dena ANALYSIS

Energy communities: Accelerators of the decentralised energy transition

How digital technologies can help us establish new roles for energy communities in the energy system of the future

Legal information

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Preface

Decentralisation, digitalisation and, to a certain extent, a democratisation of the energy supply are essential building blocks for continued progress in the necessary transformation of energy systems in Germany and Europe. These aspects come to the fore particularly in energy communities. Energy communities create new and additional opportunities for the public to actively and financially participate in the energy transition by producing and consuming electricity collectively.

In order to successfully implement the long-standing idea of energy communities, a multitude of technical, regulatory and economic preconditions need to be met. Some of these are still in the process of implementation in Germany and Europe; some we need to create from scratch and some are not yet sufficiently financially attractive. These preconditions are also interdependent to a degree and – we have to admit up to this point – they do not exist to the extent that would allow energy communities to move beyond communal energy production on a broad scale. Specifically, the necessary digital infrastructure is not yet available nationwide, nor is the current regulatory framework ideal. As a result, the market is still failing to deliver credible business models, and is thus not generating the necessary impetus or knock-on effects.

However, we are seeing some movement on the issue. Firstly, new digital solutions can help energy communities to make a decisive breakthrough and fuel their further development. For example, smart meters can provide – ideally in real time – the data necessary for new services, or for local optimisation of the energy supply by means of intelligent data analyses. Digital platforms can bring together the players involved and decentralised peer-to-peer infrastructures can even connect them directly to one another, an approach that reflects the process of direct energy trading in a special way. Secondly, Germany's new federal government's coalition agreement, which was presented in December 2021, also addresses the topic of energy communities in the context of strengthening citizen-owned energy, while at the same time making a strong and demonstrative commitment to digitalisation.

In this analysis by the Deutsche Energie-Agentur (dena) – the German Energy Agency, our aim is to take stock of the currently applicable framework conditions for energy communities in selected European countries and, on the basis of interviews and surveys, to find out which business models or digital applications are currently already working or cannot work, and for what reasons. Looking at other comparable countries in Europe should also help to give fresh impetus to the debate in Germany.

We can already tell you now that when it comes to the digitalisation of energy communities, Germany still has plenty to learn from countries like the Netherlands, Spain and Denmark. In summary, we appeal to Germany to show courage and exploit the potential that digitalisation holds for people.

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Abstract

With the Clean Energy Package, the EU has created a legal framework that strengthens the activities and rights of consumers and communities in the energy sector at the local level so that they can engage in innovative business fields such as aggregation, regional electricity (guarantees of origin), peer-to-peer energy trading, energy sharing and flexibility trading in the energy market. However, the development of energy communities in general is not new; in many cases, these communities already exist in the form of producer associations, virtual power plants and neighbourhood concepts. The definition of energy communities chosen in this analysis goes beyond the EU specifications, and includes all groups of individual actors who voluntarily accept certain rules in order to act together in the energy sector to pursue a common goal.

Benefits associated with energy communities include greater acceptance for regional renewable electricity, increased expansion of RES plants, reduction of renewable energy subsidies, economic participation in the energy transition, a reduction in the load on the electricity grid through precise balancing of local supply and demand, continued cost-efficient operation of post-EEG plants and incentives for new RES plants without subsidy.

Currently, energy communities are primarily active in electricity generation, supply and consumption. These activities are also the focus when it comes to the use of innovative digital technologies. Aggregator models that bundle decentralised energy generation plants as virtual power plants in order to offer products in centralised electricity markets such as spot or balancing energy markets are common. Activities such as regional electricity (guarantees of origin), peer-to-peer energy trading, energy sharing and flexibility trading offer additional opportunities for energy communities. In addition to trading transactions between producers and consumers, trading relationships also arise between energy communities and grid operators.

The extent to which today’s centralised energy markets offer efficient solutions for the increasingly decentralised energy system is currently the subject of a number of research and pilot projects. New concepts are being developed for the requirements of a highly decentralised renewable energy supply, for example, for decentralised market platforms and optimising system-friendly behaviour. Analysis shows that digital technologies and energy communities are both enablers for the decentralised energy transition and critical factors in its success. The goal is to reach a point where they can enable decentralised plants and consumers to switch effortlessly between self-consumption, trading markets and system services in a real-time energy economy. At present, such changes – and, indeed, even the simple task of switching electricity suppliers – are still tied up in bureaucracy and, above all, time-consuming.

The core technologies for the fields in which energy communities can be utilised are smart meters, platforms, data management systems, distributed ledger technologies and smart contracts. The communication units in smart meters provide the basis for the digitalisation of the electricity system, and are the point where physical electricity flows and economic transactions intersect. This foundation enables energy communities to participate in local electricity and flexibility markets in real time. Digital platforms bring together, combine and compare a variety of data from different sources in order to offer new products and services. They are ideally suited for connecting decentralised energy generation plants with energy consumers. In combination with smart contracts, distributed ledger technologies such as blockchain facilitate direct transactions between market participants that are traceable, verified automatically and conducted without a central intermediary. Because of this, the technology can help to facilitate peer-to-peer transactions, as it is able to process transactions involving very small quantities of energy using short time units, both logically and, above all, economically. Combining DLT with smart meters provides a transparent, tamper-proof and decentralised way of documenting various electricity attributes on the basis of digital signatures. In order to facilitate more widespread application of such approaches, market communication must be adapted accordingly, real-time forecasts must be produced for decentralised actors, market mechanisms will be needed for local markets, the capacity for handling large volumes of data must be established and a digital plant identity register needs to be set up.

The energy communities included in our survey deemed the investment in digital technologies worthwhile. They stated that activities and processes were being improved, but that it was necessary to build up extensive knowledge and add staff at the same time. The use of digital technologies motivates most energy communities to optimise their plant operation, expand communication and establish new business models and service offerings. The energy communities included in the survey stated that there were a number of clear obstacles to the success of this approach, primarily the lack of skilled workers, the regulatory framework conditions in the energy market, the bureaucratic workload required and obtaining the necessary investments.

Germany can benefit from the experience in implementation of the Netherlands, Spain and Denmark, especially with regard to the legal framework and market communication. Digital solutions for the technical optimisation of market communication are available in Germany, but these require the further development of specific process regulations and market design. With regard to the rollout of smart meters as a central digital infrastructure, Germany still has a relatively long way to go. There is also still a need to catch up in terms of the implementation of collective self-consumption at the building level as defined in the RED II. Compared to other countries, Germany does not yet have a concrete draft law on energy sharing (collective self-consumption) at either the building or the energy-community level.

Creating an appropriate regulatory framework, expanding the digital infrastructure and conducting targeted research will enable a new dynamic for the decentralised energy transition to unfold through energy communities and digital technologies. Along with that, economic incentives must also be established. The situation should be evaluated continuously to assess how these innovative energy communities integrate into their respective national energy markets, and what challenges and advantages arise for the energy system as a result.

1 Initial situation – Energy communities and digital technologies for a decentralised energy system

Decentralised renewable energy plants are part of a changing energy economy, and are becoming increasingly relevant due to climate protection targets. New stakeholders are participating in the energy system, such as individual prosumers and tenants who supply themselves with electricity using their own photovoltaic (PV) systems. Community supply concepts for neighbourhoods and municipalities also exist; for example, some municipal utilities are supplying consumers with renewable electricity or innovative energy products and services. However, the increasing **decentralisation of energy production** also brings with it increasing complexity and new challenges, such as a greater need for coordination. The existing energy systems needs to integrate a large number of fluctuating generation plants in a systematic way. Due to their technical performance, renewable energy plants are often connected to the distribution grid at low-voltage level, and the control workload is increasingly shifting from the high-voltage to the low-voltage grid. In order to balance electricity supply and demand with split-second precision, decentralised consumption and generation units need to be actively integrated into the energy system and coordinated. At the same time, electricity demand is rising due to increased **electrification of the heat and transport sectors** (for example, heat pumps and electric vehicles) and the associated coupling to the electricity sector, i.e., the integrated energy transition.

In addition to this, post-EEG plants[1] and decreasing feed-in tariffs are making alternative business models such as those based on self-consumption or local energy trading attractive for plant operators. For small generation plants in many EU countries, there is already a financial advantage to consuming, trading or exchanging electricity themselves rather than feeding it directly into the grid (Szichta and Tietze 2020). With the Clean Energy Package, the EU has created a legal framework that strengthens the activities and rights of consumers and communities in the energy sector at the local level so that they can engage in the energy market directly. Two of the directives in this legislative package, the Electricity Market Directive (IEMD) and the Directive on the Promotion of the Use of Energy from Renewable Sources (RED II), address central regulations on **collective self-supply** and **energy communities**, and explicitly call for decentralised energy production and consumption by private actors to be facilitated and promoted. Germany has thus far failed to transpose these EU requirements into national law, thereby slowing down new business models and innovations. Above all, the energy sharing called for in these directives – the joint consumption of self-generated electricity at communal facilities using the public electricity grid – is almost impossible in Germany. The existing individual self-supply and the landlord-to-tenant electricity model do not offer nearly enough incentives to consume renewable electricity locally, and are also insufficient as incentives for new producer-consumer communities.

For the next stage of the energy transition – the increasing decentralisation of generation and storage facilities and their economic operation in the electricity market, which is also undergoing change – **digital technologies** are considered not only an enabler, but a critical factor for success. This includes digital solutions for use both in industry and by prosumers and end consumers, such as in the form of tools for forecasting, control, monitoring, management and billing. With the corresponding expansion of the digital infrastructure,

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[1] Post-EEG plants are renewable energy plants that lose their payment entitlement under the EEG after a period of 20 years. This affects the first operators of EEG plants from 2021 onward.

these tools can facilitate the reduction of grid bottlenecks at the low-voltage level in the future, as well as the implementation of local and regional flexibility and temporary island operation by means of a cellular approach. In this way, digitalisation offers an economically efficient means of ensuring security of supply, even with a high share of renewable power generation.

Furthermore, plants owned by local stakeholders should be able not only to feed energy into local and national energy markets, but also to participate in them. Ideally, decentralised plants and consumers will be able to switch effortlessly between self-consumption, trading markets and system services in a real-time energy economy. At present, such changes – and, indeed, even the simple task of switching electricity suppliers – are still tied up in bureaucracy and, above all, time-consuming.

Furthermore, digitalisation is shaping **new business models** of energy trading, which are established when individual, communal and also general economic advantages prevail. Digital technologies and processes, including smart meters, peer-to-peer platforms, big data analytics and distributed ledger technologies such as blockchain, are seen as key to innovations such as virtual power plants, real-time assessments, smart grids and efficient trading of the smallest quantities of energy (see Mayer and Brunekreeft 2020; dena 2019). As such, they facilitate the transition from a centralised energy system to a decentralised and more complex model in line with the three-pronged energy policy objectives for the energy transition: economic efficiency, environmental compatibility and security of supply.

While large companies in the energy industry are increasingly digitalising their business processes, many small players are still only just starting out on this path. A lack of skilled workers, the bureaucratic workload and the fact that the regulatory framework is often still lacking have hindered the development of smaller supply points and producers and also the short- and medium-term use of new digital technologies.

The new German government's **coalition agreement** indicates that positive developments can be expected for energy communities in the future. Since the government intends to inject new momentum into the energy transition as a whole, there will be a renewed focus on the further expansion of decentralised renewable energy plants and a new electricity market design (see 2021 Coalition Agreement).

The coalition intends to bolster regional renewable electricity, and set in motion the pending reforms to the landlord-to-tenant electricity model and energy sharing for energy communities. In addition to this, the agreement outlines plans to simplify and strengthen the existing landlord-to-tenant electricity and neighbourhood concepts as part of amendments to the tax, transfer and apportionment system. The government aims to remove obstacles to citizens' energy projects in order to increase their impact on the acceptance of the energy transition. As a result of this, it is hoped that prosumers acting both individually and collectively, and also energy communities, will be able to participate in local, regional and national electricity markets and offer system services in balancing energy markets.

Alongside these plans, the German government also wants to advance the modernisation, digitalisation and controllability of the distribution grids. In order to lay the groundwork for this, it intends to significantly accelerate the rollout of smart meters (see 2021 Coalition Agreement). In order to ensure a dynamic balancing of supply and demand for millions of market players, millions of transactions that enable fast and efficient interactions will be needed. To achieve this, further developments are required in the exchange of information between distribution system operators (DSOs) and transmission system operators (TSOs), in bottleneck management and in market communication, and a flexible and adaptive regulatory framework will be necessary in the future.

In light of this situation, this study provides an overview of the EU framework legislation on energy communities and its implementation status in the various Member States. The understanding of energy communities in this analysis goes beyond the definition of energy communities used in the EU's Clean Energy Package. For the purposes of this study, Energy Communities are described as follows: *'An energy community is a group of individual stakeholders (citizens, companies, public institutions) who voluntarily accept certain rules in order to act together in the energy sector to pursue a common goal.'* This enables a broad analysis of which new business models can be created in the context of energy communities using digital technologies, and how they can help to accelerate the decentralised energy transition. These innovative approaches provide an impression of the dynamics that digital technologies can unleash in light of the changing stakeholder structure, the increasingly small-scale nature of the energy system and the requirements of the electricity market.

The study aims to answer the following questions:

- What are energy communities and what is their potential significance within the energy system?
- What digital fields of activity and core technologies are relevant for carrying out the activities of energy communities, especially newer business models?
- Which EU countries have advanced frameworks for the use of digital technologies in terms of data and infrastructures in energy communities?
- From the stakeholders' point of view, which hurdles need to be removed in order to exploit the potential of energy communities for the energy system?

1.1 Methodology/approach

The following methodological steps were carried out to address the questions:

- **Field analysis:** The field analysis covers the EU's legal definition of energy communities and introduces an extended definition of the term in the context of the study. This was followed by an in-depth investigation of the current and future digital fields of activity and core digital technologies within energy communities, which was based on research projects, European and country-specific studies, case studies, scientific articles and other public sources from associations, initiatives and companies. Part of the field analysis involved an investigation of the state of digitalisation and energy communities in three selected EU countries.
- **Structured interviews**: Structured interviews were conducted with experts in digital technologies relating to energy communities in order to find out about their experiences with the current state of use and the future development of the core technologies in question. The interviews were addressed at energy experts with experience in the use of decentralised energy generation and scientists who had experience with digital technologies in energy communities.
- **Online survey**: A written, standardised online survey on the use of digital technologies was conducted among the relevant stakeholders in the energy communities.

Section 2 of this study presents the EU framework legislation on individual and collective self-consumption and energy communities, together with the legal implementation of this legislation in the EU Member States. Section 3 presents an extended definition of the concept of energy communities. This expanded definition forms the basis for the questions examined in all the subsequent sections. Section 4 explains the main fields of activity within energy communities and presents the associated core digital technologies.

Section 0 then takes a look at three European countries which can be seen as more advanced than Germany with regard to the facilitation of energy communities and their access to the electricity market on the one hand and, on the other hand, in terms of their use of digital technologies in the energy system and in energy communities. Section 6 presents the results of the survey on the use of digital technologies in European energy communities. In addition to questions about the specific digital technologies that are being used, this section also addresses the associated experiences, expected potential and current obstacles. The final part of the study, Section 7, summarises the results of the study and options and next steps for the further development of energy communities.

2 EU framework legislation

Across Europe, citizens, communities, municipalities and companies are engaged in building and operating their own renewable energy plants under a wide variety of framework conditions. The groundwork for this was laid by the liberalisation of the electricity market, which began more than 20 years ago with the unbundling of the grid, generation and consumption, and has now been significantly expanded upon by the EU's Clean Energy Package. In principle, the EU Commission seeks to enable all stakeholders to participate competitively in the energy system, and its legislation explicitly supports small market players and decentralised generation and consumption (see BUND and BEEn, 2019).

In particular, the new versions of the Renewable Energy Directive (RED II) (EU) 2018/2001 and the Internal Electricity Market Directive (IEMD) (EU) 2019/944, which form part of the Clean Energy Package, contain key regulations on individual and collective self-supply with renewable energies, and also on the renewable energy communities (RECs) and citizen energy communities (CECs) defined here.

In addition to supplying themselves with energy from their own plants, citizens can join together and organise energy communities within the energy system. The energy market is changing and increasingly integrating these new players, but it also places demands on them. The two-way supply of energy between prosumers and the collective energy supply within energy communities lead in turn to transformation and innovation. Local energy communities can act in a system-friendly way and flexibly balance electricity supply and demand. Decentralised flexibility is considered one of the most important prerequisites for the energy market of the future. For individual consumers within a community, the incentive is not only the price but also other shared goals, such as regional renewable energy supply, CO_2 reduction, participation in the energy system and the quality of their energy supply (see Fischer 2021). Local market mechanisms can be beneficial if, as in energy communities, there is explicit local demand for local supply. This is the case when there is a clear preference for locally generated electricity, or when local flexibility is used to avoid grid congestion in the same distribution grid (see Wagner et al. 2021).

Concepts for collective self-supply have been under discussion for some time in a number of EU Member States, and in some cases have already been introduced. For energy communities, the transposition of the EU legal framework in 2020 represented progress. The implementations of the IEMD needed to be completed by the end of 2020 while the RED II needed to be fully implemented by mid-2021 (see Frieden et al., 2020).

2.1 Key terminology in the EU framework legislation

The Clean Energy Package sets the framework for energy communities, specifically in two particular directives. The primary aim of the IEMD is to ensure a level playing field in the energy market, while the RED II looks to promote the expansion of renewable energies (see Hansen et al., 2019). Renewable energy communities (RECs) are defined in the RED II as communities of renewable electricity and heat production. Citizen energy communities (CECs) are described in the IEMD as a new role in the energy market; their scope is limited solely to the generation of electricity, including by non-renewable (technology-neutral) means. Through the RED II, the EU requires Member States to promote the expansion of renewable energies, including through renewable energy communities, and to take these communities into account in their support schemes. The IEMD is aimed above all at ensuring a level playing field.

Both directives enable citizens to organise themselves collectively within the energy system in the form of an association, cooperative or comparable organisation. In addition to this, the IEMD includes an optional right to operate a distribution grid, while the RED II states that energy communities must not be discriminated against as distribution grid operators (see Frieden et al., 2019). However, energy communities should not be purely commercial market players; they should combine economic objectives with ecological and social goals. To this end, common criteria and activities are defined in both directives:

- **Governance:** Open and voluntary participation on the part of the members of the energy community.
- **Ownership and control:** Participation and effective control are in the hands of citizens, local authorities and SMEs that are not primarily active in the energy sector.
- **Purpose:** Energy communities are primarily focused on creating environmental and social benefits for their members or the community, rather than economic profits.

The respective criteria for energy communities outlined in the RED II and the IEMD differ in the following aspects:

- **Geographical scope:** The RED II requires geographical proximity between the local communities and the plants they use, and states that the community should own and develop said plants. Under the IEMD, the energy does not have to be generated close to where it is consumed.
- **Activities:** Energy communities as defined by the IEMD (CECs) are only active in the electricity sector, and can also be based on renewable and fossil energy sources. RED II energy communities (RECs) are limited to renewable energy, but may include both the electricity and the heating sectors.
- **Stakeholders:** All stakeholders can participate in a CEC, as long as large commercial members or shareholders whose main economic activity is in the energy sector do not exercise decision-making power. Membership in an REC is more restricted, and only open to individuals, local authorities and micro, small and medium-sized enterprises whose participation does not represent their primary economic activity. Furthermore, Member States must also allow low-income and vulnerable households to participate in RECs.
- **Autonomy:** The RED II requires the participating members and shareholders to be autonomous. The IEMD does not require autonomy, though it does state that decision-making powers must not be vested in members or shareholders who are large or whose main business is in the energy sector.
- **Effective control:** The RED II allows for control by local SMEs. In the IEMD, medium-sized and large companies are excluded from exercising control (see Caramizaru and Uihlein 2020).

Key terminology and activities of energy communities

With regard to the potential activities of energy communities, there are certain key terms whose definitions differ slightly between the two directives. The IEMD defines ‘supply’ as ‘the sale, including the resale, of electricity to customers’. The RED II adopts the same definition as the IEMD, but uses the term ‘sale’ in place of ‘supply’. Furthermore, in addition to sales via power purchase agreements, the RED II designates special forms of sale such as peer-to-peer trading. The RED II describes peer-to-peer trading as ‘the sale of renewable energy between market participants’ via specific means, including ‘the automated execution and settlement of the transaction’. This can be done ‘either directly between market participants or indirectly through a certified third-party market participant, such as an aggregator’. The directives also define aggregation as the performance of a function by a natural or legal person that combines multiple customer loads or generated electricity for sale, purchase or auction in an electricity market (see Frieden et al., 2020).

In addition to this, the IEMD and RED II provide for the concept of energy sharing, which differs from traditional supply. The IEMD does not define energy sharing, but does state that energy communities are allowed to 'share electricity produced using generation assets within the citizen energy community among their members or shareholders according to market principles'. The RED II also calls for energy sharing, and states that 'renewable energy communities should be able to share between themselves energy that is produced by their community-owned installations'. The RED II also calls for energy sharing for collective self-consumption: 'Member States shall ensure that renewables self-consumers located in the same building, including multi-apartment blocks [...] are permitted to arrange sharing of renewable energy that is produced on their site or sites between themselves' (see Frieden et al., 2020). Furthermore, both directives define the terms 'aggregation' and 'peer-to-peer trading'.

Energy communities can both carry out traditional activities and take on new roles. So far, energy communities often carry out the following activities:

- **Generation:** Energy communities jointly use or own generation plants whose energy they do not consume themselves; instead, they feed this energy into the grid or sell it to energy suppliers or traders.
- **Supply:** Selling energy to customers. Energy communities can supply customers in their local areas, participate in aggregation activities, combine loads and flexibilities, and actively participate in electricity trading.
- **Consumption and sharing:** The energy produced in the energy community is distributed and consumed within the community.
- **Distribution:** Energy communities can own or operate their own distribution grids for electricity, heating or biogas. Energy communities may own and operate if they possess grid infrastructure.
- **Energy services:** Energy communities can offer services such as energy efficiency, energy conservation and consumption monitoring, for example, in the building sector. The range of services energy communities can offer also includes flexibility services, energy storage services, grid services and financial services.
- **Electromobility:** This includes services relating to car sharing, operation and management of charging stations, and similar services for members.
- **Other activities:** Services relating to the development of energy communities, such as campaigning, or to help reduce energy poverty (see Caramizaru and Uihlein, 2020; Frieden et al., 2020).

2.2 Collective self-consumption

The RED II (Art. 2, Paragraphs 14 and 15) provides definitions of renewables self-consumers and jointly acting renewables self-consumers. In the context of the Directive, these terms are defined as follows:

- **Renewables self-consumers:** 'A final customer operating within its premises located within confined boundaries or, where permitted by a Member State, within other premises, who generates renewable electricity for its own consumption, and who may store or sell self-generated renewable electricity, provided that, for a non-household renewables self-consumer, those activities do not constitute its primary commercial or professional activity' (The European Parliament and Council of the European Parliament and the Council of the European Union, 2018, p. L328/103).

- **Jointly acting renewables self-consumers:** 'A group of at least two jointly acting renewables self-consumers […] who are located in the same building or multi-apartment block' (The European Parliament and Council of the European Parliament and the Council of the European Union, 2018, p. L328/103).

The term 'jointly acting renewables self-consumers' refers to self-consumers who act collectively in the field of renewable electricity generation. Individual self-consumption is possible in most EU countries, but collective self-consumption (CSC) is still new (see Figure 1). Some countries already have a legal framework for this, or are in the process of developing one. The regulations of each country differ in terms of their scope, legal structure, technologies, rights for consumers, charges and taxes.

