provided power to the campus alone until October 31, when it reconnected to the grid. In the meantime, the campus became a safe haven for emergency services such as police, fire and ambulance, who used it as a base for deploying or charging equipment.

However, the use of islanding poses a number of technical challenges because managing microgrids and connecting them to the grid is complex. In particular, the conditions necessary to maintain grid stability (in voltage and frequency) within the microgrid, as well as the stability of the distribution grid when the microgrid is resynchronized with it, must be considered. Similarly, the microgrid infrastructure must be compatible with existing standards in order to maintain the balance on the grid.

4.7.3 Possibly make savings

Reducing network transits leads to network cost savings. Optimizing the distance between energy production and consumption has two main consequences. In the short term, the most immediate consequence of using a microgrid is the reduction of electrical losses caused by the transmission of electricity. In the long term, infrastructure investments in networks could, under certain conditions, be reduced.

The microgrid can be seen as a tool for optimizing network capacities: the network is sized according to the production peak. Also, the development of renewable energies can lead to an even greater oversizing of the grid. Rather than increasing the power transit capacity on the transmission and distribution lines, a microgrid facilitates the smoothing of consumption peaks locally and helps maintain the balance between supply and demand at any given time. The added value of microgrids lies in the network control devices they include. For example, it becomes easier to allocate consumption at peak times between the various production facilities. Ultimately, better network sizing leads to more efficient management of investments in electricity distribution networks.

Among the French territories involved in the deployment of microgrids is the city of Nice, which has hosted the Nice Grid demonstrator, proposing, in particular, an alternative to increasing the transit capacity of the single 400 kV line that supplies the city.

Depending on its size, the microgrid can eventually play the role of an aggregator, which sells or buys capacities or electrical energy on the markets. In order to be able to respond quickly and efficiently to the balancing or peak demand of the grid, it is necessary to act jointly on generation and on a large volume of potential shaving. However, if we want to ensure that the network has a volume of shaving while guaranteeing industrial customers a limited impact of shaving on their processes or tertiary customers a limited impact on the comfort of building occupants, it is necessary to have great flexibility by aggregating a large number of sites. In addition to activating shaving capacities, the aggregator must generate, manage and validate shaving scenarios on the various sites to optimize the potential, flexibility and reliability of its action. The largest microgrids can thus be considered as aggregators.

Microgrids thus help to improve the availability, resilience, quality and reliability of electricity distribution networks.

4.8 Smart management of microgrids

The future development of the electrical system should lead to the deployment of smart grid technologies, in particular to reduce costs. Making electrical networks smart consists, to a large extent, in instrumenting them to make them communicative and remotely controllable. The integration of information and communication technologies into the networks makes them communicative and allows them to take into account the needs of the players in the electrical system, while ensuring more efficient, safe and economically viable electricity transmission.

The transmission network is already instrumented, in particular for security of supply reasons. On the other hand, distribution networks are still poorly equipped with communication technologies, due to the very large number of structures (substations, lines, etc.) and consumers connected to these networks. The challenge of Smart Grids is therefore mainly at the level of distribution networks, i.e. precisely at the microgrid level. Under the effect of the new energy transition policies and the digital revolution, intelligent microgrids, microgrids that integrate the information and communication technologies of Smart grids, are replacing the traditional microgrid approach. Simple" microgrids are now becoming Smart microgrids.

Previously, the balance of the electrical system was achieved mainly by steering the energy supply according to demand, at the best supply and cost conditions. Today, the new energy situation no longer allows the power system to be managed in this way. The adjustment that balances the electrical system is done not only by supply but also by demand. The management of the networks, until now centralized and unidirectional from production to consumption, is progressively becoming distributed and bidirectional. The solution of simply reinforcing the networks is sub-optimal and difficult to achieve, given the difficult acceptability of the new infrastructures and the significant investment costs involved. Smart microgrids can therefore be an important opportunity for certain territories. Smart grid technologies associated with the concept of microgrids can help network managers to adapt to the challenges of decentralized energy production, particularly by considering these new smart microgrids as a flexibility tool.

5 Peer to peer grids

5.1 Definition

A peer-to-peer (P2P) electricity grid is a type of electricity grid in which individual consumers can both produce and consume electricity. In a P2P grid, electricity is generated and distributed locally, rather than being centrally produced and transmitted over long distances. This decentralized approach to electricity generation and distribution allows consumers to sell excess electricity they generate back to the grid, and to buy electricity from other local sources when they need it.

P2P electricity grids are often powered by renewable energy sources such as solar panels or wind turbines, and are designed to be more resilient and reliable than traditional grid systems. They can also potentially reduce the costs of electricity for consumers by eliminating the need for expensive transmission and distribution infrastructure. However, there are also challenges to implementing P2P grids, such as the need for new regulatory frameworks and the potential for technical issues with integrating different sources of electricity into the grid.

5.2 Benefits and challenges

5.2.1 Benefits

One of the main benefits of P2P electricity grids is that they can help to reduce our reliance on fossil fuels and promote the use of renewable energy sources. This can help to reduce greenhouse gas emissions and combat climate change. P2P grids can also potentially increase energy security by reducing the need to import electricity from faraway sources. In addition, P2P grids can allow consumers to take more control over their energy usage and potentially save money on their electricity bills.

5.2.2 Challenges

There are several challenges to implementing P2P electricity grids. One of the main challenges is the need for new regulatory frameworks to govern the operation of these grids. This includes establishing rules for buying and selling electricity, ensuring that the grid is reliable and safe, and protecting the rights of consumers. Another challenge is the technical complexity of integrating different sources of electricity into the grid. This includes issues such as voltage and frequency control, which can be difficult to manage in a decentralized system.

5.3 Examples

There are several examples of P2P electricity grids around the world. One example is the Brooklyn Microgrid in New York City, which allows neighbors to buy and sell excess solar power. Another example is the Westmill Solar Cooperative in the UK, which is owned and operated by a group of local residents who have installed solar panels on a shared site. In Germany, the Energiewende (energy transition) movement has promoted the development of decentralized renewable energy sources, including P2P electricity grids.

6 Energy trading in private grids

6.1 Introduction

In a P2P electricity grid or in a microgrid, energy is typically traded using a platform or marketplace that allows consumers to buy and sell excess electricity. These platforms can be operated by utilities, energy companies, or third-party organizations.

Consumers who produce excess electricity from renewable energy sources, such as solar panels or wind turbines, can sell this excess electricity back to the grid. This is often done through a process called net metering, in which the excess electricity is credited to the consumer's account and can be used to offset their future electricity usage.

Consumers who need electricity can buy it from other local sources, such as their neighbors or other members of the P2P grid. The price of electricity in a P2P grid is typically based on supply and demand, and can vary depending on factors such as the time of day and the availability of renewable energy sources.

In addition to buying and selling electricity, some P2P electricity grids also allow consumers to trade other forms of energy, such as heat or gas. These systems can use smart meters and other technologies to track energy usage and facilitate trades.

Overall, P2P electricity grids offer a way for consumers to take more control over their energy usage and potentially save money on their electricity bills. They also promote the use of renewable energy sources and can help to reduce greenhouse gas emissions.

6.2 Pricing mechanism

One of the main benefits of P2P energy trading is that it allows individuals and small groups to participate in the energy market and potentially earn money by selling excess electricity that they generate from renewable sources, such as solar panels or wind turbines. This can help to increase the adoption of renewable energy and reduce reliance on fossil fuels.

P2P energy trading platforms typically use a variety of pricing mechanisms to match buyers and sellers and facilitate transactions. As mentioned earlier, fixed price, auction, time-of-use, and dynamic pricing are all common mechanisms used in P2P energy trading.