- **Scope**: In most cases (e.g., in Austria), collective self-consumption projects do not use a public grid. For consumers behind the same connection point, however, this can be extended (as is the case in France).
- **Legal structure**: Collective self-consumption requires the establishment of a legal organisation in some countries, while in others, less formal arrangements are permitted.
- **Technologies:** Most of the regulations in the Member States relate to renewable energies.
- **Consumer affairs and consumer protection**: Most of the regulations grant consumers the right to choose their own energy supplier.
- **Grid charges, levies, surcharges and taxes**: As a rule, no grid fees are charged for electricity transport that does not use the public grid. However, there are differing approaches to the application of levies, charges, etc., for collective self-consumption. Some countries grant an exemption from the electricity tax, while others levy the full tax rate (see Hansen et al., 2019).

The IEMD also contains a comparable formulation for self-consumption with its definition of the term 'active customer'[2]. Despite using different terms ('customer' and 'consumer'), the IEMD and the RED II share similar concepts. However, the definition of the term 'active customer' in the IEMD is broader than that of 'self-consumer' in the RED II. The latter also includes flexibility mechanisms, energy efficiency programmes and non-renewable self-generation. The IEMD does not define *'jointly acting customers'*, though it does state that '*Member States may have different provisions applicable to individual and jointly-acting active customers in their national law, provided that all rights and obligations set out under this Article apply to all active customers'* (Art. 15.1b of the draft recast of the Electricity Directive) (see Toporek and Campos, 2019).

2.3 Progress of legal implementation in the EU

In most Member States, there was progress in the legal implementation of the RED II in collective self-consumption and renewable energy communities (RECs) in 2020. National implementations of collective self-consumption mostly refer to direct electricity use in multi-apartment and commercial buildings, often without use of the public electricity grid. Switzerland, Austria and France had already created legal frameworks for collective self-consumption prior to the conclusion of the Clean Energy Package, including in buildings not connected to the public electricity grid. Spain, France and Italy also provide for the use of the public grid within the framework of collective self-consumption.

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[2] For the purposes of this Directive, 'an "active customer" means a final customer or a group of jointly acting final customers, who consumes or stores electricity generated within its premises located within confined boundaries, or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy-efficiency schemes, provided that those activities do not constitute their primary commercial or professional activity'. (The European Parliament and the Council of the European Union 2019, p. L158/139)

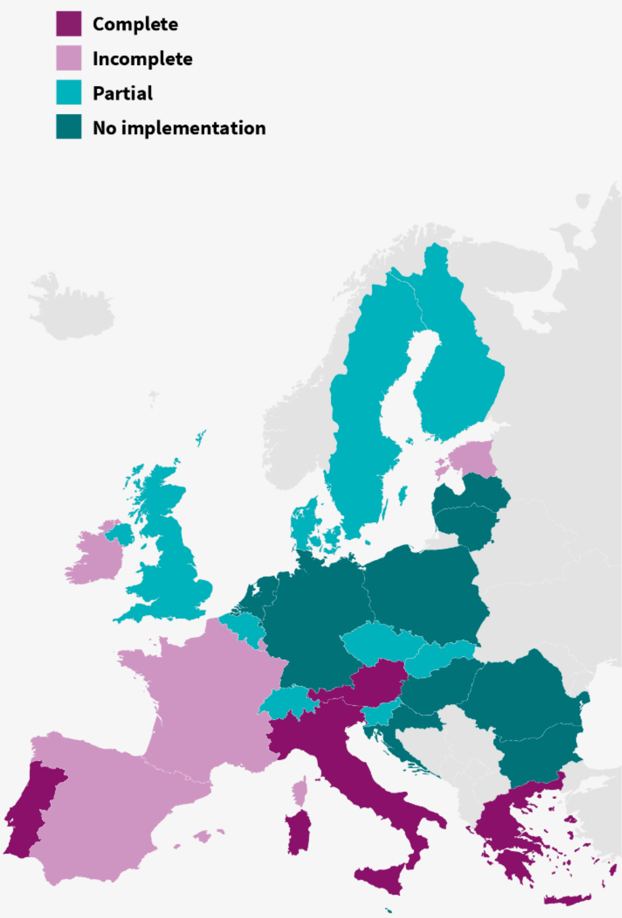
With regard to the legal implementation of RECs, Greece had already created a comprehensive legal framework back in 2018, and was thus a pioneer (see Peraudeau 2019). Portugal, Belgium (Wallonia and Flanders), Lithuania, France, Austria, the Czech Republic, Luxembourg, Estonia, Ireland, Italy, Sweden and Slovenia have also now all fully or partially implemented the European framework for RECs. The implementation of citizen energy communities (CECs) in the Member States based on the IEMD is less advanced, despite an earlier implementation deadline (see Figure 1). Concrete legislative proposals have been made by France, Belgium (Flanders), Austria and Denmark. Greece did not make any distinction between CECs and RECs (see Frieden et al., 2020).

Countries yet to commence implementation

Poland, Croatia, Cyprus, Latvia, Germany and the Netherlands have all yet to make any legal proposals for collective self-consumption or energy communities (CECs and RECs). The legal frameworks already in place in the Netherlands and Germany for the regulation of certain energy cooperative activities, such as energy generation and the provision of energy efficiency services, are considered a good basis for further development in line with EU requirements. In the Netherlands, for example, tax relief is guaranteed for electricity generation by cooperatives and owners' associations that apply to members in the same or neighbouring postcode areas (*Postcoderegulering*, see also Section 5.1.1). Croatia plans to implement the EU requirements in the course of 2021 (see Frieden et al., 2020).

In addition to this, Germany (with its landlord-to-tenant electricity model), Bulgaria, Romania and Slovakia all have strategies in place for the implementation of collective self-consumption; however, these do not fulfil the concept of energy sharing. For collective self-consumption, this means that the owners, operators and consumers of a system may be identical persons or entities.

	EU-Länder	CSC	REC	CEC
🟪	Austria	yes	yes	yes
🟪	Greece	yes	yes	yes
🟪	Italy	yes	yes	yes
🟪	Portugal	yes	yes	
▨	Estonia	yes	(yes)	(yes)
▨	France	yes	(yes)	(yes)
▨	Ireland	no	(yes)	no
▨	Luxembourg	(yes)	(yes)	
▨	Spain	yes	(yes)	(yes)
🟦	Belgium	(yes)	(yes)	no
🟦	Czech Republic	no	(yes)	(yes)
🟦	Denmark	yes	no	(yes)
🟦	Finland	yes	no	no
🟦	Slovakia	yes	no	no
🟦	Slovenia	yes	no	(yes)
🟦	Sweden	yes	no	no
🟦	(Switzerland)	yes	yes	no
🟦	United Kingdom	yes	no	no
🟩	Bulgaria	no	no	no
🟩	Croatia	no	no	no
🟩	Cyprus	no	no	no
🟩	**Germany**	no	no	no
🟩	Hungary	no	no	no
🟩	Latvia	no	no	no
🟩	Lithuania	no	no	no
🟩	Malta	no	no	no
🟩	Netherlands	no	no	no
🟩	Poland	no	no	no
🟩	Romania	no	no	no



CSC: Collective Self-Consumption,
REC: Renewable Energy Community,
CEC: Citizen Energy Community

Figure 1: Overview of the implementation status of the IEMD and the RED II in the EU-27 (Source: own figure based on Karg (2020))

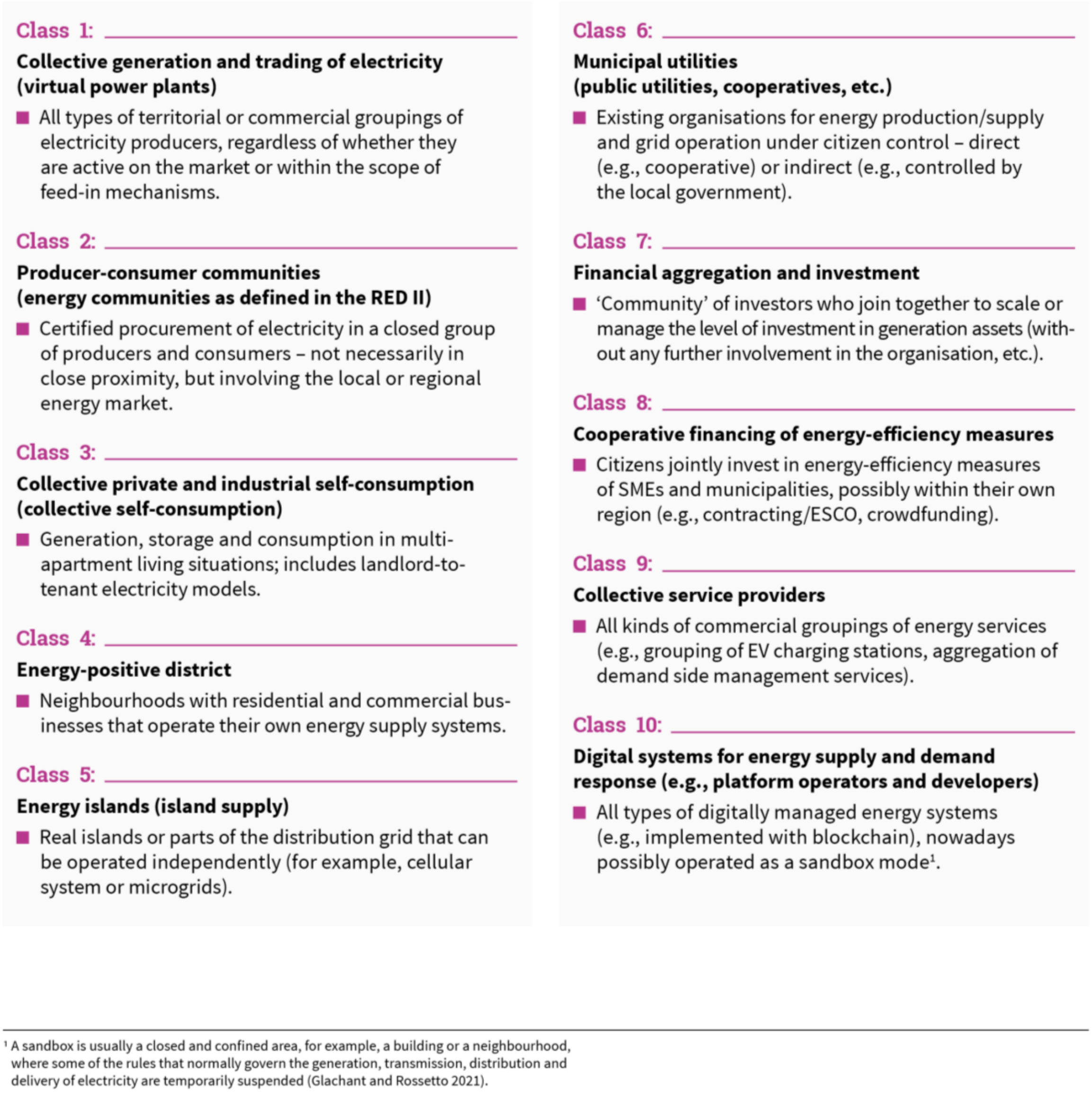
3 Energy communities – Expanded definition of the term from the perspective of business models

To date, the literature uses many terms for citizen-led energy initiatives, for example: community energy, community renewable energy, integrated community energy systems, clean energy communities, local community initiatives, low-carbon communities, energy communities, communities, community energy, energy cooperatives, cooperative energy, cooperatives and others.

The definition in this study extends beyond the established EU framework in the RED II and IEMD. This reflects the fact that, in principle, the development of energy communities is not new; they are already active in the integration of decentralised renewable energy production in the form of virtual power plants, municipal utilities and neighbourhood concepts, amongst others. By examining energy communities beyond this framework, a multitude of other business models that contribute to accelerating the decentralised energy transition manifest through the increased use of digital technologies. Broadening the scope to include stakeholders pursuing an economic interest can reveal an entirely new dynamic, including in light of the competitiveness achieved by PV- and wind-based renewable energies. Based on new partnerships and innovative cooperative relationships between diverse stakeholders (citizens, companies, the energy industry and municipalities), pioneer energy communities can develop that increasingly use innovative and smart digital technologies. In this way, they create added value for their members and society that goes beyond the joint generation of renewable energies. For this reason, no approach should be explicitly excluded on the basis of EU legislation, rather scope for investigation should be unreserved. This study follows the expanded definition of energy communities of the 'Energy Communities' working group of the ERA-Net Smart Energy Systems network (see ERA-Net 2021), formulated as follows:

An energy community is a group of individual stakeholders (citizens, companies, public institutions) who voluntarily accept certain rules in order to act together in the energy sector to pursue a common goal. This includes to a certain extent (direct or indirect) community involvement in the organisation and the sharing of outcomes (beyond financial gain) for the purposes of a common goal (exclusively or including) in relation to energy, which means, for example: 1. purchasing energy as a collective group, 2. and/or management of energy demand and supply, 3. and/or generation of energy, 4. and/or provision of energy-related services, 5. and/or providing mechanisms that promote energy-related behavioural changes (Karg and Hannoset (no year)).

Energy communities can be formed **locally** or **virtually** with a group of members who share the same purpose (see Biresselioglu et al. 2021). The ERA-Networking group has categorised energy communities into ten classes, which are listed in Table 1:



Class 1:

Collective generation and trading of electricity (virtual power plants)

- All types of territorial or commercial groupings of electricity producers, regardless of whether they are active on the market or within the scope of feed-in mechanisms.

Class 2:

Producer-consumer communities (energy communities as defined in the RED II)

- Certified procurement of electricity in a closed group of producers and consumers – not necessarily in close proximity, but involving the local or regional energy market.

Class 3:

Collective private and industrial self-consumption (collective self-consumption)

- Generation, storage and consumption in multi-apartment living situations; includes landlord-to-tenant electricity models.

Class 4:

Energy-positive district

- Neighbourhoods with residential and commercial businesses that operate their own energy supply systems.

Class 5:

Energy islands (island supply)

- Real islands or parts of the distribution grid that can be operated independently (for example, cellular system or microgrids).

Class 6:

Municipal utilities (public utilities, cooperatives, etc.)

- Existing organisations for energy production/supply and grid operation under citizen control – direct (e.g., cooperative) or indirect (e.g., controlled by the local government).

Class 7:

Financial aggregation and investment

- ‘Community’ of investors who join together to scale or manage the level of investment in generation assets (without any further involvement in the organisation, etc.).

Class 8:

Cooperative financing of energy-efficiency measures

- Citizens jointly invest in energy-efficiency measures of SMEs and municipalities, possibly within their own region (e.g., contracting/ESCO, crowdfunding).

Class 9:

Collective service providers

- All kinds of commercial groupings of energy services (e.g., grouping of EV charging stations, aggregation of demand side management services).

Class 10:

Digital systems for energy supply and demand response (e.g., platform operators and developers)

- All types of digitally managed energy systems (e.g., implemented with blockchain), nowadays possibly operated as a sandbox mode[1].

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[1] A sandbox is usually a closed and confined area, for example, a building or a neighbourhood, where some of the rules that normally govern the generation, transmission, distribution and delivery of electricity are temporarily suspended (Glachant and Rossetto 2021).

Table 1: Classification of energy communities into classes

Figure 2 shows the characteristics of energy communities according to important features, existing and future business models and their status quo in Germany.

Class 2 energy communities
Producer-consumer community

Prosumers supply themselves and other members of the energy community with electricity from their own systems using the public grid. Usually geographically close-by, though potentially also for specific purposes.

Business model: (P2P) – Energy sharing, regional electricity

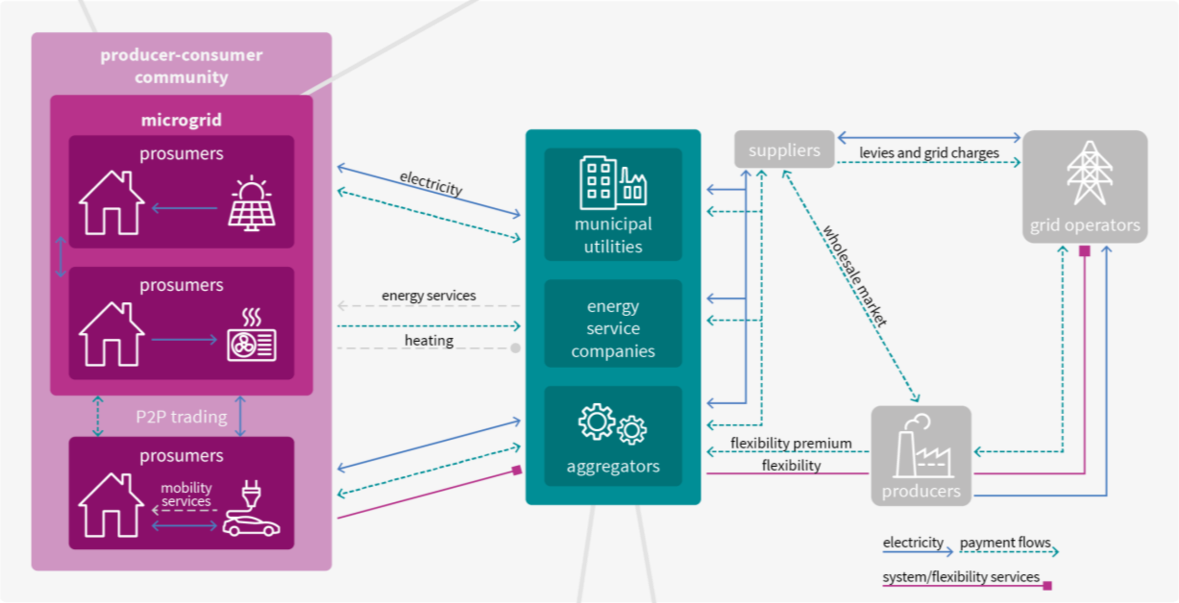
Status quo: In Germany, regional electricity via other direct selling, though costly and not really profitable.

Class 3, 4, 5 energy communities
Microgrid community

Power generation from own systems via own grid (microgrid) of consumers in apartment buildings (landlord-to-tenant electricity model*), neighbourhoods or islands. A connection to the public grid is available.

Business model: Landlord-to-tenant electricity supply

Status quo: *Not possible in Germany, as system owners and consumers are not the same.



Class 1, 6 energy communities
Virtual power generation community

Producer-side decentralised electricity community made up mostly of aggregators that offer electricity on the market bundled via direct selling. No geographical proximity necessary.

Business model: Virtual power plants, cooperative

Status quo: Virtual power plants, municipal utilities or cooperatives. In the case of cooperatives, members can jointly own generation facilities but not supply themselves directly.

Class 7–10 energy communities
Services for energy communities

Individually outsourced services for energy communities, such as plant financing, energy efficiency services, demand response, supplier services, software/hardware solutions.

Business model: Contracting, cloud models, software-as-a-service, demand response (load plant), supplier services (forecasting, billing, etc.)

Status quo: Applied in the area of decentralised energy

Figure 2: Classification of energy communities (Source: own illustration based on ERA-Net (2021) and Brown et al. (2020)

4 Selected digital technologies in energy communities

The activities of energy communities can encompass all aspects of the value chain from generation, distribution, storage and supply through to consumption (see Section 3), but have so far focused on joint investment in local renewable energy generation projects and on energy supply.

The **fields of application for digital technologies** in energy communities are geared towards these activities. Thus, the focus so far has been primarily on electricity generation, supply and consumption. In future, energy sharing and services in the areas of energy efficiency, electro mobility and heating will also increase in significance.

4.1 Opening up new fields of application and market roles in the energy system

With digitalisation, new business models are emerging at the local level involving market developers, including companies, citizens' initiatives led by local authorities or natural persons. Energy communities may be active in the areas of **aggregation**, **peer-to-peer trading**, **energy sharing** and **flexibility provision** (see Benedettini et al. 2019). They are establishing themselves in the energy market, becoming more professional and striving for new roles including as suppliers, aggregators and traders (see Lowitzsch et al. 2020). For direct regional balancing of supply and demand on the market that goes beyond simple balancing, energy communities can take on an important function in larger energy cells.

Offering new services to their members such as flexible loads, generation facilities or storage provides new economic incentives to energy communities (see Klaassen and van der Laan 2019). A large number of energy communities have primarily an inner community focus, honing in on aspects like maximisation of self-consumption using storage and energy management systems or local energy exchange. In order to exploit the advantages of local generation and consumption further, trading on electricity markets and balancing energy markets, which previously were reserved for larger market players, will also become attractive to them in the future. Energy communities can make better use of resources and thus, for example, optimise home storage systems for self-consumption and the balancing energy market in order to achieve greater economic efficiency. Up to now, decentralised players have generally used external aggregation services to offer their electricity on existing trading markets (direct selling) and balancing energy markets.

Consuming energy where it is generated offers advantages, for example, as regards the need to expand the electricity grid and surrounding issues of resilience (see Körnig and Menke 2020). At the same time, the need for coordination in the energy system increases with the number of volatile renewable generation plants. Efficient integration is already a major challenge for many grid operators today, both on a technical and economical level. The following are seen as benefits of the shared use of electricity at the local level beyond individual buildings: increased acceptance of RES electricity by local residents, jointly optimised electricity generation, increased expansion of RES installations, reduced cost for RES subsidies, economic participation in the energy transition, a reduction in the load on the electricity grid through the precise balancing of local supply and demand, continued cost-efficient operation of post-EEG plants and incentives for new RES installations without subsidy.

‘If we look at the energy system from a technical perspective, we are moving from the centralised state that existed at the beginning to an increasingly decentralised future. Of course, decentralised generators do not only exist on their own, but are also again aggregated, for example, into virtual power plants in a cellular system. By contrast, however, the energy market is still centrally organised as a regulated oligopoly by means of the EEX, the balancing energy markets and so on. This raises the question of whether marketplaces should not also be decentralised – or at least regional products traded on central marketplaces’ (expert interview 2021).

The extent to which today’s centralised energy markets can be efficiently linked with new solutions for the increasingly decentralised energy system is currently a much-discussed question in research and pilot projects. In the future, new markets such as peer-to-peer trading platforms will offer decentralised stakeholders prospects for energy sharing and energy trading within the energy community as well as direct access to trading transactions beyond the confines of their own plant(s). From the customer’s point of view, the electricity’s origin can be an important driver in purchasing decisions. In addition to trading transactions between producers and consumers, trading relationships also arise between energy communities and grid operators. As local grid bottlenecks occur due to the regional distribution of renewable energies and the available grid capacities, small-scale flexibility options (battery storage capacity of PV plants or electric vehicles, load management in households) in physical proximity to renewable plants can provide added benefits for local renewable energy generation and distribution grid operation. Organising flexibilities to help facilitate grid operation can reduce local grid bottlenecks and, in future, also solve them economically at distribution grid level (see Koch et al. 2021). Energy communities thus become part of the **geographical optimisation** of the production, use and organisation of energy**.** The digital fields of action for energy communities derived from this are presented in more detail below.

4.1.1 Aggregation

‘Aggregators are definitely among the pioneers in the use of innovative digital technologies, because they rely on extensive and precise data for their business models. Aggregators that offer balancing power, for example, have to switch their plants flexibly in the shortest possible time. This is possible only with a significant degree of digitalisation. It is worth noting here that the market role of “aggregator” as such has not yet been defined’ (expert interview 2021).

Within the framework of existing aggregator models, the bundling of decentralised energies is already taking place in the form of virtual power plants, whose operators offer their products on existing centralised electricity markets such as spot or balancing energy markets (class 1 energy community) (see Wagner et al. 2021). Products include both bundled energy from small RES plants and demand response resources from industrial and commercial electricity customers (see Poplavskaya and Vries 2020). Sonnen GmbH aggregates the electricity storage capacity of private electricity customers and thus offers products on the balancing energy market. Since 2018, the company has received prequalification for primary control power and is thus one of 29 providers in Germany. Offering these services with a virtual network of home storage systems is unique worldwide (see Sonnen GmbH 2021).

Flexibility on the supply side is provided by optimising electricity generation from flexible resources such as combined heat and power (CHP) plants, biogas plants, etc., and by using energy storage systems. Optimisation is based on historical and forecast data on demand, generation and pricing (see IRENA 2019). The aim of aggregators is to create minimum parameters for wholesale market offerings and valuable products for stakeholders such as TSOs at a wholesale level (see Glachant and Rossetto 2021).