In a fixed price model, the seller sets a price for the electricity they are offering, and the buyer agrees to pay that price. This can be a simple and straightforward way to facilitate transactions, but it may not always reflect real-time supply and demand conditions.

In an auction model, buyers and sellers submit bids and offers for the electricity they are interested in buying or selling, and the platform uses an algorithm to match buyers and sellers at the best price. This can help to ensure that transactions are completed at a fair price based on current market conditions.

Time-of-use pricing charges different prices for electricity depending on the time of day. This can help to reflect the fact that electricity demand and supply can vary significantly over the course of a day. For example, electricity may be more expensive during times of high demand, such as during the evening when people are using appliances, and cheaper during times of low demand, such as the middle of the night.

Dynamic pricing adjusts the price of electricity in real-time based on supply and demand. This can help to ensure that the price of electricity reflects current market conditions and encourages the efficient use of electricity.

As a conclusion, the pricing mechanism for P2P energy trading is designed to provide a fair and transparent market for buying and selling electricity, and to encourage the use of renewable energy sources.

6.3 The role of Blockchain in energy trading

Blockchain technology is one option to revolutionize the way energy is produced, distributed, and consumed by enabling peer-to-peer (P2P) energy trading.

In traditional energy systems, energy is generated by central entities and distributed through a network of transmission lines to consumers. This centralization leads to inefficiencies and a lack of transparency in the energy market.

P2P energy trading, on the other hand, allows individuals and businesses to buy and sell excess energy directly with each other, rather than relying on a central authority. This can lead to more efficient and cost-effective energy markets, as well as increased access to renewable energy sources.

Blockchain technology can facilitate P2P energy trading by providing a secure and transparent platform for recording and verifying energy transactions. It can also enable the use of smart contracts, which can automatically execute energy trades based on predefined conditions.

Blockchain can enable the use of smart contracts in P2P energy trading. A smart contract is a self-executing contract with the terms of the agreement between buyer and seller being directly written into lines of code. Smart contracts can be used to automate the process of energy trading, making it faster and more efficient. For example, a smart contract could automatically execute an energy trade when certain conditions are met, such as when the price of energy reaches a certain level or when a certain amount of energy is produced.

Overall, the use of blockchain in P2P energy trading has the potential to democratize the energy market and create more equitable and sustainable energy systems, as it adds a layer of verifiable transparent code.

6.4 Platform for energy trading

6.4.1 Principle

P2P energy trading using blockchain technology works by enabling individuals and businesses to buy and sell excess energy directly with each other, rather than relying on a central authority. Here's a general overview of how it works:

Energy producers, such as individuals or businesses with solar panels or wind turbines, generate excess energy that they do not use.
Energy producers can sell this excess energy to other individuals or businesses through a P2P energy trading platform.
The platform uses blockchain technology to record and verify energy transactions, as well as to facilitate the use of smart contracts if desired.
Energy consumers can buy energy directly from producers using the platform, rather than buying energy from a traditional utility company.
The platform may also facilitate the tracking of renewable energy production and consumption, allowing buyers to know the source of the energy they are purchasing.

6.4.2 Examples

There are several platforms that facilitate P2P energy trading using blockchain technology.

Here are a few examples:

- LO3 Energy
- Power Ledger
- WePower
- Grid+
- Electron
- Ponton
- Veridium Labs
- Grid Singularity
- The Sun Exchange
- Energy Web Foundation
- Greeneum
- Prosumer

7 Usage of an energy exchange Framework: Grid Singularity

7.1.1 The Grid Singularity Framework.

Grid Singularity (https://gridsingularity.com) is a simulation platform that enables P2P energy trading and the optimization of energy use. It allows individuals and businesses to buy and sell excess energy directly with each other, as well as to optimize energy use through the use of smart meters and algorithms. Grid Singularity operates in multiple countries, including Austria, Germany, and the United States.