One example is NEXT Kraftwerke in Germany. Virtual energy communities can be implemented by joining aggregator models and energy suppliers in a way similar to that of green energy suppliers. However, since the products are purchased on the energy exchange, the targeted selection of individual producers by consumers is not possible directly, but only through the choice of suppliers.

4.1.2 Peer-to-peer energy sharing and peer-to-peer energy trading

Peer-to-peer transactions offer a new trading environment in the electricity sector, characterised by the active participation of small players. The focus is on energy deliveries between consumers with their own generation plants (prosumers). Peer-to-peer exchange provides these market players with direct access to each other, so that electricity trading transactions and electricity deliveries become possible without central intermediaries such as exchanges, brokers or energy suppliers (Kreuzburg 2018). In addition to independence from traditional energy suppliers, the aim is also to enable greater participation in the energy system, which should lead to more efficient energy use and cost savings across the economy (see EKSH 2021). In future, however, energy communities could integrate local producers and consumers of the low-voltage grid into decentralised electricity and flexibility markets at a local or regional level and facilitate trading between them. This offers added value, especially in the local management of bottlenecks. Such decentralised markets can also interact with wholesale markets. Peer-to-peer models may represent a new selling option especially for post-EEG plants after the feed-in tariff expires.

The terms ‘peer-to-peer energy trading’ and ‘peer-to-peer energy sharing’ are closely linked and have often been used synonymously. Bogensperger et al. 2021 therefore use their own definition of peer-to-peer energy sharing to create a clear distinction from peer-to-peer energy trading.

Peer-to-peer energy sharing involves energy consumers sharing their surplus energy with other energy consumers on the same hierarchical level to enhance the benefits of community. Energy consumers can act individually or as a group, functioning purely as energy consumers or also in the role of producer (prosumers). The economic benefit is not the only incentive to participate in an energy sharing community. Equally important are community benefits such as the electricity’s origin, minimisation of community electricity costs, reduction of community CO_2 emissions, reduction of peak loads, improved grid utilisation, increased system stability and reduced energy imports.

Energy consumers in **peer-to-peer energy trading** by comparison are self-interested and financially oriented. The most important goal in this respect is to maximise the individual economic benefit. The incentive of higher prices motivates prosumers to sell surplus energy to other energy consumers instead of selling it on the energy exchange.

Energy sharing communities may be set up with geographical constraints within neighbourhoods, towns or counties, for example, and pursue common goals. However, it is also possible for a group of like-minded people not tied to a particular location to pursue common goals in an energy sharing community. For both peer-to-peer energy sharing and peer-to-peer energy trading, having a market design is essential in order to define the stakeholders, their responsibilities and the applicable operating and pricing mechanisms (see Bogensperger et al. 2021).

‘Energy cooperatives would prefer to do everything themselves, including creating a local energy market. However, this is often not possible. A regional energy market, for example, can be effectively organised via a distribution grid operator. This overarching market player can then also establish incentives in the first place’ (expert interview 2021).

Although many community energy projects aim to facilitate direct trading between energy consumers, private individuals tend to lack knowledge of the energy sector, the regulatory environment or IT (full supplier obligations pursuant to Section 41 of the EnWG), which is why peer-to-peer business models are currently mostly arranged via intermediaries (see EKSH 2021). Peer-to-peer trading transactions involving intermediaries require a digital platform solution (see Section 0) for implementation, which provides an open platform for buyers and sellers who join, thus creating a two-sided market. The platform operators can take on different roles in this respect. If the platform operators act as intermediaries, they purchase energy and deliver it to the end customers, like the role played by traditional utilities. However, platform operators can also act exclusively as a service provider, that is, only support and handle deliveries between stakeholders in the background (see EKSH 2021). With regard to tradable products, the platform is subject to the regulatory framework of the energy industry. Current examples of peer-to-peer platforms include sonnenCommunity, a virtual energy community operated by sonnen GmbH, the energy-as-a-service platform of Lumenaza GmbH, Belgium-based Bolt and the Dutch-based Vandebron.

Within peer-to-peer energy sharing communities, in addition to the transaction costs of participants, their scope and scale also change, because participants act collectively as a larger overall community. For example, they make joint decisions and coordinate their resources together.

A practical example is the **energy community Partagélec in France**. Here, the municipality of Penéstin and the local energy syndicate Morbihan énergies have included a group of small businesses in a common business park in the initiative. A 40 kWp PV system was installed on a building owned by the municipality, with the electricity from this covering primarily the building’s consumption. Beyond this, the remaining electricity is used to supply the 12 companies via the public grid. If the companies do not consume the electricity within the same 30-minute period in which it is generated, the energy cooperative Enercoop purchases it. State-owned grid operator Enedis, which operates the smart meters for measuring the electricity fed in and out as well as the local distribution grid, provides the data for calculating the self-consumption of each community member (see Glachant and Rossetto 2021).

Innovative peer-to-peer pilot projects in Germany

In Germany, innovative projects in the area of local energy markets (peer-to-peer energy sharing and peer-to-peer energy trading) already exist:

- In the **Allgäu Microgrid Project in conjunction with OLI Systems GmbH**, local producers and consumers tested local energy trading via an app in 2018. Consumers could set a maximum electricity price and trading took place every 15 minutes, depending on availability. Distribution was carried out via merit order and settlement via smart contracts using a blockchain (see Brenner et al. 2020).
- Wuppertal’s public utility **Stadtwerke Wuppertal** allows their customers to compile their own electricity purchases from a renewable portfolio using the Tal.Markt platform. Their selection is documented with a blockchain, and the electricity costs are billed transparently. The municipal utility guarantees the residual electricity supply if the customers’ chosen plants cannot provide sufficient power (see Brenner et al. 2020).

- The local energy market platform of Allgäuer Überlandwerke developed as part of the **pebbles project**[3] took into account the network topology and the projected network utilisation in order to minimise grid congestion. The multi-criteria optimisation underlying the platform enables quarter-hourly transactions and uses flexibilities from battery storage and controllable loads (heat pumps, charging stations for electric vehicles) if required. During the trial period from the end of 2020 to the end of 2021, around 6,000 transactions were carried out daily via smart contracts using blockchain technology. It was revealed that local energy markets can minimise the need for grid expansion and grid congestion management (see AÜW 2021b; 2021a).
- **Grid Singularity GmbH** offers an open-source simulation environment for the operation of local energy markets. The D3A tool creates a digital twin of the energy plants involved and enables plant operators to use a bidding agent with AI, with the option of also configuring market parameters such as pricing or trading intervals (see Brenner et al. 2020).

Digital technologies

‘The use of local energy markets is not necessarily reliant on a specific distributed ledger technology, but requires the rollout of smart meters and changes to the regulatory framework’ (expert interview 2021).

Peer-to-peer applications are technically possible, for example, using blockchain technology, which stores transactions in an automated, tamper-proof and decentralised manner. In combination with automatically executed rules (smart contracts), fluctuating, decentralised, renewable energy generation and the consumption of household consumers can thus be aggregated in real time (see EKSH 2021). To facilitate this, market communication must be adapted, forecasts must be produced for decentralised stakeholders in real time, market mechanisms for local markets must be established, technologies for handling large volumes of data must be available and a modern registry of installations must be set up (for example, Blockchain Machine Identity Ledger). However, it is essential to provide a high level of security, as a blockchain application in electricity trading, unlike purely digital blockchain applications (e.g., like those used in finance), involves physical deliveries (see Kreuzburg 2018). DLT takes on a ledger function that can provide the very important attribute of ‘trust’ at low cost. The necessary alignment to the physical restrictions is not automatically resolved through the use of digital technology, though fast and reliable transactions create the possibility for smaller-scale balancing.

The interface between physical electricity flows and economic transactions is a so-called smart meter (see Section 4.2.1). With the smart meter gateway, for example, price signals can be received and combined with various forms of selling (see Kreuzburg 2018).

For peer-to-peer interactions, data security, data protection, data integrity and the speed of transactions between prosumers are very important. In this respect, distributed ledger technology such as blockchain, in combination with smart contracts (see Section 4.2.3) has shown great potential in overcoming these challenges, as it offers prosumers transaction security that allows them to exchange energy data without the need for certified third parties. A fast communication and IT infrastructure, the Internet of Things[4] and artificial intelligence are other important aspects (see Tushar et al. 2020).

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[3] See https://pebbles-projekt.de/.

[4] The Internet of Things generally refers to a system of interconnected, Internet-capable technical devices that are able to independently collect and transmit data via a (wireless) network without human intervention.

4.1.3 Provision of flexibility

Through targeted control of generation and consumption, energy communities could offer flexibility products and contribute to system stability through grid services (frequency control, balancing energy reserves, provision of flexibility areas and black-start responsibilities). In flexibility markets, incentives can arise to control demand-side consumption behaviour (demand response) from both local generation units and storage systems on the supply side. The goal is to ensure economical trading transactions that are beneficial to the grid in order to be able to compensate for instabilities in the electricity grid. In this way, the smallest players in the future energy system will participate in central tasks of system security. Digitalisation is a basic prerequisite for implementation and provides the basis for smaller-scale business and role models via cost efficiency.

Peer-to-X markets such as peer-to-grid are new and connect small players with grid operators. In this market process, the sellers are small, while buyers can be any other type of player such as TSOs or DSOs. With the aid of such markets, local distribution system operators should also be able to procure ancillary services to resolve local grid bottlenecks and other problems such as voltage fluctuations, which are becoming more frequent due to decentralised generation and the increasing electrification of end consumers in transport and heating. Providers can configure flexibility services on a platform either individually or bundled.

Within the energy system, various measures can be used to provide flexibility. Until now, flexibility has mostly been based on the control of supply from large, centralised power plants. Due to the expansion of fluctuating renewable generation plants, flexibility in the system needs to be reexamined. New flexibility services therefore include direct control of consumption behaviour (demand response), in addition to direct control of local generation units and storage systems. In future, greater flexibility will be necessary on the consumption side than had previously be the case. Household, commercial and industrial customers can provide flexibility services. Due to low flexibility volumes of individual decentralised plants, aggregation measures pay off (see Nixiang 2020).

In the WindNODE project, the flexibility potential in six German states (Berlin, Brandenburg, Saxony, Thuringia, Mecklenburg-Western Pomerania, Saxony-Anhalt) was demonstrated. The greatest technical potential is currently on the generation side, which could provide approx. 54 GW through down-regulation (negative flexibility). On the demand side, potential in the order of approx. 3.4 GW could also be made available (see WindNODE Verbund 2021).

When the distribution grid infrastructure reaches its physical limits, digitally networked generators, storage facilities and consumers could react in a decentralised manner and (cross-sectoral) optimisation could be sought at a local and regional level. This principle of subsidiarity is also the basis of cellular energy systems, which can drive the expansion of renewable energies while transmission grids are relieved of having to carry out grid stabilisation measures (see VDE 2019). Flexible stakeholders could adjust feed-in capacities to aid other, less flexible consumers and be financially compensated for this. Such incentives could be implemented via regional flexibility markets, which, with sufficient levels of digitalisation, could be organised on a very small scale via decentralised price signals (see Strohmayer et al. 2019). Frequently, distribution grid operators are involved in the development of local flexibility markets in order to be able to resolve grid bottlenecks in a low-cost manner in the future. However, detailed information is required for this purpose, because, in order to resolve location-specific congestion in a targeted manner with local flexibility, distribution system operators need location-specific information such as grid status data, which is generally not available in Germany at present either on existing day-ahead and intraday energy markets or on balancing markets managed by TSOs (see Valarezo et al. 2021).

‘The responsible distribution grid operator will increasingly face the task of balancing local loads, which is where it would be well suited as the responsible contact partner for the energy cooperatives. In my estimation, many distribution system operators would also organise local markets, even though the electricity market is still centrally organised’ (expert interview 2021).

The flexibility market models developed in various European countries in recent years can be divided into the categories ‘market platforms’ and ‘aggregator platforms’:

- **Market platforms** are marketplaces where decentralised energy producers or aggregators directly offer flexibility services where TSOs and DSOs serve in the role of buyer. Examples of newly developed platforms are: Cornwall Local Energy Market (pilot project in England), enera (pilot project in Germany), GOPACS (in operation in the Netherlands since 2019) and Piclo Flex (in operation in England since 2019). All of these platforms aim to enable flexible generators at a distribution grid level to offer flexibility services.
- **Aggregator platforms** are platforms on which decentralised energy producers offer their flexibility services via an independent aggregator or an energy supplier acting as an aggregator. Examples of such platforms are: tiko Energy Solutions AG (in operation in Switzerland), Equigy (pilot project of TSOs from Germany, the Netherlands, Italy and Switzerland), Quartierstrom 1.0 (pilot project in Switzerland) and Repsol Solmatch (in operation in Spain).

4.1.4 Guarantees of (regional) origin

Since the liberalisation of the electricity market, the origin of electricity must be traceable for end consumers. Electricity suppliers in Germany are therefore obliged to show their customers a percentage-based list of the energy sources from their balancing group on their annual electricity bills. Since 2012, this has been regulated in the Energy Industry Act (Section 42 of the EnWG) and in the Renewable Energy Sources Act (Part 5, Section 2, Paragraphs 78 and 79, EEG).

Guarantees of (regional) origin describe certain attributes of quantities of electricity fed into the grid. In Germany, the Federal Environment Agency (UBA) issues guarantees of origin to renewable generation plants for electricity produced and fed into the grid if the electricity is not already remunerated under the EEG. However, these guarantees of origin do not provide the end customer with any information on the simultaneity and geographical proximity of production and consumption. Up to now, guarantees of origin have only existed in Germany in the form of certificates from a balancing perspective. Consumers cannot track their electricity consumption by plant, but only by the percentage of power generated. The market will foreseeably require new forms of green electricity verification. In view of the overarching goal of decarbonisation, digital CO_2 certificates could also play a larger role in the future; these digitally verify location- and time-specific information on the CO_2 content of electricity and also enable offsetting across sectors. (see Strüker et al. 2021).

On the basis of guarantees of regional origin, electricity suppliers can demonstrate that they supply regional EEG electricity within the framework of electricity labelling. The register of guarantees of regional origin ensures that the regional quality of the electricity is only sold once. In this way, consumers can procure electricity from their region. A region in this respect is a postcode area that includes consumer connections and generation plants within a radius of 50 kilometres.

The UBA started the register of guarantees of regional origin in 2019. From the perspective of energy supply companies, there is the question of the appeal of such a designation in economic terms. According to studies, an increased willingness to pay on the part of customers is to be expected (see UBA 2021).

Energy communities can derive great benefits if intelligent operational optimisation at the local level can bring electricity generation and consumption in line with each other. If electricity is consumed when and where it is generated, this lowers the load on electricity grids, with potential savings in terms of grid usage fees, for example. Guarantees of origin that provide a high spatial and temporal granularity can provide clear information to an energy community on the percentage of electricity consumed as and where it is produced.

Digital technologies

Distributed ledger technologies, in combination with smart meters, can be used to document various electricity characteristics in a transparent and tamper-proof manner. Digital signatures of energy units and the use of smart contracts, which verify the properties of electricity units and run automated rules such as remuneration, can increase the efficiency of processes. This allows new peer-to-peer trading business models and new grid fee regulations to be implemented (see Strohmayer et al. 2019). Technically, a guarantee of origin consists of data collection and data reconciliation. Due to its technical properties, the blockchain, for example, lends itself to the implementation of a digital guarantee of origin. For this, the stakeholders involved must be known and registered in order to record electricity generation and consumption, for example, at 15-minute intervals, and to write the data either directly from meters, via a smart meter gateway or via metering data management systems of the metering point operators, to the blockchain or a conventional central database. As soon as this data is available, generation and consumption data can be compared every 15 minutes. To optimise allocation, boundary conditions can be established, such as the simultaneity of generation and consumption, the geographical distances of stakeholders, the electricity mix preferences of consumers and network topological parameters to verify that higher grid levels were not used. Having an existing smart meter infrastructure is a precondition for digital guarantees of origin using blockchain technology (see Strauß et al. 2020). Another key requirement for the suitability of blockchains for guarantees of origin is interoperability with a potential blockchain-based registry of installations (Abraham et al 2021).

4.2 Digital core technologies as a prerequisite

The core technologies of the above-mentioned fields of application of energy communities are **smart meters**, **platforms and data management systems** as well as **distributed ledger technologies** (for example, blockchain) and associated **smart contracts**.

‘The key thing about blockchain is that it offers an alternative to the trading mechanisms that have existed up to now, for example, it allows P2P sharing. Blockchain is often used when thinking beyond the energy market system: It can lay the groundwork for completely new market mechanisms and for all forms of sharing, for example. Blockchain, if used properly, would help create a whole new business ecosystem’ (expert interview 2021).

In addition to these core technologies, which are explained in more detail below, other digital tools are also relevant for energy communities and will only be briefly touched on. Tools for digital and predictive maintenance as well as tools for modelling generation, consumption, grid and storage forecasts are viewed as highly innovative by energy communities. Big data technologies for real-time data analysis, artificial intelligence such as machine learning and robotic process automation involving the use of bots for time-consuming or error-prone processes will also be important in the near future.

Furthermore, self-consumption is an important driver for the introduction of home energy management systems (HEMS) on European markets. In the household sector, HEMS can optimise energy consumption and contribute to lowering costs, for example by monitoring the energy consumption of appliances. In combination with decentralised renewable energy systems, HEMS offer great potential for self-consumption optimisation, especially in terms of the use of storage systems or for electromobility. HEMS can also be connected to smart meters and convert the incoming and outgoing data into user-friendly formats on end devices (see Benedettini et al. 2019).

Data is the starting point for digital value creation. The energy industry's data landscape is difficult to navigate, and issues relating to data availability and access can slow down digital innovation. Problems are caused by data quality and data security and also by the highly complex regulations and large number of stakeholders (e.g., distribution grid operators) in the energy industry. Data relevant to the energy industry is not clearly defined. The IEMD specifies the required data as metering and consumption data of customers as well as data required to change suppliers, for load control and for other services without further explanation. Data is essential for innovation in the energy industry, such as new digital products or processes (Corusa et al. 2021).

In the future, data will be an important factor in the successful establishment of energy communities. Due to the high cost of data access, the use of open-source data sets and models is an alternative. Planning energy communities primarily requires the dimensioning of local generators and connected systems; once in operation, the more important task involves managing systems and consumers in a targeted manner in order to make improvements. Open-source data sets and analytics tools help to accelerate development processes, since collecting and cleansing one's own data is not required to get started. The end result is lower costs. In practice, knowledge of consumption patterns, grid constraints and local weather conditions is necessary. At the outset, data from similar existing projects on the dimensioning of energy communities can be used, which will be updated to include one's own data over time. During operation, energy flows must be recorded and optimised through plant or demand control. With peer-to-peer concepts, self-sufficiency can be maximised through internal trading within the energy community. This increases efficiency and minimises issues caused by grid feed-in into higher grid levels.

A general distinction is made between data sets, models and tools. A data set, for example, contains raw or cleaned observational data for further analysis, usually in the form of time series sometimes supplemented with metadata. One example of a data set would be the electricity demand of a building per unit of time (time series), including metadata on the geographical location and demographic data on the building's occupants. Models, on the other hand, use information from real or synthetic data sets. Models based on synthetic data sets are useful when no real data is available. Models for storage systems such as battery inverter units are used, for example. Tools can be used either directly or indirectly to provide services in the energy sector. There are tools developed specifically for the energy sector, but also general ones from other sectors. There are tools for data visualisation, modelling and optimisation as well as for monitoring energy flows. Examples include Load Profile Generator (LPG), Sandia Labs PV Performance Model Program (PVPMC), QuESt – Optimising Energy Storage and the Open Energy Modelling Framework (OEMOF). In general, the use case determines whether it makes sense to use real or synthetic data. If the relevant use case is to be simulated as accurately as possible, real data sets are preferable. Conversely, synthetic data models are well suited for future scenarios such as the impact of energy communities on a region's greenhouse gas emissions.

Future energy communities benefit above all from open-source data from similar projects and existing data from open-source visualisation and modelling tools. Today, data on electromobility, such as on energy consumption, movement patterns or the long-term monitoring of batteries, is often unavailable. In addition, there is no data on interior climate control such as heating, air-conditioning and ventilation. Some open-source data, models and tools are available to energy communities, but this requires programming skills as intuitive user interfaces are still not common (see Kazmi et al. 2021).

4.2.1 Smart meters

General function

Smart meters are the basis for the digitalisation of the electricity system. In the smart grid of the future, electricity consumers and generators will communicate digitally with each other. Smart meters ensure a robust and efficient energy system consisting of a large number of small, volatile and decentralised renewable energy installations. They also facilitate consumers playing an active role in the energy market and will enable individual load management in the future, for example, via price signals. With the rollout of smart meters, an interoperable, open platform will be created that makes services available independently of providers (see BMWi 2021; EC 2021; FfE 2019b).

Relevance to energy communities

The digitalisation of the energy system, based on smart meters, gives new energy market participants, including citizen energy cooperatives, aggregators and energy service providers, the opportunity to offer new services to their members and customers. Examples include peer-to-peer energy sharing or participation in local electricity and flexibility markets in real time. Smart meters allow consumers to view their current energy consumption data and dynamically adjust their behaviour in the energy system based on incentives (see BMWi 2021; Tounquet and Alaton 2020). The smart meter records consumption by volume and time and can provide this data to authorised third parties in real time. In this way, the rollout of smart meters can help gain access to data on a household level in order to replace the standard load profile with highly granular readings in the medium term (Bogensperger et al. 2018).

Definition

Smart meters consist of two components: a modern metering device and a communication unit, the smart meter gateway (SMGW). The technical layout and the planned market rollout of smart meters are subject to the Act on the Digitalisation of the Energy Transition in Germany.

Description of technology

The modern measuring device of the smart meter consists of an electronic measuring unit and a digital display. It differs from earlier electric meters (Ferraris three-phase meter) in that it can output the actual electricity consumption and the actual time of use for the users, thus providing a detailed view of consumption. A modern metering device itself can neither be read out remotely nor can it transmit meter readings on its own. The modern metering device can be integrated into a communication network via the smart meter gateway communication unit. The smart meter gateway thus represents the core element of the smart meter: It enables the collection, processing, storage, deletion and transmission of measured values and associated data with associated timestamps, with a view towards data protection, data security and interoperability.

The SMGW can send and receive signals, enabling communication between, for example, the grid and the generation plant in both directions. In addition to data processing and transmission, the German smart meter architecture also offers the option to issue switching commands. In future, small PV systems or storage systems of prosumers are to be controlled based on to demand and in line with data protection requirements (see FfE 2019b; 2019c; BNetzA 2021a; 2021b; 2021c).

Possible applications

Smart meters are used to upgrade the current European electricity grid to a smart grid. In the future, this integrated data and energy network will enable the grid-based control of an increasing number of flexible consumption units, such as private charging stations for electric vehicles or heat pumps, via smart meters, and can thus help to reduce grid expansion to an economically efficient level. The European Commission recommends ten minimum functions for smart meters in all EU member states (Commission Recommendation 2012/148/EU), distributed across the five categories: end consumers (a, b), metering point operators (c, d, e), commercial aspects of supply (f, g), data security and protection (h, i) and decentralised generation (j):

a) Transmission of measured values directly to the consumer and/or a third party;
b) Updating readings frequently enough to utilise energy saving programmes;
c) Enabling remote reading by operators;
d) Facilitating two-way communication for maintenance and monitoring;
e) Allowing sufficiently frequent readings for grid planning;
f) Support for progressive tariff systems;
g) Remote control of supply ON/OFF AND/OR flow or power limitation;
h) Provision of secure data communication;
i) Fraud prevention and detection;
j) Import/export and reactive consumption measurement.

The first-generation smart meters already developed in Germany are primarily for smart metering and submetering. With **smart metering**, the actual energy consumption and the actual time of use are recorded. These meter readings are visualised in intervals of 15 minutes and open up innovative tariff schemes. **Submetering** refers to the additional measurement of gas, water and heat consumption. Heat cost allocators can be integrated, for example, in central heating systems in multi-family dwellings for the transmission of consumption data. Implementation in smart grids is planned for the first software update. The necessary recertification process for this has been initiated.

For **smart grid implementation**, the real-time transmission of the actual feed-in of generation plants, the collection and transmission of grid status data and the management of consumption plants (bidirectional connection) are planned. In the future, the application areas of smart mobility, smart home and smart services will be implemented. **Smart mobility** refers to the integration of the charging infrastructure of electric vehicles. **Smart home** applications include home automation systems and **smart services**, which denote other value-added services in the context of the integrated data and energy network (see BMWi 2021; BSI 2020; Tounquet and Alaton 2020; Pitì et al. 2017).

State of the art/practical application

The installation of smart meters is mandatory in Germany for all generation plants with an installed capacity of 7 kW or more and for consumers with an annual electricity consumption of more than 6,000 kWh. Consumers with lower annual electricity consumption can also be equipped with smart meters if the metering point operators adhere to strict price guidelines. In addition, controllable consumption devices pursuant to Section 14a of the EnWG – this also includes electric vehicles – are equipped with smart meters. All new buildings, buildings following major renovations and metering points for which smart meters are not mandatory will at minimum be equipped with modern metering devices (without SMWG).

With the market declaration of the BSI in January 2020, the mandatory rollout started at the end of February 2020. Within the three years after this, plans called for ten per cent of mandatory installations to be implemented by metering point operators and for 95 per cent of mandatory rollout measures to be completed by the end of 2032 (see BDEW 2021; FfE 2019a).

In March 2021, however, the Münster Higher Administrative Court halted the rollout. Lawmakers subsequently responded quickly and made improvements, and the rollout has now resumed despite certain gaps in the framework (see VDE 2021; BNetzA 2022). So far, the rollout in Germany in accordance with the respective mandatory rollout requirements has mainly encompassed modern metering devices (without SMGW), not smart meters: The mandatory rollout of modern metering equipment started in January 2017. According to the monitoring report of the Federal Network Agency (BNetzA), the rollout quota for modern metering devices specified for July 2020 has already been met by all metering point operators in December 2019. This corresponds to 5.8 million compulsorily installed modern metering devices (see Fleischle et. al 2020). Following the 2020 market declaration, only a few mandatory measuring points were equipped with smart meters. The temporary halt of their rollout by the Münster Higher Administrative Court (OVG) on the grounds that the smart meters available on the market do not meet legal requirements and that the underlying approval procedure at the Federal Office for Information Security (BSI) was allegedly not formally and properly established (cf, OVG NRW 2021; SmartGridsBW 2021) delayed the rollout, which was already off to a slow start. An exact number and the rollout quota for smart meters have not currently been published. After the first year of rollout, a number in the low six figures was estimated (Fleischle et al. 2020).

A survey conducted amongst responsible metering point operators from May 2021 shows that 19 per cent of companies surveyed had already commenced rollout (market share of metering point operators in terms of mandatory metering points: approx. 42 per cent) (see pwc 2021). Other smart meters have also been developed and used in the recent past as part of research projects. Furthermore, hardware manufacturers offer communication tools for the digital networking of their proprietary systems, with which inverters, storage units, heat pumps and, in some cases, electric vehicles can be operated as efficient stand-alone systems. However, research and commercial manufacturer systems are generally not standardised and in many cases do not comply with the BSI security specifications to which the smart meter gateway is subject (expert interview 2021).

Illustration

Figure 3 shows a smart meter infrastructure for prosumers as an example. The components shown perform the following tasks: The home area network facilitates the networking, visualisation and controlling of peripheral devices such as heating systems, electricity storage units, household appliances, etc. The in-house meters for electricity and, where applicable, gas, water and heating transmit their readings to the SMGW via the local metrological network. Via the wide area network, the SMGW communicates with the SMGW administrator and also with external market players in order, for example, to transmit consumption data. Controllable local systems (CLS) are systems with IT components on the CLS interface of the SMGW that are not part of the smart meter, though they do use the secured communication channel of the SMGW.

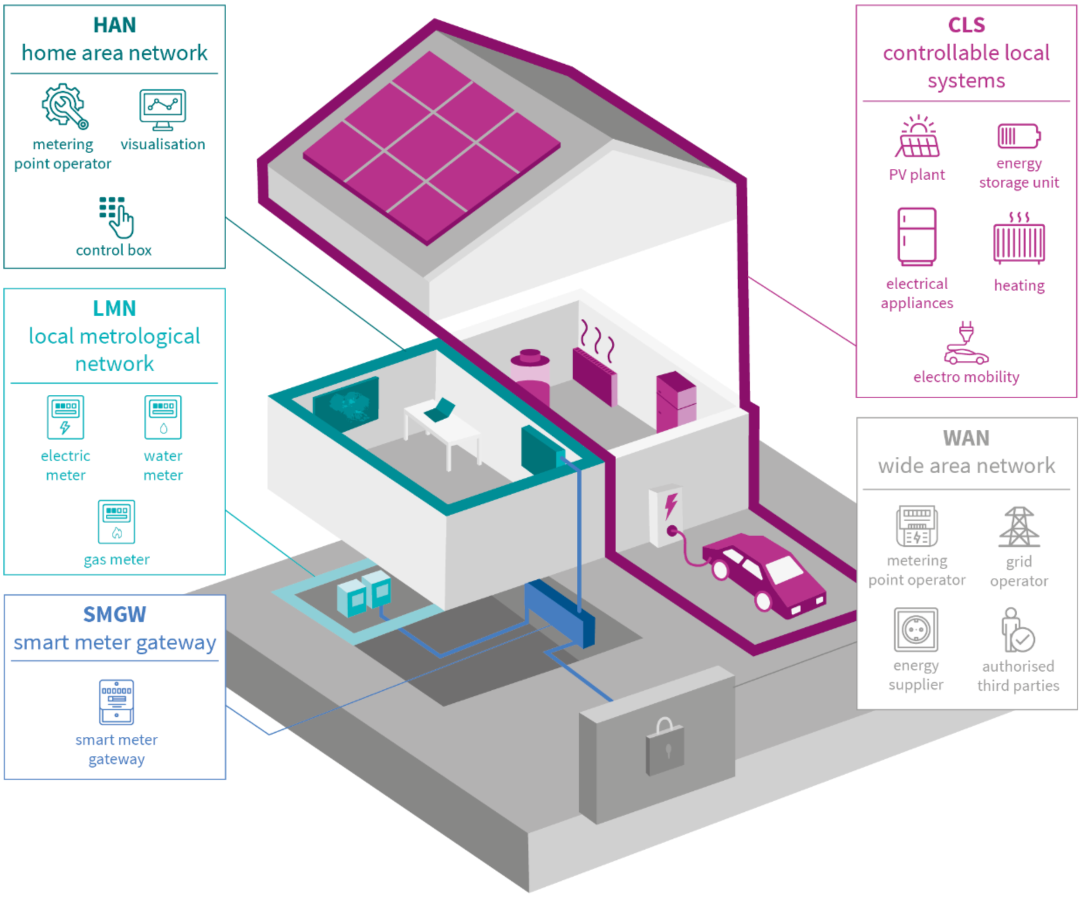

Figure 3: **Diagram of a smart meter infrastructure for prosumers (source: FfE 2019b)**

4.2.2 Platforms and data management systems

General function

Digital platforms are used to bring together, combine and compare a variety of data from different sources in order to offer new products and services.

Relevance to energy communities

Platforms are ideally suited for connecting decentralised energy generation plants with energy consumers (energy platforms). They enable transactions between producers and consumers who would have difficulty connecting to each other without this digital infrastructure (see Kloppenburg and Boekelo 2019). Platforms can provide the integrated technical basis for many basic processes in energy communities, such as user and master data management, the management of data access rights for different user roles, visualisations of energy data and customer relationship management.

Definition

The term ‘platform’ is used in two ways: On the one hand, it refers to the technical infrastructure → the technical platform and, on the other, the logical model → the transaction platform (enera 2021).

Description of technology

A **technical platform** consists of different layers (platform architecture) for clearly definable individual tasks. This includes, for example, a system integration layer that connects technical systems that provide raw data via digital interfaces and protocols. In the context of energy platforms, this includes, for example, plant or smart meter data on energy production or consumption or data on weather or price forecasts. Other possible layers include the data collection layer, the data integration layer and the data access layer, in which the raw data can be collected, structured, transformed and, depending on the user role (e.g., supplier, producer, consumer) retrieved. These data layers form the platform’s data management system. The service layer of a platform provides applications for end users, such as intra-household electricity billing, cost analyses and peer-to-peer trading relationships.

A **transaction platform** mediates a transaction between different parties based on the established market logic. For example, the purchase or sale of energy or flexibility can be carried out with the support of algorithms in order to derive maximum financial benefit (see enera 2021; Strauß et al. 2020; ERA-Net 2021).

Energy platforms are typically implemented as cloud platforms (for example, in the enera, SMECS, Ecogrid 2.0, pebbles projects or by commercial providers such as Lumenaza). In principle, platforms can be implemented as on-premise solutions, cloud solutions or as a hybrid on-premise/cloud solution. A cloud platform differs from an on-premise platform in that the required platform hardware, i.e., server capacity with demand-based storage space and computing power, and also in that the application software or parts thereof are provided by external service providers. Compared to on-premise platforms on the energy community’s own hardware, cloud computing offers advantages such as more efficient utilisation of computing resources and the high scalability of cloud services based on the needs of customers (for example, according to the number of members or customers of the energy community) (see Wilfer 2018; enera 2021; Floyd 2017) .

Possible applications

Energy platforms take many forms. They differ in terms of their connection to the electricity grid and their possible uses for consumers. Distinguishing features with regard to the grid connection include whether the platform enables prosumer installations to be connected and, if so, whether smart meters are also integrated into the platform or whether the platform otherwise enables participation in the construction and operation of new installations. On the consumption side, the key feature that distinguishes one platform from another is whether it enables individual business processes for energy customers (e.g., for peer-to-peer energy sharing) or whether it assumes overarching responsibility in energy trading as the coordinating body.

Based on these distinguishing features, there are three distinct types of energy platform: platform of origin, community platform and access platform. **Platforms of origin** ensure transparent peer-to-peer energy trading: Depending on the platform design, they allow consumers to choose the existing prosumer installation from which they want to purchase electricity or prosumers to choose the consumer they want to supply with their surplus energy. **Community platforms** guarantee the self-supply of local or virtual energy communities. They coordinate flows of energy into and out of a shared pool or a virtual power plant. The decentralised prosumers on community platforms relinquish control over their existing system in part to the platform's energy management system. Depending on the configuration, this can serve different purposes, such as increasing self-sufficiency, reducing energy prices or providing flexibility. Decentralised prosumers can thus participate in energy markets or share energy with each other by means of virtual power plants. Community platforms create a clear line of division between one's own 'grid' and the rest of the energy system. By means of **access platforms**, consumers are given the opportunity to take a financial stake in renewable energy plants. Crowdfunding models are often used for this purpose. In this way, stakeholders who on their own do not have the necessary capital can help support RES expansion and share in the profits from energy sales (see Kloppenburg and Boekelo 2019).

State of the art/practical application

Platforms are widely used in energy communities (see Wien Energie GmbH 2020; Kloppenburg and Boekelo 2019). The digitalisation potential in energy communities has not yet been optimally exploited. While that is true, interest in digital products, including energy platforms, is increasing with the growing realisation of what new services and business models are made possible by digital tools. In many cases, energy platforms are developed in projects in which energy communities are involved. Examples of this include the German projects pebbles (for a brief description see Section 4.1.2), SMECS and enera[5]. There are also more and more commercial digital platform providers on the market whose products are tailored to energy communities.[6]

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[5] SMECS project: https://www.smecs-projekt.de/ and enera project: https://projekt-enera.de/.

[6] For a list of European energy platform providers, see the joint programming platform website of ERA-Net Smart Energy Systems (funded under EU Horizon 2020) at: https://www.eranet-smartenergysystems.eu/Partners/Digital_Platform_Providers.

Illustration

Figure 4 shows the stakeholders in a flexibility market platform.

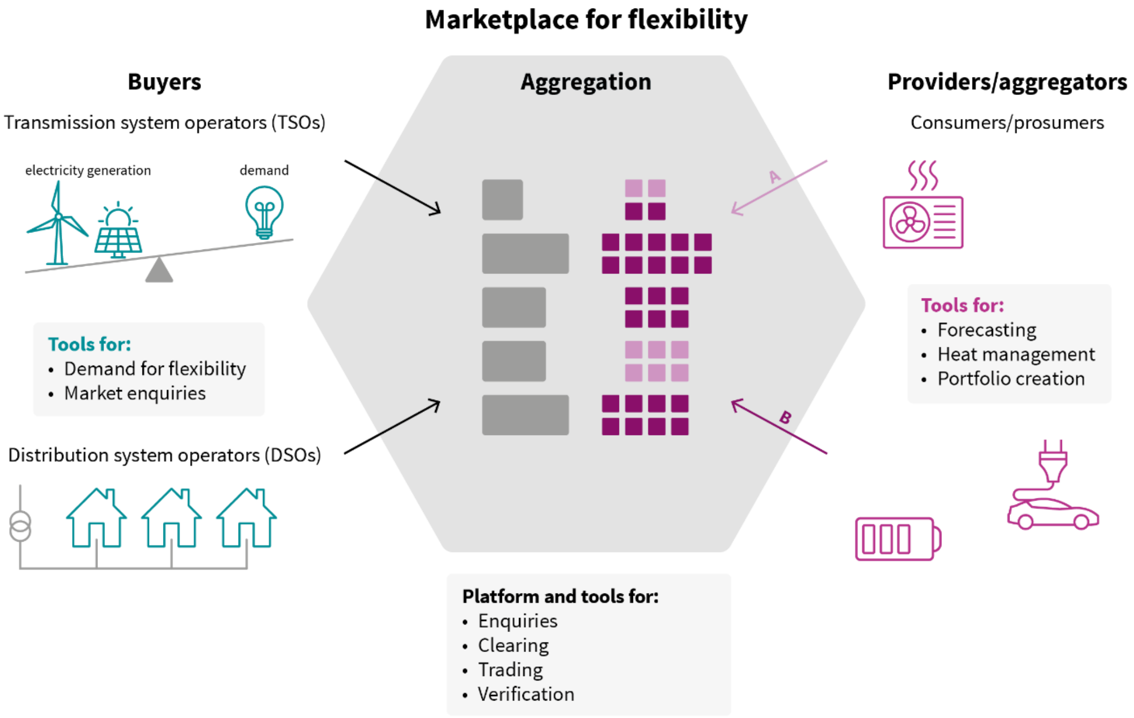


Figure 4: **Stakeholders in the flexibility market platform (source: EcoGrid 2.0 2019)**

4.2.3 Distributed ledger technologies, blockchain, smart contracts

General function

Distributed ledger technology (DLT) is a collective ledger that is stored decentrally across all members of a DLT network. In a distributed ledger, transactions carried out between network members are not documented at a central location (for example, on a central server); instead, identical copies of the ledger are distributed amongst several or all members. These distributed copies are continuously updated so that all participating members always have an up-to-date version of the ledger. Using DLT, the current cash position of all DLT network members can therefore be traced at any time without a central database (see chrissikraus 2019).

Relevance to energy communities

Existing and future energy communities are and will continue to be characterised by the application and use of different types of technical installations, infrastructures and markets from the diverse sectors of energy, building, transport and industry, along with ones spanning an array of sectors. The challenge faced in the market transformation considered to be necessary in this context from a research perspective relates to how to achieve a balance between local, regional and national energy management and the technical coordination of infrastructures. To cost-effectively optimise the energy system from the distribution to the transmission grid (with the provision that the current security of supply be maintained), it is necessary to skilfully coordinate all system components and transform them into optimised and intelligent energy system management. Decentralised markets and systems using DLT, such as the blockchain, provide added levels of flexibility. Today, centralised electricity markets typically end at the electric meter of the grid connection point. Cost-effective communication mechanisms to mediate and process market transactions, which in the future will include DLT, will enable higher-level markets for small generation plants, loads and storage systems to open downstream from the meter and decentralised markets to develop. Through the appropriate combination of distributed data storage and cryptographic procedures, which is characteristic for DLT, it is possible to create trust between energy producers and consumers who do not know each other and establish a transparent, tamper-proof billing and trading system. Using DLT such as blockchain, the stakeholders are directly connected to each other on the basis of a peer-to-peer infrastructure. Transactions encompassing energy, flexibility and corresponding monetary values are carried out directly between the stakeholders involved using automated verification processes and then documented. In this way, there is no need in particular for a central intermediary, which is still required at this time, as the stakeholders of a DLT network are directly connected to each other on the basis of a peer-to-peer infrastructure (see dena 2019; Zoerner et al. 2020).

Definition

The terms ‘DLT’ and ‘blockchain’ are often used synonymously in technical articles, newspapers and blogs. However, blockchain is merely the most prominent type of DLT and also the most significant one at the moment in practical application in general and in the energy system in particular. In the blockchain, data records, or blocks, are constantly being linked together using cryptographic processes to create a growing chain. Not all DLTs are based on block chaining as an ordering principle. One alternative is a directed acyclic graph. Conversely, one thing that all DLTs share in common is that they consist at their core of a distributed database that ensures the accuracy of transaction data via a predefined algorithm (known in the DLT world as a consensus mechanism).

An additional optional component of DLT are smart contracts, which are programs stored within the DLT that can process activities automatically. Smart contracts allow for a high degree of automation, as they can handle business processes, for example. Smart contracts are also described as ‘computer programs’ on the DLT (dena 2019; Bogensperger et al. 2018).

Description of technology

Since blockchain can be viewed as the current standard in DLT and has already been examined in detail in the recent past with regard to its potential and possible applications in the energy system in general (see Bogensperger et al. 2018; dena 2019) and in energy communities in particular (see Zoerner et al. 2020; Strauß et al. 2019), it will first be presented here. Smart contracts are described based on the widely used Ethereum blockchain.

Blockchain technology is a distributed database system: What makes it different from conventional database structures, where the data used is in the hands of a few individuals, is that all members of the blockchain network (‘nodes’) are involved in data management and also ensure data integrity, instead of keeping the data in the hands of individual members. A consensus mechanism is used to ensure agreement on the order and content of previous changes to the database in this decentralised structure. The consensus mechanism ensures agreement on past transactions in the network in discrete time steps by means of regulated and verifiable automatic mechanisms and checks their correctness in order to prevent the manipulation of transactions. There are now different forms of consensus mechanisms. The two main ones that are most widely used, sometimes in adapted form, are proof of work (PoW) and proof of stake (PoS). In the proof-of-work consensus mechanism used in the Bitcoin blockchain, network participants use their relevant computing power to solve complex mathematical puzzles. This process is carried out continuously and in parallel by the network participants, also called miners, which is the main reason for the relatively high energy consumption of the Bitcoin blockchain, for example. Ultimately, the network participant who solves the puzzle the fastest is allowed to create, or mine, the corresponding block and is rewarded for this with a predefined amount of Bitcoin or the cryptocurrency used in the network. The proof-of-stake consensus mechanism is currently used in the majority of new crypto projects entering the market. The second largest DLT network by market cap after Bitcoin – Ethereum – is also in the process of transitioning from a proof-of-work to a proof-of-stake consensus mechanism. With proof of stake, the blocks are not created by miners, but by validators. Each validator places a certain amount of the respective cryptocurrency used in the network to also prove their ‘trustworthiness’. The higher the share of the relevant validator in the network, the higher the probability of generating blocks. This process is in turn orchestrated by an algorithm running in the background. An ‘ordinary’ participant in the network who only has a limited amount of the cryptocurrency can also nominate one of the network validators and transfer his/her funds to the validator for a period of his/her choosing. Since the blockchain does not provide any central points of attack for this reason compared to conventional databases, it guarantees a high degree of security for the exchange of digital goods. The chaining of the blocks verified via the consensus mechanism (all operations in the blockchain within the discrete time period) is carried out by means of hash values based on the previous block in each case. On this basis, blockchain technology creates trust between mutually unknown transaction participants despite the absence of a trustworthy intermediary, whereby traditional intermediaries such as payment service providers can be replaced by uncorruptible technology. All members of the blockchain network can view the blockchain at any time, enabling transparent monitoring of the interactions taking place. In addition, this data is always accessible, as availability does not depend on a single, central server. In order to provide for the anonymity of network members and transparency throughout the entire blockchain system, they are pseudonymised by means of a public key. These public keys are accessed using the individual private keys of network members. This asymmetric encryption offers a high level of security (see Bogensperger et al. 2018; Zoerner et al. 2020; chrissikraus 2019). The sequence of a transaction between two members of a blockchain network is shown in detail in Figure 5.

Ethereum blockchain smart contracts are small applications that are uploaded to the blockchain. The program code of the smart contracts is executed as additional content of a transaction. Nearly all use cases for DLT in the energy sector use a smart contract platform (see dena 2019). A practical example for the use of smart contracts is automated annual meter reading, which proceeds as follows: The smart meter periodically sends (daily, for example) electricity consumption data to a node of the blockchain. The node receives the data and executes the smart contract as part of the check, which, in this example, means that the smart contract checks the timestamp of the data. If the data is not from the set reference date in December, it is discarded. Only the consumption data for the reference date is recorded in the blockchain as the annual consumption value. In this example, the smart contract acts as a filter that only adds the prescribed information to the blockchain (see Strauß et al. 2019).

The development of DLT to date can be divided into three phases/generations: The original, first generation uses the blockchain as a digital registry to store transactions (e.g., Bitcoin). The second generation, which builds on this, has smart contracts for the automatic execution of transactions or contracts (e.g., Ethereum). The third generation of DLTs currently being developed is intended to solve the existing problems of scalability, interoperability and privacy (examples of third-gen DLTs include Cardano, Solana, Polkadot, Terra, Avalanche, Polygon, Cosmos, Fantom and Hedera).

Possible applications

From the energy industry’s perspective, the blockchain with the aforementioned characteristics should not be viewed as a missing piece in the puzzle that will solve all the challenges faced by an energy system that will be decentralised and democratised in the future. However, their further development offers promising approaches and can be seen as a significant driver for the creation of new digital business models that contribute to the successful transformation of the energy system (see dena 2019). In the context of energy communities, the following are some of the technical use cases for DLT that have already been well studied, are suitable and can be expected to yield gains in efficiency compared to current methods:

- Peer-to-peer energy trading and energy sharing (primarily for post-EEG plants);
- Origin labelling of the smallest quantities of energy by generation type and region in high temporal granularity directly linked to physical boundary conditions (primarily for post-EEG plants);
- Simplified process to switch suppliers;
- Certificate of provision for balancing power and flexibility (see Bogensperger et al. 2018).

In the dena study (2019) and in Bogensperger et al. (2018) , these and other use cases are examined in detail. It is noted that use of the technology can only create effective incentives in the energy system if the regulatory framework is adapted to the real-world conditions of the use cases (see ibid.).

Another DLT use case that could lead to an increase in efficiency across the entire energy system and thus also in and between energy communities through an increased level of automation is currently being thoroughly tested: the management of distributed plants. For the energy system of the future, which consists of a vast number of small, decentralised plants for energy generation, storage and consumption, a digital installation identity register for all reporting processes promises to deliver advantages in terms of cost efficiency compared to the current market data register. This is where the Blockchain Machine Identity Ledger (BMIL) pilot project of the Future Energy Lab comes in: a digital and decentralised directory for device identities. Complementary to smart metering, it enables the integration of millions of decentralised generation plants into the energy system and provides the basis for a variety of other digital value-added services (see Future Energy Lab 2021).