The Grid Singularity-Exchange Framework is a platform that allows users to interact with the grid in a number of ways. It provides a platform for users to buy and sell electricity, trade renewable energy certificates, and participate in demand response programs.

Users can connect to the grid through the Grid Singularity-Exchange Framework by installing smart meters or other metering equipment that is capable of communicating with the platform. Once connected, users can use the platform to monitor their energy consumption, set up alerts for high usage, and track their energy use in real-time.

Users can also use the Grid Singularity-Exchange Framework to buy and sell electricity. For example, a user with a solar panel system may have excess electricity that they can sell back to the grid. The Grid Singularity-Exchange Framework allows users to connect with buyers and sellers of electricity and facilitate the exchange of electricity.

In addition to buying and selling electricity, the Grid Singularity-Exchange Framework allows users to trade renewable energy certificates (RECs). RECs are certificates that represent the environmental attributes of renewable energy generation, such as the reduction of greenhouse gas emissions. Users can use the Grid Singularity-Exchange Framework to trade RECs to offset their carbon emissions or to demonstrate their commitment to using renewable energy.

Finally, the Grid Singularity-Exchange Framework allows users to participate in demand response programs, which are programs that incentivize users to reduce their energy consumption during times of high demand on the grid. Users can use the Grid Singularity-Exchange Framework to enroll in demand response programs and receive financial incentives for reducing their energy usage during these times.

7.1.2 Working principle

Here is a general overview of how Grid Singularity works:

- Energy producers, such as individuals or businesses with solar panels or wind turbines, generate excess energy that they do not use.

- Energy producers can sell this excess energy to other individuals or businesses through the Grid Singularity platform.
- The platform uses blockchain technology to record and verify energy transactions, as well as to facilitate the use of smart contracts if desired.
- Energy consumers can buy energy directly from producers using the platform, rather than buying energy from a traditional utility company.
- The platform also uses smart meters and algorithms to optimize energy use by matching supply and demand in real-time. This can help to reduce energy waste and improve the efficiency of the energy market.

We chose to use Grid Singularity in the present project because of its quality and the fact that it's open source.

7.2 Simulation description

In the scope of this project the grid aspects will be more thoroughly studied in WPT4: pilot projects. In this work package, one of the technical goals is to assess the impact of our framework on the physical electricity grid. In the Grid Singularity framework, the market is described, and the different entities can interact together as prosumers. They are described with consumption and production capabilities, bids for energy buying and selling are matched. The energy that isn't match at each time period is sold our bought to the retailer, this can happen retail price is more advantageous or if there is no offer left to be matched.

The simulation is conducted on several 15-minute timesteps, power fluctuations in these periods will have to be compensated by the grid operator.

In the pilot from Liege (WPT4.1), the electrical grid of the University of Liège has been modelled and will be used for physical simulation of the energy exchange computed by Grid Singularity. Using a mathematical simulation method called power flow, we will input the different power injections and withdrawals at each point of the grid and deduce the electrical state of the whole grid in this specific configuration.

The outputs given by the power flow are variables for the electrical state of the grid including:

- **The voltage level of each of the buses**. At each node of the grid, where a prosumer can be connected, there will be a specific voltage level determined the power flows. This value should be close to the nominal level, for example 0.95 to 1.05 pu.
- **The active and reactive powers flowing in each line**. This is directly linked to the voltage level and the current in the line.
- **The losses of the network.** Each line has a resistance, which induces power losses due to Joule effect. These losses should be compensated by someone, as if entity A sells a certain amount of energy to entity B, this amount will not fully arrive to B.

Due to the nonlinear nature of these losses, it is hard to have a direct causality for the amount of lost energy.

7.3 Grid fee mechanism

For the simulation, several grid fee mechanisms will be studied and compared to the standard fixed grid tariff.