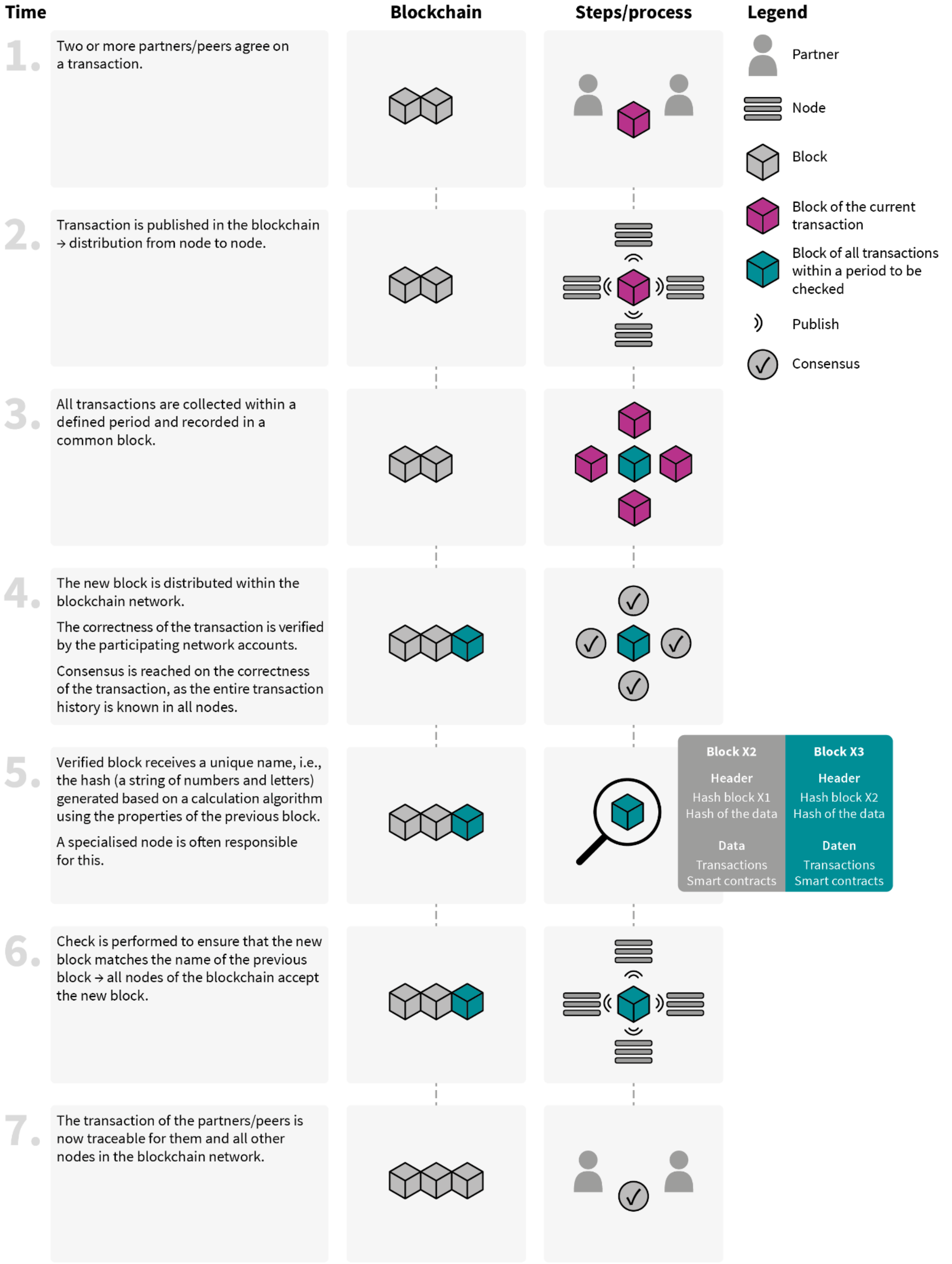
State of the art/practical application

Based on the number of global projects on the use of DLT in the energy industry conducted in 2018 and 2019, it can be inferred that the technology is slowly but steadily becoming a significant part of a real-time energy economy due to its exciting applications and technology-specific unique selling points (see Zoerner et al. 2020; Bogensperger et al. 2018). However, the widespread use of scalable DLT suitable for the masses still faces a number of hurdles at this time. On the one hand, there is the complexity of the technology, which remains high. And because of the limited amount of high-quality documentation on individual systems and applications, it continues to be viewed as technology for experts only that is at an early phase of its development. Ready-to-use standard solutions currently are few and far between, and there are still numerous limitations within the existing blockchain systems. Nevertheless, blockchain solutions for large-scale business models are expected in the next few years. Alongside the existing limitations owing to the solution being in an early stage of development, there are sector-specific constraints as well. For example, the hardware required for recording data – typically a smart meter – is often not yet widely available or not yet configured in such a way that the data can be transferred directly to the blockchain. The rollout of smart meter is proceeding at a sluggish pace, which is slowing down the proliferation of the technology in Germany in the short term (see dena 2019).

In addition to the current technical and economic constraints, there are also legal limitations as well. Smart contracts that can automate and execute contracts that have already been initiated are not yet compliant with current contract law (see dena 2019; Bogensperger et al. 2018).

Illustration

Figure 5 illustrates the steps in a transaction between two members of a blockchain network.



1. Two or more partners/peers agree on a transaction.

2. Transaction is published in the blockchain → distribution from node to node.

3. All transactions are collected within a defined period and recorded in a common block.

4. The new block is distributed within the blockchain network.

The correctness of the transaction is verified by the participating network accounts.

Consensus is reached on the correctness of the transaction, as the entire transaction history is known in all nodes.

5. Verified block receives a unique name, i.e., the hash (a string of numbers and letters) generated based on a calculation algorithm using the properties of the previous block.

A specialised node is often responsible for this.

6. Check is performed to ensure that the new block matches the name of the previous block → all nodes of the blockchain accept the new block.

7. The transaction of the partners/peers is now traceable for them and all other nodes in the blockchain network.

Figure 5: Steps in a transaction between two members of a blockchain network (Source: amended according to Strauß et al. 2019)

5 Energy communities in selected EU countries

In Denmark, the Netherlands, Sweden and Germany in particular, energy communities have a history that dates back to the 1970s. There are now collaborative initiatives across Europe of different sizes and with different technologies, legal structures and stakeholders (Karg and Hannoset (no year)). The most common legal structure is a cooperative.

Due to different definitions of energy communities, their number varies in the literature. For example, certain sources in Denmark only consider wind energy communities (see Wierling et al. 2021), while the REScoop network (the association of citizens' initiatives and cooperatives for clean energy in Europe) also includes energy communities with district heating and PV generation in this respect. The significance of energy communities based on their number has yet to be studied in depth. According to numbers published by the REScoop network, there were a total of 3,000 energy communities in Europe at the beginning of 2014. Biresselioglu et al. (2021) estimate that there were around 3,500 energy communities in 2020. The 2014 figure from the REScoop network places a large part of them in two countries: Germany (approx. 800) and Denmark (650) (see Wierling et al. 2021; Heras-Saizarbitoria et al. 2021). Since energy communities have yet to be systematically classified and documented, it is not yet possible to quantify their numbers and distribution across the classes described in Section 3. However, experts estimate the following distribution:

'REScoop counts nearly 2,000 energy cooperatives in Europe that produce and feed in energy. This corresponds to class 1 in our classification7 of energy communities. Below this, classes 2 and 3 continue to dominate' (expert interview 2021).

Denmark and Germany are considered pioneers when it comes to energy communities. Their progress differs, as Denmark has been a leader in the development of energy communities since the 1970s, with strong growth up until the 2000s. Germany, by comparison, has been active since the 1980s, but has seen a boom in new energy communities especially since the Fukushima disaster in 2011. In Denmark, there has been a sharp decline since the 2000s. Up to that point, a large part of wind installations were owned by citizens (see Heras-Saizarbitoria et al. 2021). Of the 1,109 wind energy cooperatives that once existed, only 12 per cent are still in existence today, with this number continuing to fall. In Germany, PV cooperatives and citizen-owned wind farms are widespread, while PV projects for energy communities are rare in Denmark. In Denmark, there are also energy communities in the district heating sector (see Wierling et al. 2021).

As regards energy communities in other EU countries, relevant developments are now being seen in countries like Austria and the Netherlands (as well as the United Kingdom). In the Netherlands, there are now 600 energy communities (see Bridge 2021). Although energy communities in the Netherlands have also seen success with respect to citizen-owned wind installations, they enjoy a small market share of the total supply of wind power overall. Compared to northern European countries, the trend in southern Europe has been significantly slower (see Heras-Saizarbitoria et al. 2021). In view of current developments, Spain, Italy, Portugal and Greece are in part quite far along in implementing the EU framework, meaning practical implementation can be expected. With regard to renewable energy communities as defined by the RED II (REC), Dröschel et al. (2021) have led discussions on the status of implementation projects in Poland, Portugal, Spain, Italy and

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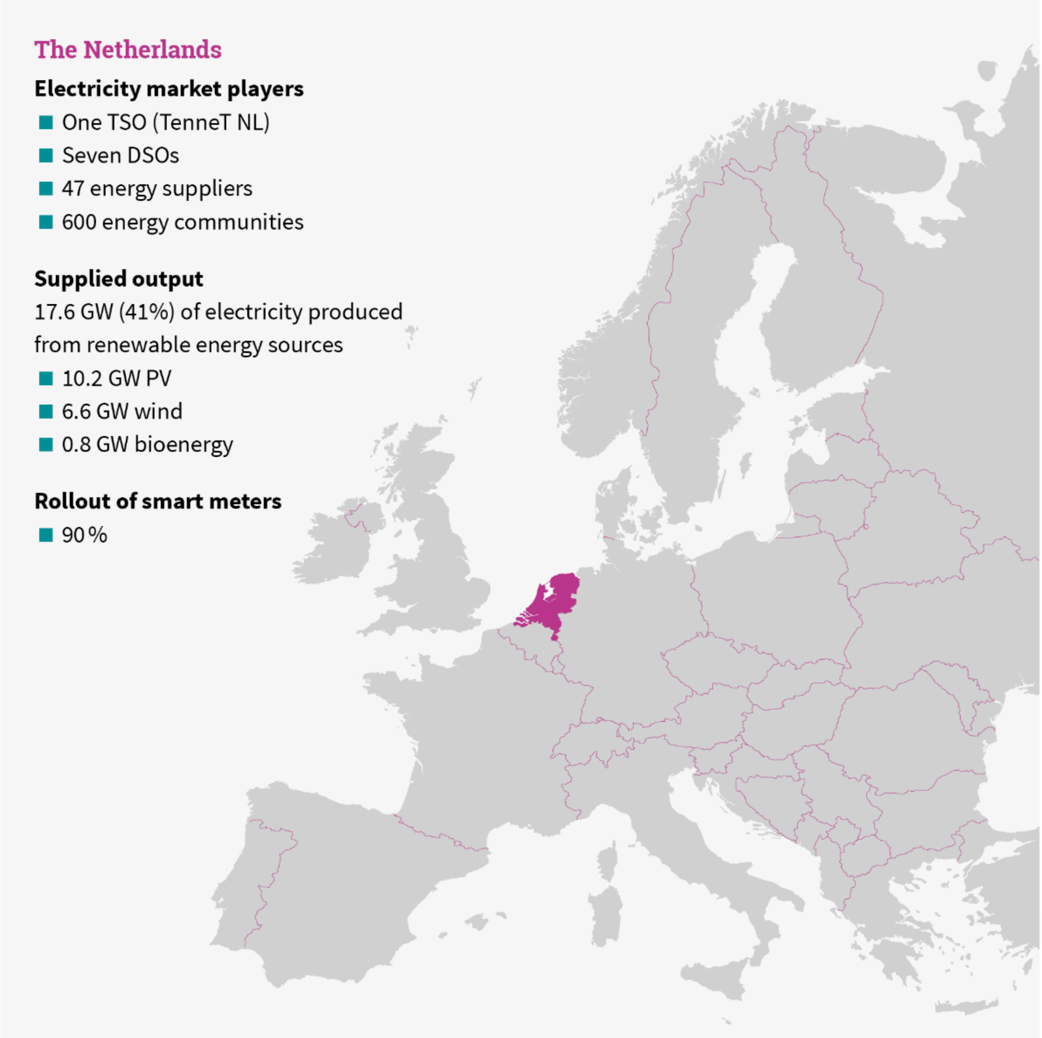
[7] For classification see Figure 2Figure 2.

Austria. These reveal that there is only an active renewable energy community as defined in the RED II in Italy.

The selection of the countries to be examined in the study was based on the following criteria: relevance of energy communities, status of digitalisation and share of electricity from renewable energies. Denmark and the Netherlands are historically significant to the development of energy communities. Despite the fact that the EU framework has not yet been transposed there, there is a long tradition in those two countries. In the area of digitalisation, the communication infrastructure for the use of digital technologies is a key cornerstone for energy communities. Denmark, Spain and the Netherlands are amongst the top-five countries in the EU in the rollout and upgrading of broadband networks (fibre optic and updated cable networks) at the household level. In these countries, just under 90 per cent of households have a broadband connection. In Germany, by contrast, this is only the case in 35 per cent of households. These communication networks are a foundation for emerging technologies such as 5G mobile networks. Since this communication technology creates the basis for connecting a vast number of devices while also offering low latency times, progress in this area is important in order to create a real-time energy economy (see Rossetto and Reif 2021). The smart meter rollout, too, is nearly complete in Denmark, the Netherlands and Spain, while in Germany it has been temporarily halted by the courts (see Section 4.2.1) (see Smart Energy Europe 2019). Spain, along with Denmark and the Netherlands, is well suited for this analysis, as it is a geographically large country focused in terms of renewable energy on PV systems, especially as regards energy communities.

5.1 The Netherlands

In the wake of the oil crisis in the 1970s, environmental policy trends in the Netherlands shifted away from nuclear energy towards increased energy conservation and green energy alternatives. By the late 1980s, the first energy initiatives were set up with a focus on wind power. The energy communities that were to follow in the 2000s, having been established as part of market liberalisation, promoted collective conservation efforts and the production and supply of green energy under the motto *‘energie van, voor en door ons zelf’* (energy from, for and by ourselves). While large energy companies were in the process of being privatised, a new co-operative movement was developing. Those involved in the movement had always identified with the concept of energy democracy and associated the technological energy transition with direct citizen participation and democratic control (see Proka et al. 2018). There are now more than 600 energy communities (see Bridge 2021) in the Netherlands which typically take the legal form of a cooperative (see Toporek and Campos 2019). The electricity system in the Netherlands, with its approximately nine million supply points, is coordinated and managed by one transmission system operator, seven distribution system operators and 47 energy suppliers. Figure 6 provides important key data.



The Netherlands

Electricity market players

- One TSO (TenneT NL)
- Seven DSOs
- 47 energy suppliers
- 600 energy communities

Supplied output

17.6 GW (41%) of electricity produced from renewable energy sources

- 10.2 GW PV
- 6.6 GW wind
- 0.8 GW bioenergy

Rollout of smart meters

- 90 %

Figure 6: **Overview of the electricity market and energy communities in the Netherlands (sources: Bridge 2021; dena 2021; IRENA 2021 Ritchie and Roser 2020)**

5.1.1 Regulatory framework

The 1989 Dutch Electricity Act allowed renewable energy producers access to the electricity grid and guaranteed a fixed purchase price. Subsidies for renewable energies are subject to the subsidy system *Stimulering Duurzame Energieproductie*, or 'Stimulation of sustainable energy production' (SDE extended to SDE+ and to SDE++ in 2020). The Dutch Electricity Act (last amended in 2018) does not explicitly define individual or collective self-consumption, yet the net metering regulations and the postal code systems (*Postcoderoosregeling*) set incentives in it for different forms of self-consumption (see Campos et al. 2020; Proka et al. 2018). PV systems with a capacity below 15 kWp do not fall under regulation by the SDE++ and can use net metering. With the net metering subsidy, self-consumers only pay for the net difference between that surplus electricity that they feed into the grid and the electricity they draw from the grid over a given period of time. In terms of balancing, surplus electricity is offset with purchased electricity at another time.

Self-consumption for Dutch net metering must be less than 10,000 kWh and it is balanced annually; in addition, energy taxes can be avoided (see Campos et al. 2020). Municipalities that collectively generate electricity from renewable sources (collective self-consumers) can use the net metering postal code system in order to reduce their energy tax rate for self-consumption of renewable electricity of collective self-consumers if they are located within the same or an adjacent postal code area[8] (see Palm and Holmgren 2020). In 2019 net metering was extended until 1 January 2023, after which it is to be phased out by 2031. From 2031 onwards, self-consumers will only receive the market price for the surplus electricity they produce (six cents per kWh currently) without the tax exemption (see Nixiang 2020). Net metering systems are not without controversy, as they do not provide a time-based incentive to feed electricity into the grid and the grid fees avoided through self-consumption are passed on by the grid operator to the remaining consumers (see Brown et al. 2020).

In addition to the above-mentioned regulations, the Netherlands created a regulatory innovation framework (regulatory sandbox 'Experiments in Decentralised Sustainable Electricity Production', or EDSEP) from 2015 to 2018 together with regulators, grid operators, cooperatives, consumer organisations, grid organisations, local authorities, civil society and engineering firms – yet without any thoughts given to the RED II and the IEMD. This legal construct is limited to cooperatives and associations in the electricity sector that rely on renewable energies. The framework expects a minimum participation rate of 80 per cent for private end consumers in the cooperatives. In addition, the regulation safeguards their autonomy by explicitly excluding co-determination rights in the management for DSOs, TSOs or legal entities that (in)directly generate or supply electricity. In addition, it lays down the details of the principle of effective control. Energy communities can operate their own private electricity grid. Pilot projects can be freed from tasks and responsibilities of a network operator within this legal framework promoting innovation. Furthermore, no supply licences are necessary for the supply of small end consumers (see Peraudeau 2019). Eighteen pilot projects were granted the adopted exemptions at the beginning of the implementation of the EDSEP innovation framework, of which 15 are still active. A maximum of 20 new applications could be submitted annually. The EDSEP has predefined all exemptions from the Dutch Electricity Act. They included the right to own and operate the grid, reductions on grid charges, metering from the DSO, obligations and exemptions from supplier licences, regulations on transparency and liquidity of energy markets and exemptions on billing and data management. The first pilot projects make full use of all exceptions.

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[8] When energy communities use the postal code system, it is often referred to as 'collective net metering' because they use a collective meter (net meter) (see Toporek and Campos 2019).

By comparison, similar frameworks in the UK have not specified exemptions, but have left it up to projects to determine which are desirable, in an attempt to encourage innovation. Italy, on the other hand, only implemented certain exemptions in a very targeted manner with selected business models. The duration of the exemptions in the Netherlands was set at ten years and was the longest compared to the UK and Italy, which set between two and four years. The concept is optimal for experimenting with regulations, but it has been established that some concepts tested in it cannot be repeated (see Bridge 2021). Based on the experiences with the EDSEP, the Netherlands wants to set up a successor regulation whose scope can then also include, for example, DSOs and energy suppliers, in addition to homeowners and energy communities, also in order to expand new business models for aggregators and flexibility markets, among other things (see Schittekatte et al. 2021).

CECs (see Section 2) are also possible in the Netherlands, in addition to RECs, and several Dutch energy communities can be defined as CECs. These communities benefit from the market of guarantees of origin in the Netherlands (regulation on guarantees of origin) (see Campos et al. 2020).

5.1.2 Digitalisation of the Dutch energy market

The development of a central office for standardised data exchange (communication hub) in the Netherlands began in 2007. For this purpose, the independent service provider Energie Data Services Nederland (EDSN) was founded. It has been carrying out the market communication centrally since 2007. In 2013, EDSN implemented an independent central data hub for communication in the electricity and gas market. The predecessor had already been implemented in 2000 as a pure clearing house to facilitate balancing and settlement among the players in the electricity and gas market and to create a central administration of all connections and communications among them. Market participants use the data hub to request data from other market participants at a central point and exchange messages transparently and in a standardised manner. The databases are centrally managed as access to connections and messages of the market players via the EDSN’s data hub. However, metering and billing data transmitted to EDSN by distribution and transmission system operators remain decentralised with those responsible for the quality, accuracy and provision of this data. Access to the data of other market players is provided by means of market communication messages centrally via EDSN. A prerequisite for the automated data exchange via EDSN is the availability of this data, which was made possible by the complete smart meter rollout in the Netherlands. For example, with EDSN, the Netherlands makes it possible to switch suppliers within 24 hours, thus fulfilling the requirements of the Clean Energy for all Europeans Package (compare with Germany: up to 15 days). EDSN also has a central structural data directory of plants that produce, store and consume electricity. With this data, grid operators can better predict energy flows and thus operate the power grid more efficiently. However, use is tied to an official market role. The structural data can also be used by initiatives in an aggregated format. Access to the data is also to be expanded and centrally regulated by the end of 2021 according to the original plan, in order to make it easier for new players to enter the energy market and to enable new business models.

TSOs, DSOs and other market participants were involved in the development of the hub. The small number of just ten suppliers facilitated the coordination processes (see EDSN (no year); dena 2021).

5.1.3 Application example: peer-to-peer direct selling (Vandebron)

Vandebron offers a nationwide direct selling platform for private renewable energy plants with flexibility services for the transmission grid via blockchain-coordinated charging control of electric vehicles.

Vandebron Energie B. V. is a green energy company based in Amsterdam, the Netherlands, that supplies green electricity and CO_2-compensated natural gas to private and business customers nationwide. The company itself has no energy production facilities, but facilitates the sale of energy from independent energy producers (see Vandebron 2021a).

The energy producers offer a description of themselves and their systems on their own websites and set their own prices (Vandebron 2021b; 2021c). Energy consumers can purchase from the plant of their choice. The company operates an online marketplace. Via this peer-to-peer platform, more than 200 decentralised renewable energy production plants (PV, wind, biogas) are connected to more than 200,000 energy consumers (see Vandebron 2021d; 2020; Zhang et al. 2017). The energy produced is sold directly to consumers at prices set by the company itself via the Vandebron platform. For this reason, it is no longer necessary to have an intermediary for electricity trading. Vandebron can ensure one hundred per cent energy supply even when there is no wind or the sun is not shining since the power supply is organised via the national grid (see Vandebron 2021e).

Vandebron also offers ‘intelligent charging of electric vehicles’ – a service with which the company contributes to the stabilisation of the energy system. Blockchain technology is used to centrally control the charging process of hundreds of electric vehicles and react to supply and demand in the electricity grid as needed. The focus here is on the charging needs of the customers, who can specify via app when their vehicle should be fully charged and, in addition, what percentage should be available immediately. To participate in smart charging, customers need a home charging unit, a smart meter and an active energy supply contract with Vandebron; they will then receive monetary compensation. Vandebron can sell flexibility services to the Dutch TSO TenneT by using this service to regulate the charging processes of its customers up or down depending on the grid load. The company plans to integrate more IoT devices into its smart charging portfolio (see Vandebron 2021f) in the future.

Vandebron’s peer-to-peer platform belongs to the technology category of platforms of origin (see Section 4.2.2). This type of platform records the energy flows between peers and, in the case of Vandebron, enables the selection of electricity producers. In comparison, the European system of green certificates cannot offer the same guarantee of absolute transparency regarding the origin of energy (see Kloppenburg and Boekelo 2019).

5.1.4 Application example: the GOPACS market platform

The Grid Operators Platform for Congestion Solutions (GOPACS) is a newly developed market platform in the Netherlands on which DSOs can buy flexibility from market participants to avoid regional bottlenecks.

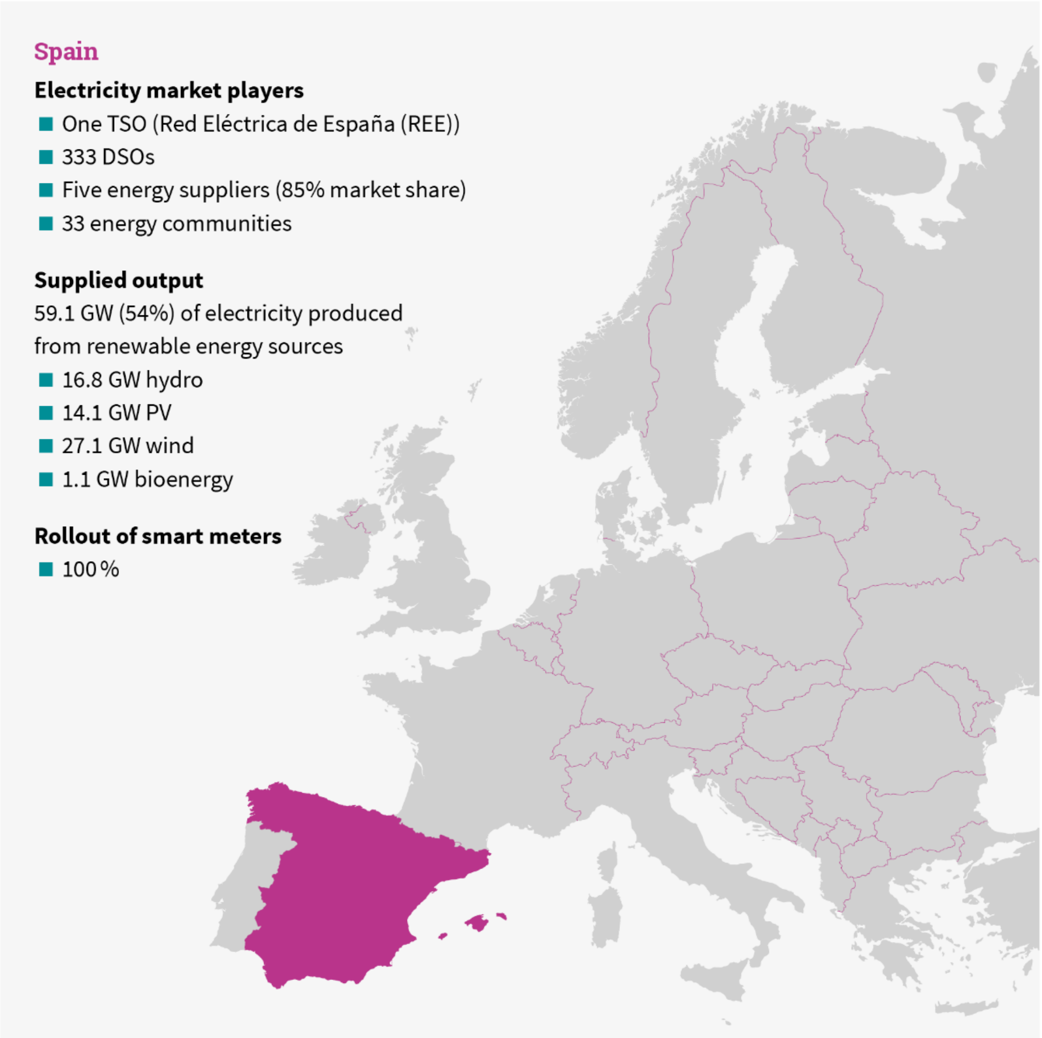
The GOPACS is owned and operated by the Dutch TSO and the four DSOs (Stedin, Liander, Enexis Groep and Westland Infra). The GOPACS is not a market platform on which flexibility offers are processed, but it acts as an intermediary between the needs of the grid operators and the markets. The aim of the platform is to offer market-oriented bottleneck management.

The GOPACS is currently connected to the Energy Trading Platform Amsterdam (ETPA), a national intraday platform, in the Netherlands. Offers from flexibility providers active on the ETPA can be procured via the GOPACS, provided they add a location ID code. The GOPACS is integrated into the existing market sequence since the flexibility is sourced from the existing intraday platform. The flexibility offers for network operators are not placed separately on the ETPA, but are considered part of the (wholesale) intraday order book.

Network operators and market participants can procure the same flexibility. Flexibility providers can offer the same flexibility for two different prices by submitting two bids, such as one portfolio bid for intraday wholesale and a second bid with location-relevant information. The flexibility provider is responsible for avoiding double activation. There is only a connection to the ETPA at the moment; however, further market connections are planned (see Schittekatte et al. (no year)). Currently, the GOPACS concept is primarily a bottleneck mitigation solution for DSOs, but it is conceivable that balancing group managers (portfolio optimisation) and TSOs (system services) would also be buyers of flexibility services. Compared to access to balancing energy markets, the threshold to participate in the GOPACS is low due to the technical access requirements. There are no specific requirements for ramp rate, response time, full activation time or deployment time. Furthermore, there is no upstream prequalification process. The minimum bid value is also lower with 0.5 MW for the GOPACS compared to 1 MW for most products in the balancing energy markets. For this reason, CECs in the Netherlands may have sufficient scale to offer services on this platform (see Nixiang 2020).

5.2 Spain

In Spain there have been two periods of creation of energy cooperatives: the first in the late nineteenth and early twentieth centuries and the second more recently since 2010. Rising electricity prices and the abolition of subsidies for renewable energies, among other things, were central to the current re-emergence of further communities. Most of them are consumption communities and only a small number of active generation projects. Som Energia and GoiEner are two large energy communities from regions (Basque country and Catalonia) with a long cooperative tradition (see Heras-Saizarbitoria et al. 2021). Figure 7 provides important key data.



Spain

Electricity market players
- One TSO (Red Eléctrica de España (REE))
- 333 DSOs
- Five energy suppliers (85% market share)
- 33 energy communities

Supplied output

59.1 GW (54%) of electricity produced from renewable energy sources
- 16.8 GW hydro
- 14.1 GW PV
- 27.1 GW wind
- 1.1 GW bioenergy

Rollout of smart meters
- 100 %

Figure 7: **Overview of the electricity market and energy communities in Spain (sources: Caramizaru and Uihlein 2020; dena 2021; IEA 2021; IRENA 2021a; Ritchie and Roser 2020; Smart Energy Europe 2019)**

5.2.1 Regulatory framework

The Royal Decree Law 15/2018 changed the framework conditions for participation in electricity generation by consumers in Spain, which had previously been severely restricted. This facilitated participation in self-consumption activities, the right to free-of-charge self-consumption, the right to joint (collective) self-consumption, as well as administrative and technical simplification, especially for small energy plants. Specifically, it is possible to have the collective self-consumption of several flat owners or in commercial areas with a maximum radius of 500 metres around the generation plants and an upper threshold of 100 kW of electricity in total. Use of the public grid is possible, but only at one voltage level (usually low voltage). For small self-consumers, there are simplified administrative procedures, a procedure for the remuneration of surplus energy fed into the grid and the waiving of grid fees.

The term ‘renewable energy communities’ (*comunidades de energías renovables*) was introduced into the legislation and the definition of the RED II was adopted with the latest Royal Decree Law 23/2020 from 23 June 2020. However, further legislative measures are needed to avoid conflicts of understanding around the definitions of market players (see Biresselioglu et al. 2021). There is no more detailed legislation for energy communities so far (see Frieden et al. 2020).

The current regulatory framework can be interpreted as a hybrid model between collective self-consumption and renewable energy communities. The stakeholders think that the radius limit of 500 metres and the cap on the grid connection level are not suitable for larger producer-consumer communities (see Dröschel et al. 2021). In Spain energy communities can offer services to their members through an energy service company (ESCO). The Spanish service market for energy communities has grown rapidly.

The electricity markets for flexibility and aggregated products are not yet sufficiently defined or fully developed in the legislation to serve as a business model for energy communities. However, such markets are being tested in local regulatory innovation frameworks developed within new projects such as IREMEL[9]. However, they do not yet offer viable business models for energy communities without subsidies (see Bridge 2021).

The existing framework for ‘energy consumption cooperatives’ (*cooperativas de consumo*) can be seen as a supporting factor for the implementation of local renewable energy projects in Spain. These cooperatives are responsible for managing various activities in the local energy environment and can implement integrated renewable energy projects. The cooperative framework with its legislation is considered to be very well suited for energy communities and can provide a basic building block for future legal regulations (see Frieden et al. 2020).

5.2.2 Digitalisation of the Spanish energy market

Currently, Spain has a decentralised data management model (SIMEL[10]) for market communication processes (see Bessa et al. 2018). It is a smart DSO-centred model with decentralised data storage and access that receives, directly or through utility companies, the hourly energy data that is registered in all smart meters.

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[9] IREMEL is a market platform in Spain that is still being developed and is designed to provide flexibility services to distribution system operators (Valarezo et al. 2021).

[10] *Sistema de información de medidas eléctricas* (Spanish metering system): As a DSO-centred model, SIMEL is a smart system with decentralised data storage and access that receives, directly or through other utility companies, the hourly energy data that is registered in all meters installed in Spain (CEER 2016).

This is data from generation plants, connections between distribution and transmission grids and supply points of small and large consumers. The consumption data of customers is automatically reported to the DSO via smart meters on a monthly basis. These readings are reported on an hourly basis and are stored together with the master data of the customers at the DSO and the TSO. The rollout of smart meters in households in Spain attained a coverage of over 99 per cent in 2018 (see Eurelectric 2020). In future, the model will have a central platform for access, whereas the DSOs will store the data. The single point of contact had been responsible for remote access to the database since 2016. In the meantime, there have been technical improvements made enabling remote access. In addition, the regulatory authority responsible in Spain – the National Commission for Markets and Competition (*Comisión Nacional de los Mercados y la Competencia*, or CNMC for short) – introduced a system that allows suppliers to download the databases of the DSOs from a central hub. The TSOs submit their databases monthly and the CNMC compiles them in a common format (see CEER 2016).

5.2.3 Application example: Som Energia

Founded in 2010, Som Energia, Sccl is the first renewable energy cooperative in Spain, which has grown rapidly and gained over 6,000 members in the first two years alone. The cooperative has grown strongly on the supply side: Som Energia now has 72,000 members and 127,000 retail contracts, of which the majority are private consumers. Its financial sustainability, which was ensured at the beginning through a simple business model and the participation of volunteers, is an important success factor for the cooperative. The cooperative started selling renewable electricity from third parties to its members, using a low-cost, web-based system for its operations. It was time-consuming and complicated, although obtaining a permit to operate and sell through the public energy system was not very costly. Over time, the cooperative acquired several renewable energy projects that had already received feed-in tariffs and invested in its own renewable energy capacity, usually small projects close to its members (currently around 10 MW of solar, biogas and small-scale hydropower plants). Som Energia promotes renewable energy for private households with the collective purchase of PV systems by its members, organised in groups of 50 or 100 systems in a regional area.

Som Energia wants to develop into a prosumer community and is involved in pilot projects to explore flexibility services from private users. Som Energia led a sub-project in FLEXCoop, an EU-funded project, to build a demand reduction framework for household consumers based on a home gateway connected to flexible installations such as heat pumps or electric vehicles in the home. In the project, Som Energia is active as an aggregator with its customers as prosumers on the Spanish day-ahead electricity market. The aim is to dynamically optimise the balance between self-consumption of energy from rooftop PV systems, remuneration for surplus energy fed into the grid, balancing energy costs and low electricity purchase prices for consumers (see Mourkousis et al. 2020). In addition, the cooperative has participated in other ICT projects, such as the Empowering project, from which the current Infoenergía service has developed. A program that performs big data analytics with data from smart meters and can provide each cooperative member with personalised energy consumption information and recommendations regarding energy efficiency and changes to new tariffs (see FLEXCoop 2020).

5.3 Denmark

Denmark has a long and successful history of involving its citizens and municipalities in the supply of electricity and heat. The Danish government has been creating framework conditions since the 1970s as a reaction to the oil crisis in order to promote energy communities and renewable energies – primarily wind energy. These included tax exemptions on revenues from community-owned wind farms, guaranteed grid connection, purchase obligations and priority transmission of wind energy, as well as the introduction of fixed feed-in tariffs. Initially energy communities had to be located in the immediate vicinity of the plant; however, this geographical restriction was later lifted. In 2016, around 2,750 MW (or 52 per cent of the installed wind capacity in Denmark) was owned by its citizens. The Danish government introduced a tendering model for renewable energies, preferably for offshore wind farms in 2018, which could hinder future citizen participation, as it is mainly financially powerful private investors who will benefit (see Roberts et al. 2014; IRENA 2020; Gorroño-Albizu et al. 2019).

Since the 1970s, energy communities that are operated by cooperatives or municipal companies have increasingly controlled the Danish district heating sector. According to the Danish authorities, there were 407 supply companies for district heating in Denmark in 2016, of which 341 were cooperatives and 47 municipal companies, which together cover 60 per cent of the district heating demand (see Gorroño-Albizu et al. 2019; Caramizaru and Uihlein 2020). Denmark has 700 energy communities, making it the second highest number of energy communities in Europe after Germany (see Caramizaru and Uihlein 2020). Figure 8 provides important key data.

Denmark

Electricity market players

- One TSO (Energinet)
- 40 DSOs
- 38 energy suppliers
- 700 energy communities

Supplied output

9.7 GW (62%) of electricity produced from renewable energy sources

- 1.3 GW PV
- 6.2 GW wind
- 2.1 GW bioenergy

Rollout of smart meters

- 100 %

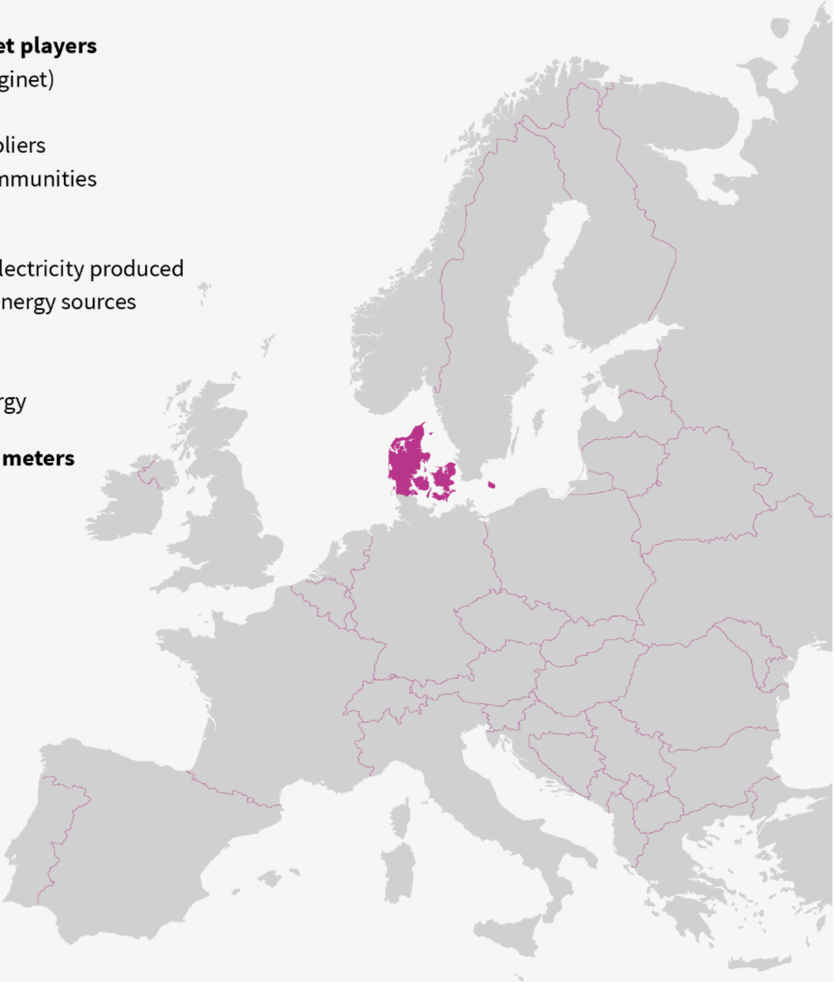

Figure 8: Overview of the electricity market and energy communities in Denmark (sources: Caramizaru and Uihlein 2020; dena 2021; IRENA 2021b; Ritchie and Roser 2020)

5.3.1 Regulatory framework

There are various mechanisms under Danish law that promote energy communities as well as the development of renewable energies. For example, the supply of electricity and heat was defined as a common good in order to prevent energy poverty – long before the energy market in the EU was liberalised in 1999. Since then, the principle of full cost recovery (non-profit rule) has applied to the regulation of energy service providers, which means that surplus revenues must be paid back to consumers through charging them lower fees. In keeping with this, the Danish energy market functions comparatively independently of free market principles (see Roberts et al. 2014).

Numerous citizen wind projects were founded as general partnerships (‘Interessentskab’, or I/S for short) in the 1980s thanks to national legislation. These cooperative-like organisations often refer to themselves as wind power cooperatives (‘Vindmøllelaug’).

Unlike a cooperative, an I/S is subject to favourable taxation on capital gains. There had been a transition in the 1980s from the feed-in tariff to a premium model in the 2000s, which led to a decline in community-owned wind projects, so the government imposed new requirements on wind energy projects between 2009 and 2020. These were now obliged to offer at least 20 per cent of the ownership shares to residents and businesses within a radius of 4.5 kilometres. However, this regulation was abolished in June 2020.

The limited liability company (‘Andelsselskaber med begrænset ansvar’, or A. m. b. A. for short) is a common form of company for not-for-profit, consumer-owned district heating initiatives in Denmark that operate a small or independent grid. These A. m. b. A. are governed by the general assembly, in which each party connected to the common district heating network has one vote. Voting rights of parties who have several consumption connections can be limited by a set of special rules (see Roberts et al. 2014). This non-profit rule has impacted the heating sector through decreasing heat prices for consumers and a continuous further development of district heating systems using the best solutions available on the market (see Gorroño-Albizu et al. 2019).

Danish tenants have held a majority in the board seats of their housing associations since 1984. The board makes administrative decisions about investments in the installation of a PV system, for example. These systems are financed through rent adjustments and supported by a majority vote of all members. The Danish Act on Social Housing (consolidated version from 2009) establishes that the tenants of social housing are members of their housing association, thereby making it responsible for operating and maintaining the housing estate (see Roberts et al. 2014). Collective self-consumption at the building level is already possible in Denmark if all generation plants and consumers of locally generated electricity are connected via a private grid and connected to the public grid via a common supply meter. These energy communities correspond to the definition of collective self-consumption according to the IEMD (see Frieden et al. 2020).

The promotion of renewable energies on the basis of a purchase obligation for electricity is composed of a fixed premium price, which is added to the market price, and a fixed feed-in tariff for electricity. Renewable energy plants with a capacity of up to 10 MW only have to apply for a grid access permit under Danish law, and not an energy production permit. This significantly reduces the administrative hurdles that a municipal electricity project, for example, has to go through before it can be put into operation. The grid expansion, which is also necessary for the connection of renewable energy plants, is the responsibility of the responsible grid operator – either the DSO or the TSO. The grid connection costs in Denmark are borne in equal parts by the system owners, the grid operators and the consumers. On the consumer side, there is a public service obligation (PSO) that depends on the amount of electricity purchased (see Roberts et al. 2014).

Denmark was the first country to introduce an electricity tax exemption for annual net metering in 1999. Prosumers received a feed-in tariff and an exemption from the PSO fee. The regulations on net metering have been continuously updated (see Martín et al. 2021). The PSO contribution can be waived completely for small PV systems up to 50 kW or micro wind systems up to 25 kW and partially for larger systems. Tenants without their own eligible installation can also be exempted from the PSO fee if the installation is fully owned by the property owner and the tenants report their electricity consumption to the grid operator on an hourly basis (see Wikberg 2019).

5.3.2 Digitalisation of the Danish energy market

Denmark's supplier-centred energy market design is very similar to the German model. However, the settlement processes between suppliers and distribution and transmission system operators in Denmark have been realised via a central data hub, called the Green Energy Hub, since 2016. The data hub records the meter readings of approximately 3.3 million connection points for consumption and generation, and the market data-relevant data exchange and business transactions between the market participants are processed in a standardised and automated manner. After the rollout of smart meters for all connection points in Denmark was completed, the meter data has been collected and processed hourly for billing purposes since 2020. The introduction of the data hub has led to the following improvements: increase in data quality (single source of truth of the Danish electricity market); significant reduction in the need for clarification between market players; reduction of the barrier for entry for new market players through standardised communication; and reduction of the players' own administrative workload, as essential business processes are handled centrally via the data hub. The Danish Ministry of Climate, Energy and Utilities, which is responsible for the energy market, appointed Energinet (an independent public company owned by said Danish ministry and transmission system operator) as the operator of the data hub in 2013, after discussions with various market players in 2012 did not lead to a final understanding. The central structure of the data hub allows for easy implementation of innovations in the market processes, as the technology only has to be implemented once.

Energinet's intention for the data hub is to meet the requirements of the Clean Energy for all Europeans Package on behalf of the responsible Danish ministry, that is, to promote sector coupling and demand-side flexibility based on the available energy data. To promote sector coupling, Energinet has joined the Equigy platform initiated by the three transmission system operators TenneT (Germany/Netherlands), Terna (Italy) and Swissgrid (Switzerland). This blockchain platform aims to make it easier for small electricity consumers and generators (such as electric vehicles, domestic PV systems, individual heat pumps) to contribute to grid balancing. Equigy acts as a digital bridge between the TSO markets and the market participants providing balancing services (see Energinet 2020).

Energinet will analyse the instrument of scarcity prices as a driving price signal on the balancing energy market and as an incentive for a system-friendly behaviour of the market participants in order to increase demand flexibility. Furthermore, innovative, sustainable business models are to be favoured and new insights gained from existing data, such as anonymised consumption and generation data from distribution grid operators (see dena 2021; Danish Energy Agency 2021).

The Green Energy Hub has been freely accessible as an open-source project since April 2021. Denmark is pursuing a goal of having the broadest possible community participation in the further development of the data hub as well as of enabling the Danish model to be used by other countries (see Energinet 2021).

5.3.3 Application example: EcoGrid 2.0

EcoGrid 2.0 is a pioneering pilot project on the provision of flexibility services in bottleneck management based on 800 aggregated electric household heating devices via a specially developed cloud marketplace supported by smart meter data and AI.

Digital tools have been developed in EcoGrid 2.0 to allow aggregators, DSOs and TSOs to request, buy, sell, activate and control flexibility for bottleneck management across small-scale distributed installations. The software developed in the project is ready for commercialisation.

The EcoGrid 2.0 project bundled flexibility services from 800 private households and summer homes for three years as part of a real-world laboratory and provided them to the distribution and transmission grid. The project was able to show that there are many flexible resources with shorter time horizons at balancing group level than at day-ahead level that can support balancing group managers in balancing their balancing groups. Household consumption could be made more flexible and activated by the aggregators via the market platform developed in the project. Heat pumps and electric heating panels were controlled for this purpose under the condition that the living comfort of the participating households was not reduced. Overall, trading transactions, each of which included direct plant control, could thus be carried out in 209 cases with the distribution grid operator and in 36 cases with the transmission grid operator (see EcoGrid 2.0 2019). A digital aggregator was created to bundle the electric heating appliances of 800 households. This software aggregator has the following connections: (1) to the household data, (2) to the control interface of the heating appliances, (3) to the flexibility clearing house market platform (FLECH for short) and (4) to a repository in which planned and executed actions are stored (see Buhler and Wiesmann 2019). The market platform implemented in the project was designed to be integrated into the existing Danish energy markets (see EcoGrid 2.0 2019). The market platform is a platform-as-a-service cloud product of a commercial provider (based on the previous project's FLECH platform; see Jansen 2017). Relevant business data from the sellers, buyers as well as the Danish data hub are processed via this platform. Basic data that was and is necessary for the development and operation of the software tools include smart meter data, weather forecasts, grid load forecasts and electricity prices. Algorithms and forecasts for consumption forecasts, among other things, were supported thanks to machine learning (see EcoGrid 2.0 2019).

5.4 Concluding notes on the implementation of energy communities in the different countries

The Netherlands has a tradition of energy communities and an adaptable existing framework already. Energy sharing is possible under postal code regulation, but further implementation of EU requirements has not yet taken place. The Netherlands has 600 energy communities. Compared to the EU, this figure is high. Even though the Netherlands was not considering the RED II or the IEMD, the country managed to create a regulatory sandbox for innovative energy communities. In addition, there is a highly advanced digital market communication system that is highly automated and standardised. This creates important prerequisites for the business models of energy communities, for example, for a change of supplier within 24 hours. Another basis is a well-developed digital infrastructure. 88 per cent of all households have a broadband connection and rollout of smart meters is at 90 per cent.