The project will be inspired from the new tariff in application in the Brussels region. They consist of a grid tariff that is dependent of the physical proximity of two actors in the grid. If they are they have a highly decreased distribution grid fees (e.g., -58% of the initial price) and if they are behind a low-voltage substation the distribution grid fees are also lowered (e.g.: -26% of the initial price). When they are behind the same high voltage substation, they have no transport (HV) fees. For the fees in the BC4P-gsy-e market simulations, there is an increasing grid fee considered for an increased distance between two agents.

This fee mechanism will be compared to different other grid tariffs that can be considered in energy community.

For example:

- Constant fee: For a local energy community, the grid can be considered private behind a given point. This would necessitate all parties behind that point to be part of the community. The yearly costs for maintaining this specific part of the grid can be considered constant, and the participant would have a given share of the constant costs depending on their share in the grid usage. The ancillary services that the grid would still provide (e.g.: balancing) would still have to be paid for by the community. It would depend on the net flow at the point of connection with the grid and accounted for each of the participants.
- Pay-for-use: The fees inside the exchange platform could be constant and proportional to the amount traded. By computing the total cost for the total volume of energy exchanged, the cost for each transaction can be computed depending on their volume.
- Self-consumption discount: the grid could simply offer a fixed rate at which the energy is discounted for the self-consumption in our platform. For example, communities of that type exist in Italy. The discounted price is fixed and does not depend on the distance or the time of day (e.g.: 0.07€/kWh).

7.4 Simulation result and impact

Our simulation will output the grid usage for our energy community and its direct energy exchanges. The market will try to maximize the local trades in order to reach an optimal price for every participant, because they are incentivized to trade locally, if their bid can be matched.

This may result in an increased usage of the local network, but it can also be noted that the market can be designed to provide services like “peak-shaving”, which would limit the maximum amount of energy flow at a single moment. By adding a price on the peak demand or the peak offer of each agent individually or for the whole community, we can encourage each agent to minimize this peak. This would mitigate the stress on the network and the need for an oversized network, as the network is sized to be able to handle the peak currents (i.e.: the maximum energy flow).

Another interesting result of the simulation is the comparison of the different grid fee mechanisms on the total income of the grid. We can already say that some would be more advantageous for one or both party in the trade. This could be quantified using the simulation, we could also see how we can regulate the market to incentivize the greener and more local energy sources.

8 Impact of geographic prosumer distribution

The geographic distribution of prosumers, or individuals or organizations that both produce and consume electricity, can impact electricity prices in a number of ways.

One way that the geographic distribution of prosumers can impact electricity prices is through the effects of supply and demand. If there is a high concentration of prosumers in a particular area, there may be more local electricity generation and a higher supply of electricity. This can lead to lower electricity prices in that area, as the excess supply may drive down the price. On the other hand, if there is a low concentration of prosumers in an area, there may be less local electricity generation and a lower supply of electricity. This can lead to higher electricity prices in that area, as the reduced supply may increase the price.

Another way that the geographic distribution of prosumers can impact electricity prices is through the effects of transmission and distribution costs. If there is a high concentration of prosumers in a particular area, the local transmission and distribution infrastructure may be able to handle the higher levels of electricity generation and consumption. This may result in lower transmission and distribution costs, which can lead to lower electricity prices. On the other hand, if there is a low concentration of prosumers in an area, the local transmission and distribution infrastructure may not be able to handle the lower levels of electricity generation and consumption, which may result in higher transmission and distribution costs and higher electricity prices.

Finally, the geographic distribution of prosumers can impact electricity prices through the effects of government policies and incentives. For example, if a government provides incentives for the development of renewable energy sources, such as solar panels or wind turbines, in a particular area, it may encourage more prosumers to locate in that area.

This can lead to a higher concentration of prosumers in that area, which can impact electricity prices as described above.

Overall, the geographic distribution of prosumers can have significant impacts on electricity prices, depending on factors such as supply and demand, transmission and distribution costs, and government policies and incentives.