For years, **Denmark** has considered electricity and heat production to be common good, which is established by a non-profit rule. Citizens' wind projects in particular are widespread in Denmark. Their numbers have decreased in the meantime, but it is around 700, which is still high in an EU comparison. The regulations in Denmark on collective self-consumption correspond to the IEMD requirements and relate to buildings, like those of most EU countries. There has been draft legislation for citizen energy communities since 2021 that allows dynamic grid rates and no longer provides for supplier obligations for aggregators and citizen energy communities. Renewable energy communities as defined by the RED II are not part of the draft law. Denmark has advanced, highly automated and standardised market communication. The settlement processes between suppliers and distribution and transmission system operators have been realised via a central data hub since 2016. Since April 2021, this has been freely accessible as an open-source project in order to involve a broad community in the further development and to enable the Danish model to be used by other countries.

The expansion of the digital infrastructure is at an advanced stage, with household broadband access at 90 per cent and a full rollout of smart meters.

Spain also has a tradition of energy communities. New legal regulations in 2018 changed the framework conditions for participation in electricity generation in Spain, which had been severely restricted until then. In addition, rising electricity prices and the abolition of subsidies for renewable energies were central to the re-emergence of energy communities. However, the number is still low (approx. 30) when compared to the rest of Europe. The framework for self-consumption is considered progressive and allows the use of the public grid, thus going beyond the requirements of the RED II. Spain also adopted the definition of the RED II in 2020. However, more detailed legislation is still lacking. The market for energy service companies (ESCOs) providing services to energy community members is growing rapidly. Markets for flexibility and similar products are not yet mature, but are being tested in regulatory innovation frameworks. The future data management model will have a centralised platform for access, which will be under the responsibility of the TSO. The DSO carries out data storage. It is a smart centred model with decentralised data storage and access that receives, directly or through other utility companies, the hourly energy data. The expansion of the digital infrastructure is at an advanced stage, with household broadband access at 89 per cent and a 100 per cent rollout of smart meters.

5.5 Legal implementation in Germany

'A prosumer is subject to the same requirements as a municipal utility if they want to sell electricity from their PV system to a neighbour currently. If we want to promote energy sharing, then the regulatory requirements and the bureaucratic processes must be reduced' (expert interview 2021).

Germany has the highest number of energy communities in Europe (more than 1,700). The existing regulatory framework for citizen-led energy communities is considered a good basis for the implementation of EU legislation. Nevertheless, the requirements for collective self-consumption and energy sharing have not yet been implemented. There are numerous citizen-led energy communities that produce energy collectively in Germany today, but collective use is not yet possible. Under the German Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz*, or EEG), producers of renewable energies in Germany have the option of either consuming their electricity themselves (self-supply, Sect. 3(19) of the EEG), marketing it themselves (market premium, Sect. 20 of the EEG) or making it available to the grid operator (feed-in tariff according to Sect. 21(1) and 21(2) of the EEG).

The existing landlord-to-tenant electricity model does not allow for collective self-consumption. There are too few incentives for producer-consumer communities that go beyond multi-apartment blocks. In practice, energy communities are not privileged and implementation is subject to high requirements.

It has been possible to receive subsidies in Germany for PV systems up to 100 kWp with a landlord-to-tenant electricity premium[11] through the EEG since 2017 (Mieterstrommodell).

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[11] The installed system capacity in Germany via the landlord-to-tenant electricity model is still at a low level (a total of 30 MW); however, it has increased since 2017 (see BMWK 2021). This is due to the low economic efficiency of the model (see Huneke and Claußner 2019). Tenants have the opportunity to

However, the possibility of collective self-consumption within the meaning of the RED II does not exist in Germany, because the German landlord-to-tenant electricity model does not constitute collective self-consumption within the meaning of the RED II. The tenants are not electricity producers themselves on a regular basis, but only electricity consumers. However, should the tenants actually be operators of the system at the same time, they would not be self-suppliers according to the EEG[12], as long as they do not form a legal entity within the meaning of the EEG (Sect. 3, item 19 of the EEG). This requirement in the Renewable Energy Sources Act to be a legal entity is again not in line with the requirements of the RED II (Sect. 21(4)). In addition, the landlord-to-tenant electricity model only refers to PV systems, whereas the RED II refers to all renewable generators (Dröschel et al. 2021).

Furthermore, it is already possible to introduce and operate peer-to-peer platforms in Germany (and Europe) currently; however, there are still some regulatory hurdles to commercial implementation. Section 80 of the EEG limits the potential in Germany, as there is a legal risk of multiple sale when selling EEG-subsidised green electricity via a regional energy platform. In the case of EEG-subsidised electricity, the safest legal route is therefore to neither label it as green electricity to consumers nor provide producer information. On the other hand, it is not a problem to sell non-EEG-subsidised green electricity (such as plants without subsidies and post-EEG plants[13]) in other direct selling. Using the regional origin of non-EEG-subsidised electricity as a selling point is possible without need for further proof. However, this should be specified by region through the purchase of regional electricity certificates in the case of EEG-subsidised electricity.

Currently, peer-to-peer models are hardly feasible in legal terms and not economically viable due to the full EEG surcharge and grid fees. Platform trading is complicated from the producer's point of view because even small prosumers are subject to full supplier obligations according to Section 41 of the German Energy Industry Act (*Energiewirtschaftsgesetz*, or EnWG), which oblige them to contractually stipulate the duration of the contract, price adjustments, termination dates, notice periods, customers' right of withdrawal, services to be provided, methods of payment, liability and compensation regulations in the event of non-compliance with contractually agreed services and the quick and free change of supplier. These obligations as well as balancing group management, forecasts, etc., can be passed on via intermediaries (see Bogensperger et al. 2018).

The legal framework also does not currently allow grid operators to incentivise grid-friendly behaviour through their own initiatives by how the grid charges are set up. So far, the low financial added values have hardly been an incentive for consumers to want to participate (see Fietze et al. 2021).

Incentives must be created for energy communities to be able to share locally generated electricity using the public grid (energy sharing) so the RED II requirements can be further implemented in Germany. The possibilities and incentives to use regionally generated electricity are very limited as long as this framework is not in place. From a purely legal point of view, an energy community in Germany cannot supply its members with its own electricity without becoming a full electricity supplier and also being subject to all levies, surcharges and taxes on electricity supplies (see Dröschel et al. 2021).

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directly purchase the electricity generated on the roof of their building or a building in the immediate vicinity within the framework of this landlord-to-tenant electricity model. There are no grid fees, grid surcharges or electricity tax in this model, in contrast to the purchase of electricity from the public grid. Since the EEG was amended in 2021, building owners as owners of the system can transfer all the obligations of an electricity supplier to, for example, power supply companies or other external service providers with the help of the supply chain model.

[12] The established requirement that the operator and end consumer be the same person applies for self-suppliers in the EEG; this needs to be abolished in order to enable collective self-consumption.

[13] Post-EEG plants are renewable energy plants that lose their payment entitlement under the EEG after a period of 20 years. This affects the first operators of EEG plants from 2021 onward.

Germany in comparison with other Member States

Most Member States have made significant progress on the RED II targets for collective self-consumption compared to Germany. In most cases, the regulations refer to the direct use of electricity in multi-apartment blocks without integration of the public grid. The use of the public grid is also regulated only in Spain, France and Italy within the framework of collective self-consumption. Spain, France and Austria have also developed models through which energy can be shared within a group of consumers without the direct involvement of a supplier (see Hansen et al. 2019).

Furthermore, producer groups can be producers and ‘de facto’ suppliers at the same time in some Member States. ‘White label’ regulations enable companies to only take over certain tasks of an electricity supplier without having to be a fully licensed supplier themselves. These models usually involve fully licensed suppliers who guarantee consumer rights and energy market connectivity. For example, in the Netherlands the integrated ‘real’ suppliers have the contractual relationship with their customers and are responsible for processes such as invoicing. Other alternatives to the full supplier model are the licence exemption, suppliers without a licence and the power purchase agreement (PPA). By means of PPAs, buyers purchase electricity from a generator at pre-agreed conditions. The PPA market for PV electricity in Spain is currently one of the largest in the EU based on a comparison within the EU (see Huneke and Claußner 2019). For example, PPAs can also be concluded between a licensed supplier and a generator within this framework, meaning that generation is contractually linked directly to the customer (see Hansen et al. 2019). Models such as consumer pooling could also be financially attractive for smaller consumers such as non-energy-intensive companies or SMEs in the future. Under such a model, several companies or a company with multiple locations can pool their demand in order to be able to purchase renewable energy at a lower cost, for example.

Digital solutions for the technical optimisation of market communication are available in Germany, but these require the further development of specific process regulations and market design. Germany significantly lags behind countries such as Denmark and the Netherlands in this regard. The underlying framework conditions must be further developed through general market design and concrete process regulations before the technologies for market communication are optimised through existing digital solutions. The market players need new role assignments and access to energy industry data to some extent in order to implement peer-to-peer business models. This was taken into account when the data hubs were developed in Denmark and the Netherlands. Data transmission, which the law requires, is central to digital market communication. It currently takes around two weeks in Germany to change suppliers, whereas in the Netherlands this can be done within 24 hours. In addition, a data platform for the billing process has proven itself in Denmark and the Netherlands, which, if adapted, can also bring advantages for Germany. However, unlike Denmark and the Netherlands, Germany has significantly more distribution system operators, which makes adjustments necessary. The expansion of the digital infrastructure is at a less advanced stage when compared to the EU, with household broadband access at 35 per cent. Some countries are already fully equipped with smart meters, including Denmark, the Netherlands and Spain, while the rollout in Germany got off to a slow start.

6 Results of the survey on the use of digital technologies in energy communities

The aim of the survey was to find out how energy communities feel about the use of digital technologies. The following main questions were considered:

- What are the areas in which energy communities deal with digitalisation?
- Which digital technologies are used or in planning?
- What are the experiences and motives of energy communities?
- What potential and what obstacles do energy communities see?
- Where is political support necessary?

The survey was conducted in September and October 2021 by means of a standardised online questionnaire in German, English and French. It was addressed to energy communities (according to Section 3) in EU Member States. Knowledge in the field of digitalisation was not a prerequisite for participation. A total of 81 energy communities participated in the survey. Absolute values are given in the evaluation graphs since only a small sample is available here. Around half of the respondents came from Germany; the others were distributed among the Netherlands, Portugal, Belgium, Austria, Luxembourg, Italy, Denmark, Croatia, Spain and Greece. Most of the energy communities surveyed are active in the field of energy production or supply. All classes described in Section 3, with the exception of class 5 (energy islands), were represented. Most of them are categorised as class 2 (energy communities as defined by the RED II) or 6 (municipal utility companies), followed by class 1 (virtual power plants) and 3 (collective self-consumption).

6.1 Use of digital technologies

The energy communities included in the survey use digital technologies both within the framework of internal processes for the administration of finances, invoices and personnel, for example, and for their external image and in corporate management for controlling and management, as well as in their core activities of energy production, metering, energy supply, sales, services, grid operation and energy trading (see Figure 9). Overall, more than half of all respondents (at least 41 of 81 respondents per area) were actively engaged with digitalisation processes in energy production, their internal processes (administration, external image, corporate management) and metering. The topics of energy supply and sales are also relevant for more than 40 per cent of the energy communities surveyed in terms of digitalisation. Only 30 per cent of respondents were concerned about issues related to digitalisation in the areas of services, grid operation and energy trading.

It also shows that on average the energy communities plan to use digital technologies in at least one other of the areas surveyed, in addition to the areas in which they already use them. The activities of sales, services, grid operation and energy trading are not relevant for digitalisation issues for about one third of the energy communities surveyed.

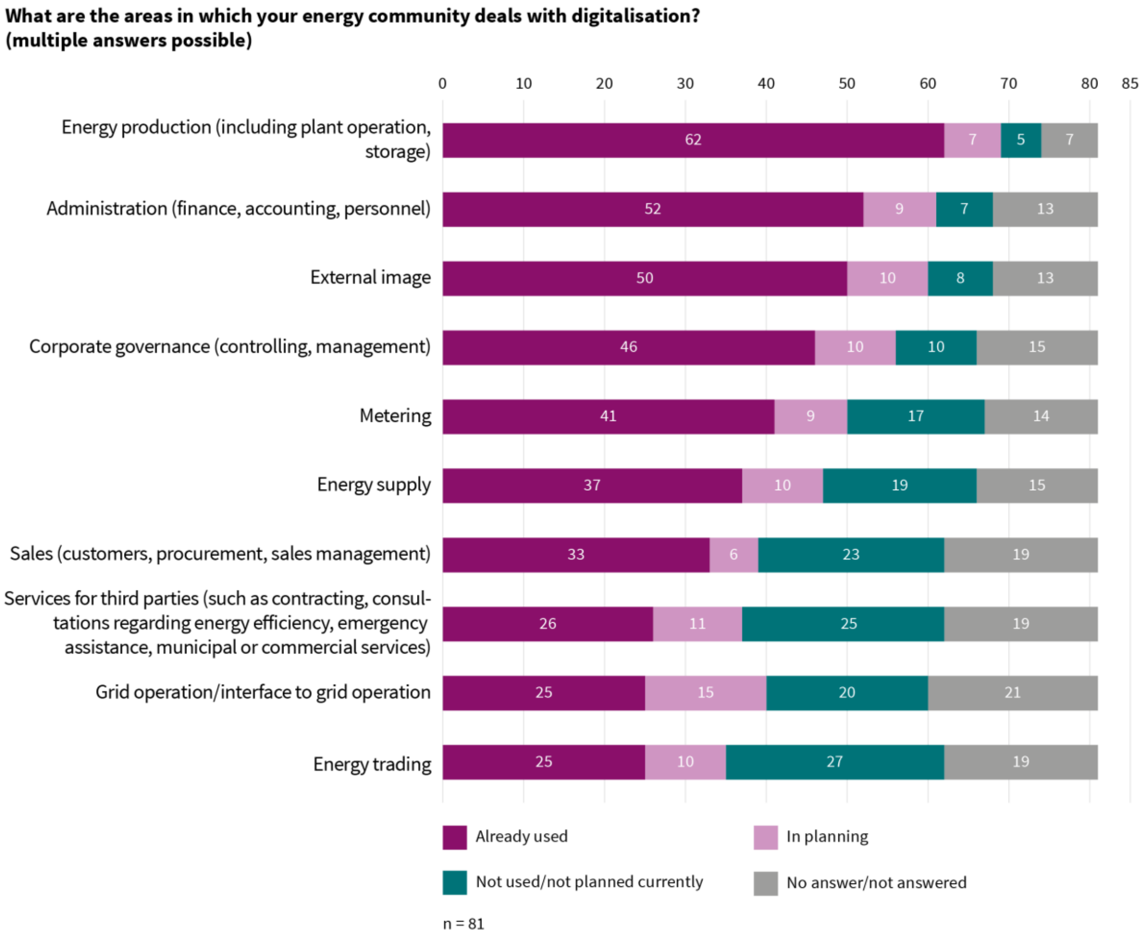


Figure 9: **Relevance of digitalisation in energy communities by activity**

The energy communities were specifically asked whether they use the three currently frequently used innovative digital technologies, smart meters, platforms and remote control technologies (see Figure 10). Out of 81 energy communities, 55 replied to this survey question as followed: The technologies described are used by the majority and in equal measure.

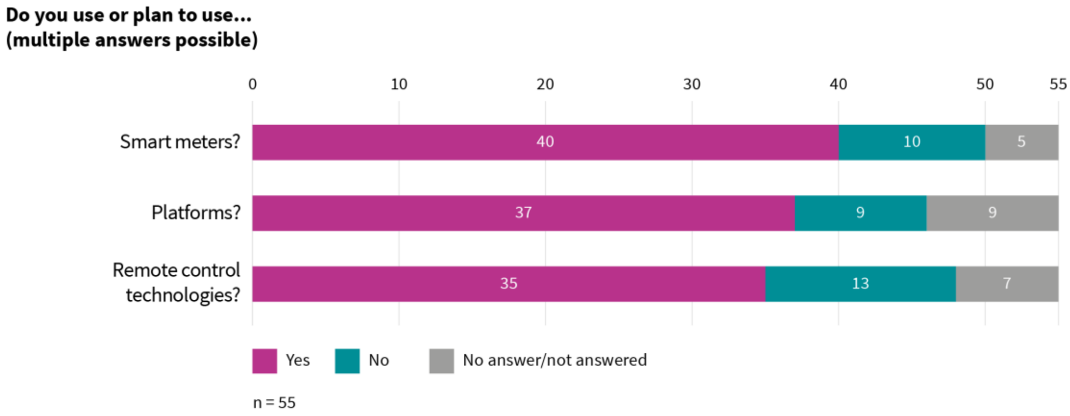


Figure 10: **Use of three innovative digital technologies in energy communities**

The energy communities were then asked whether they use or plan to use a further six technologies classified as innovative (see Figure 11). Out of 81 respondents, 47 answered this question. It turned out that 19 of 47 respondents use digital tools for maintenance and repair, and 18 of 47 use digital tools for modelling. Big data technologies are used by only 13 of the 47 energy communities. DLT, digital twin technology and robotic process automation are currently only used by a minority of respondents. The energy communities surveyed now use only one further innovative digital technology on average; however, there are plans to use an average of two further innovative digital technologies in future, or these are being examined. The major focus lies here on digital tools for modelling, with DLT leading the pack, followed by big data and digital twins.

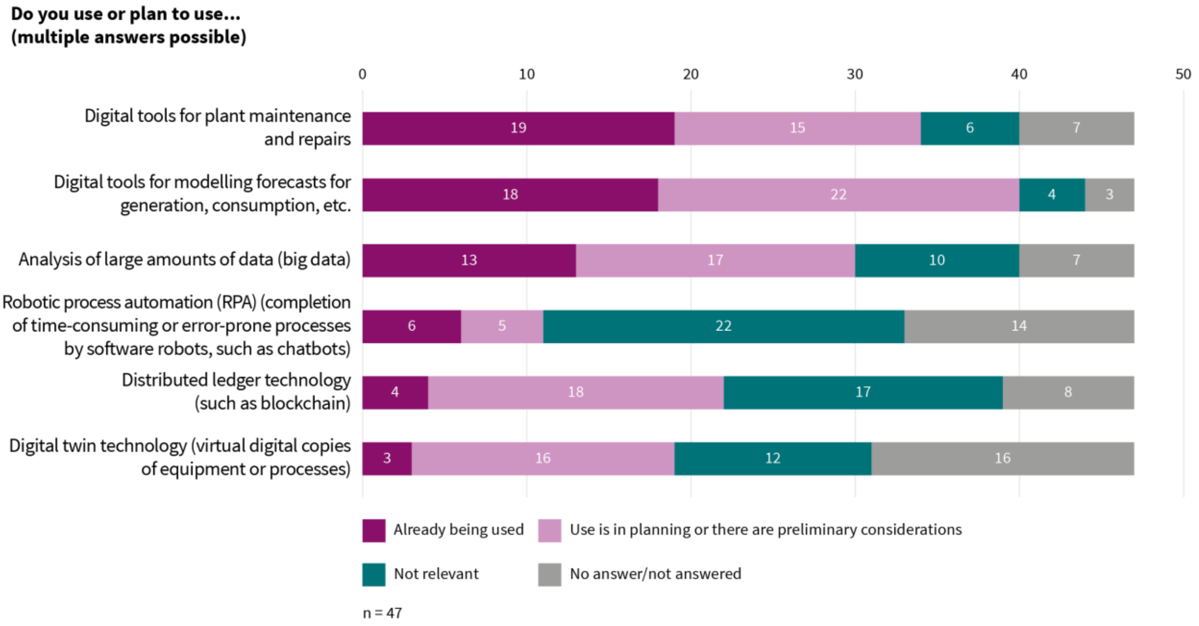


Figure 11: Use of six further innovative digital technologies in energy communities

The energy communities were also asked about the purpose for which the digital technologies are used. The energy communities that already use platforms use them primarily for virtual power plants, as an interface to customers or producers (chatbots, consumption, feed-in accounts) and for energy trading, but also already for trading flexibility. Digital tools for maintenance and repairs are used for actual maintenance (digital maintenance) and for predictive maintenance. Modelling tools are mainly used for generation and consumption forecasts, but also for forecasting grid and storage states. The majority of big data applications are used for real-time data analysis and also for artificial intelligence and machine learning. The energy communities surveyed mostly use DLT for energy trading, billing and guarantees of origin. Digital twins are used for realistic forecasting and plant monitoring. Robotic process automation technologies are used for internal company processes and for the automation of plants and processes.

In addition, the energy communities were asked whether they rely on purchased solutions or in-house developments for the digital technologies used. Here it can be seen that many energy communities that use innovative digital technologies do both.

The energy communities that expressed in the survey they use digital technologies show that the activities and processes of the energy communities could be improved, but at the same time extensive knowledge had to be built up. In addition, the majority of the energy communities surveyed (65 of 81) do not see any restrictions due to the communication infrastructure. More than half have sufficient data on hand, but they have had to invest in both human resources and knowledge. However, they believe that the necessary investments will be amortised within ten years. The positive experiences in the quality of data compared to the quality of data were somewhat lower. When it comes to the introduction of digital technologies, the energy communities surveyed believes that the current legal framework makes compliance difficult (see Figure 12 as well as Figure 15).

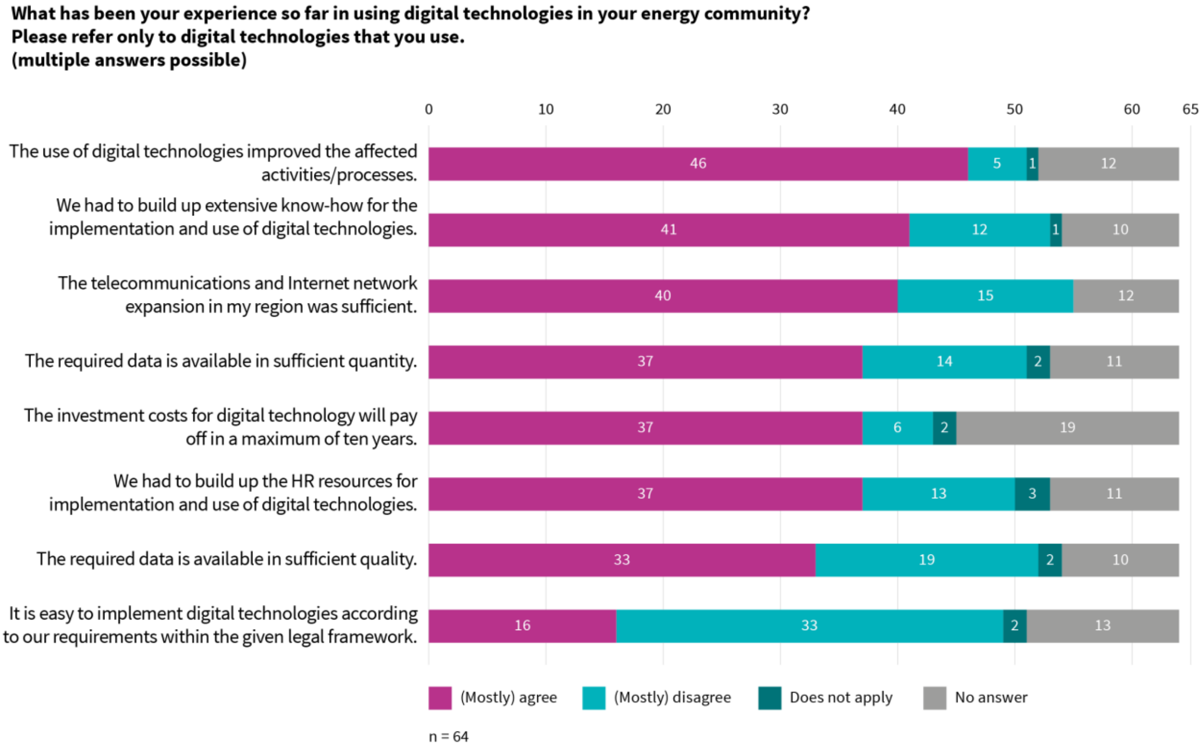


Figure 12: **Experiences of energy communities in the use of digital technologies**

Figure 13 illustrates the factors that motivate the energy communities surveyed to implement digital technologies. Out of 81 energy communities, 65 have named their motives here: More than half of the respondents listed the optimisation of plant operation, the expansion of communication, new business models and offers of additional services as the main motivating factors in the use of digital technologies.

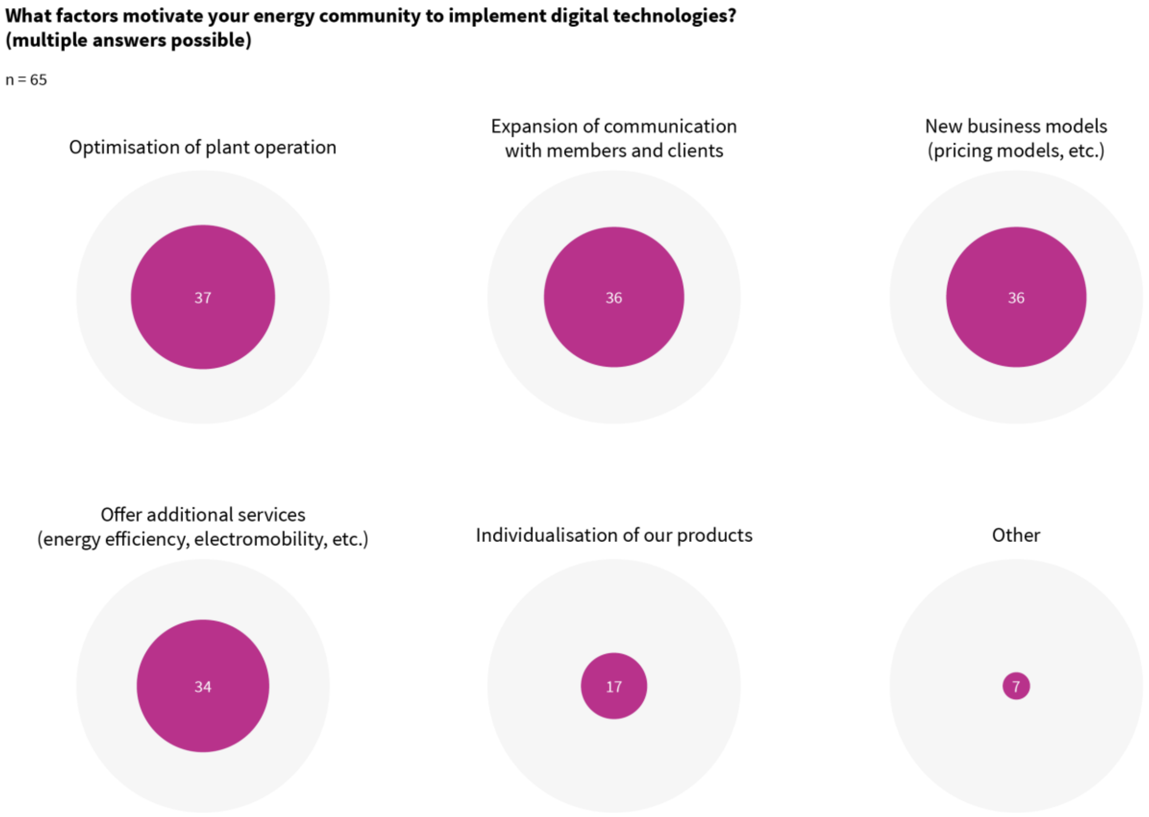


Figure 13: **Motivation of energy communities to use digital technologies**

6.2 General potential and barriers

The energy communities surveyed were also asked to indicate potential, obstacles and wishes for political support related to digital technologies, in addition to the use of these technologies. It was not necessary to have specific user experiences to answer the question. Out of 81 energy communities, 59 replied: The energy communities see high or very high potential in digital technologies for modelling, smart meters, platforms and remote control technologies (see Figure 14). Digital tools for maintenance and repairs and big data technologies also have high or very high potential according to the energy communities. By comparison, the respondents rate the potential of digital twin technologies less highly. The respondents believe that DLT and robotic process automation have little or no potential for the activities of energy communities for the most part.

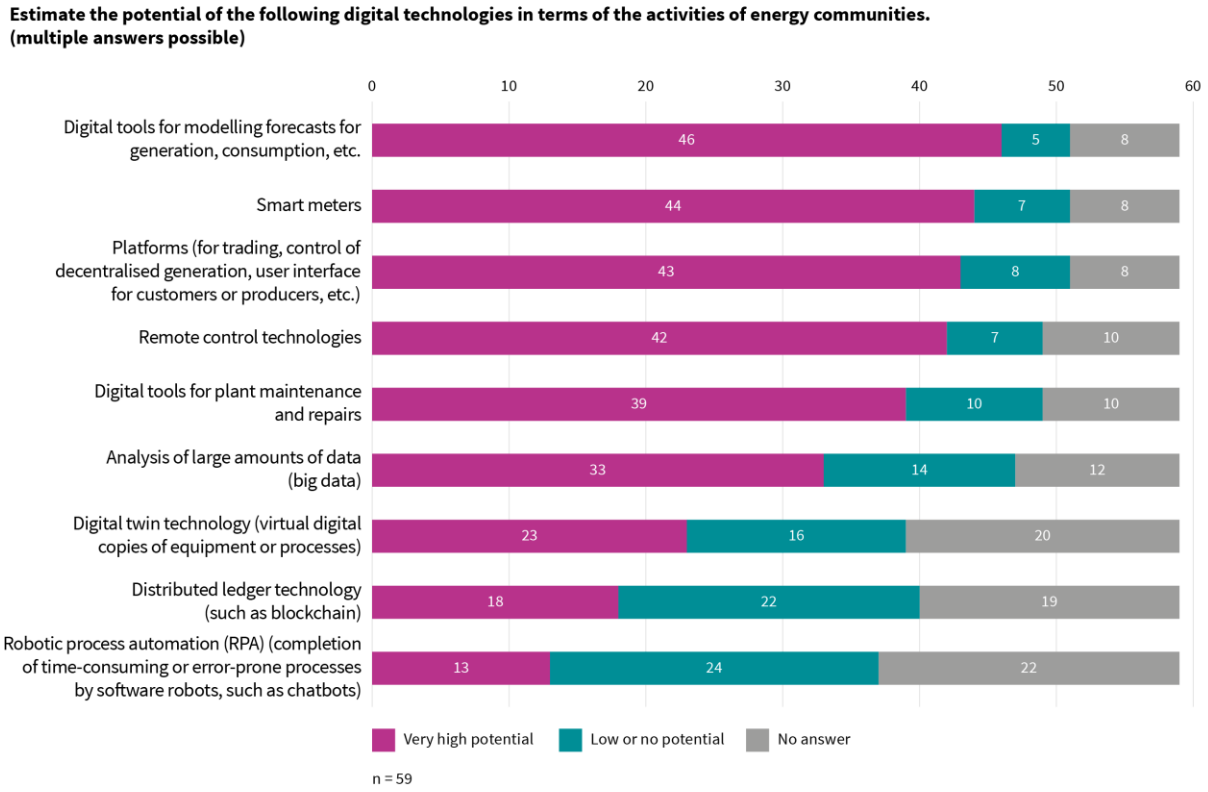


Figure 14: **Potential of digital technologies for energy communities**

Out of 81 energy communities surveyed, 65 commented on the barriers to the use of digital technologies (see Figure 15). The energy communities included in the survey stated that there were a number of clear obstacles to the success of this approach, primarily skilled workers, the regulatory framework conditions in the energy market, the bureaucratic workload required, and obtaining the necessary investments.

The respondents perceive infrastructural issues such as broadband connections as a minor obstacle. Likewise, strategic considerations, the added value of digital technologies and questions about IT security and data protection pose few obstacles. The availability of products on the market or even IT resources is considered to be as often a barrier as it is not one at all.

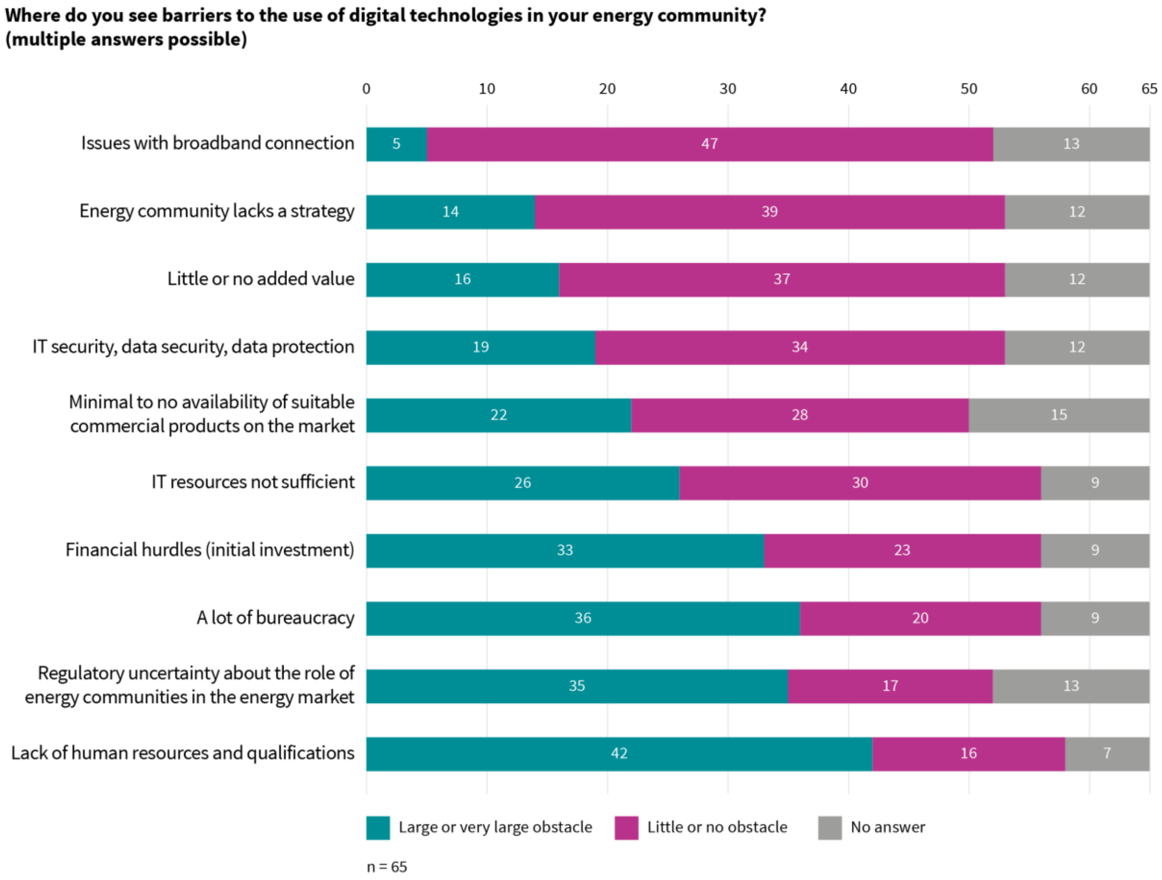


Figure 15: **Obstacles to the use of digital technologies in energy communities**

The amount of political support that energy communities require reflects this (see Figure 16**Fehler! Verweisquelle konnte nicht gefunden werden.**). From the perspective of the energy communities, support is needed in market design and in their most important task, energy sharing, that is, the sharing of electricity among the members of the energy community. The energy communities also see a need for political support in the necessary infrastructures and technical standards.

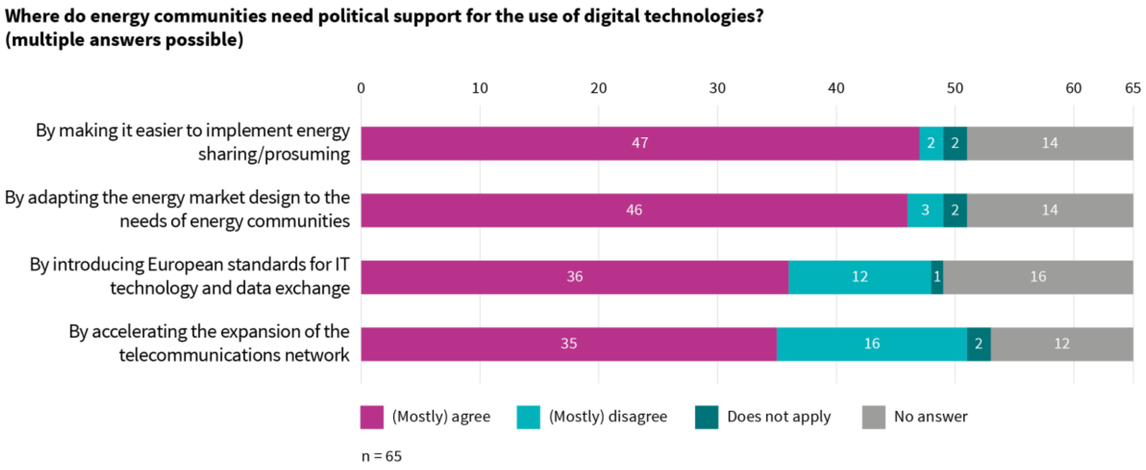


Figure 16: Political support required by energy communities in terms of digital technologies

6.3 Concluding notes on the use of digital technologies in the energy communities surveyed

The majority of energy communities surveyed were actively engaged with digitalisation processes in the context of energy production, their internal company processes (administration, external image, corporate management) and in metering. Energy supply and distribution are also areas of relevance in terms of digitalisation, whereas the topics of services, grid operation and energy trading are still not highly relevant. In addition to the areas in which energy communities were already engaged in digitalisation, the average reply indicates that there are plans to enter an additional area.

Specifically, the energy communities surveyed currently use smart meters, platforms and remote control technologies with high frequency. In addition, some energy communities use digital tools for maintenance and repairs, modelling or big data technologies. Modelling tools lead the way in terms of planned technology deployments, closely followed by big data technologies, DLT, digital twin technologies and digital tools for maintenance and repairs. It has also been shown that energy community rely on both purchased and in-house developments for the digital technologies used.

Energy communities that use digital technologies could improve their activities and processes, but they also needed to build up extensive knowledge at the same time. The energy communities surveyed indicated that data volumes and communication infrastructure hardly posed any problems for them, whereas data quality did pose a problem more frequently. The investment is considered worthwhile. The majority of energy communities listed the optimisation of plant operation, the expansion of communication, new business models and offers of additional services as motivations for the use of digital technologies.

When it comes to the introduction of digital technologies, the energy communities surveyed believes that the current legal framework makes legal compliance difficult.

The energy communities see the potential of digital technologies primarily in modelling tools, smart meters, platforms and remote control technologies. The energy communities included in the survey stated that there were a number of clear obstacles to the success of this approach, primarily skilled workers, the regulatory uncertainty regarding the role of energy communities, the bureaucratic workload required, and obtaining the necessary investments. Accordingly, there is a need for political support in the implementation of energy sharing and in energy market design with regard to energy communities.

7 Summary and next steps

The EU has created favourable conditions for collective self-consumption and energy communities within the meaning of the Internal Electricity Market Directive (IEMD) and the Renewable Energy Directive II (RED II). These reinforce the rights of consumers to participate in innovative business fields such as aggregation, regional electricity (guarantees of origin), peer-to-peer energy trading, energy sharing and flexibility trading in the energy market.

However, the development of energy communities in general is not new; in many cases, these communities already exist in the form of producer associations, virtual power plants and neighbourhood concepts. With regard to the development and use of digital technologies, these represent the starting point for the further development of future energy communities within the meaning of the EU directives as well as beyond. The definition of energy communities chosen in this analysis goes beyond the EU specifications and is described as follows:

‘An energy community is a group of individual stakeholders (citizens, companies, public institutions) who voluntarily accept certain rules in order to act together in the energy sector to pursue a common goal. This includes to a certain extent (direct or indirect) community involvement in the organisation and the sharing of outcomes (beyond financial gain) for the purposes of a common goal (exclusively or including) in relation to energy, which means, for example: 1. purchasing energy as a collective group, 2. and/or management of energy demand and supply, 3. and/or generation of energy, 4. and/or provision of energy-related services, 5. and/or providing mechanisms that promote energy-related behavioural changes (Karg and Hannoset (no year)).

The following advantages are associated with energy communities: acceptance for regional renewable electricity, increased expansion of renewable energy plants, reduction of renewable energy subsidies, economic participation in the energy transition, relieving the burden on the electricity grid through precise balancing of local supply and demand, continued commercial operation of post-EEG plants and incentives for new renewable energy plants without subsidies. The extent to which today’s centralised energy markets offer efficient solutions for the increasingly decentralised energy system is currently the subject of a number of research and pilot projects. New concepts are being developed for the requirements of a high decentralised renewable energy supply, for example, for decentralised market platforms and optimising system-friendly behaviour or for the implementation of ‘cellular’ energy systems (or distributed or embedded energy systems) according to the principle of subsidiarity. Analysis shows that digital technologies and energy communities are both enablers for the decentralised energy transition and critical factors in its success.

Currently, energy communities are primarily active in electricity generation, supply and consumption. These activities are also the focus when it comes to the use of innovative digital technologies. **Aggregator models** that bundle decentralised energy production plants as virtual power plants by optimising demand, production and prices on the basis of historical and forecast data (see IRENA 2019) in order to offer products in central electricity markets such as spot or balancing energy markets are widespread. Activities such as **regional electricity** (guarantees of origin), **peer-to-peer energy trading**, **energy sharing** and **flexibility trading** offer additional opportunities for energy communities. In addition to trading transactions between producers and consumers, trading relationships also arise between energy communities and grid operators.

Guarantees of (regional) origin describe specific attributes of quantities of electricity fed into the grid, such as green electricity or regionality (see Section 4.1.4). Producers can use it to prove that they supply regional electricity, for example. In future, we can also expect guarantees of origin with high temporal and spatial granularity (hourly or every 15 minutes, for example), which are based on digital readings and make it transparent in an energy community which share of electricity was provided when and where.

Peer-to-peer transactions offer a new trading environment for smaller players in the electricity sector. The focus is on energy deliveries between consumers with their own generation plants (prosumers). Peer-to-peer exchange provides these market players with direct access to each other, so that electricity trading transactions and electricity deliveries become possible without central intermediaries such as exchanges, brokers or energy suppliers (see Kreuzburg 2018). **Peer-to-peer energy trading** can take place within and outside energy communities. In distinction to peer-to-peer energy trading, which is usually about maximising self-consumption, **peer-to-peer energy sharing** involves energy consumers sharing their surplus energy with other energy consumers on the same hierarchical level to enhance the benefits of community. Energy consumers can act individually or as a group, functioning purely as energy consumers or in the role of producer (prosumers). The economic benefit is not the only incentive to participate in an energy sharing community. Equally important are community goals such as regional supply, minimisation of community electricity costs, reduction of community CO_2 emissions, reduction of peak loads, improved grid utilisation and system stability, and reduction of energy imports.

The use of digital technologies enables energy communities to participate in **peer-to-x markets** (see Section 4.1.3). These include peer-to-grid markets that connect smaller players as well as energy communities with the larger players (TSOs and DSOs) to trade flexibilities between them, for example. In these markets, local DSOs can procure ancillary services to resolve local grid bottlenecks and other problems such as voltage fluctuations. New flexibility market models in the form of market or aggregator platforms have been developed and tested in various European countries as part of pilot projects in recent years.

It is already possible to introduce and operate peer-to-peer platforms in Germany (and Europe) currently; however, there are still some regulatory and bureaucratic hurdles to commercial implementation (see Section 5.5). Section 80 of the EEG also limits the potential in Germany, as there is a legal risk of multiple sale when selling EEG-subsidised electricity via a regional energy platform. The legal framework also does not currently allow grid operators to incentivise grid-friendly behaviour through how the grid charges are set up. So far, the low financial added values have hardly been an incentive for consumers to want to participate on existing peer-to-peer platforms (see Fietze et al. 2021). However, these models may represent a new marketing option especially for post-EEG plants after the feed-in tariff expires. In future, however, peer-to-peer energy sharing communities could integrate local producers and consumers of the low-voltage grid into decentralised electricity and flexibility markets at the local or regional level and enable trade between them.

The core technologies for the fields in which energy communities can be utilised are **smart meters**, **platforms**, **data management systems**, **distributed ledger technologies** and **smart contracts**. When it comes to digital technologies, data is an important prerequisite for the application and implementation of operational business models (see Section 4.2). In future, data will be an important success factor in the establishment of energy communities, as data is a component and requirement of digitalisation. Future energy communities benefit from open-source data from comparable initiatives and existing energy communities as well as from open-source visualisation and modelling tools.

The communication units in **smart meters** provide the basis for the digitalisation of the electricity system, and are the point where physical electricity flows and economic transactions intersect. Smart meters are the foundation that enables energy communities to participate in local electricity and flexibility markets in real time. So far, the rollout in Germany in accordance with the respective mandatory rollout requirements has encompassed overwhelmingly modern metering equipment (without communication unit), not smart meters (with communication unit) (see Section 4.2.1). The Münster Higher Administrative Court suspended the rollout of smart meters in March 2021, delaying their market launch that was already off to a slow start.

Digital platforms (see Section 4.2.2) are used to bring together, combine and compare a variety of data from different sources in order to offer new products and services. Platforms are ideally suited for connecting decentralised energy generation plants with energy consumers (energy platforms). They enable transactions between producers and consumers who would have difficulty connecting to each other without this digital infrastructure (see Kloppenburg and Boekelo 2019). Platforms can provide the integrated technical basis for many basic processes in energy communities, such as user and master data management, the management of data access rights for different user roles, visualisations of energy data and customer relationship management.

Distributed ledger technologies (DLT), like blockchain, enable direct transactions of energy and monetary values between market participants, which can be traced and automatically verified. Because of this, the technology can help to facilitate peer-to-peer transactions, as it is able to process transactions involving very small amounts of energy using short time units, both logically and, above all, economically. DLT eliminates the need for central data storage (see Section 4.2.3) and can do without intermediaries such as exchanges and energy suppliers, which in turn leads to economic advantages. An additional component of DLT is smart contracts: programs stored within the DLT that handle automated processes, thus enabling a high degree of automation in business transactions. The potential importance of smart contracts increases with the number of transactions in the energy market. Combining DLT with smart meters provides a transparent, tamper-proof and decentralised way of documenting various electricity attributes on the basis of digital signatures. DLT is currently still in the development and pilot stage in the central application areas of guarantees of origin, peer-to-peer markets, energy sharing and distributed asset management. In order to facilitate more widespread application of such approaches, market communication must be adapted accordingly, real-time forecasts must be produced for decentralised players, local market mechanisms will be needed, the capacity for handling large volumes of data must be established and a digital asset identity register needs to be set up (for example, the Blockchain Machine Identity Ledger (BMIL) project).

The **survey conducted among energy communities** (see Section 6) shows that the use of digital technologies has improved activities and processes, but that it is also necessary to build up extensive knowledge and add staff at the same time. Available data and communication infrastructures were less of a problem than the available data quality from the point of view of the energy communities surveyed. The use of digital technologies motivates most energy communities to optimise their plant operation, expand communication and establish new business models and service offerings. The investment is considered worthwhile. The energy communities included in the survey stated that there were a number of clear obstacles to the success of this approach, primarily the lack of skilled workers, the regulatory framework conditions in the energy market, the bureaucratic workload required and obtaining the necessary investments.

The players confirmed the most important digitalisation topics in the activities of energy production, supply and distribution of energy communities. It is here where energy communities use digital technologies for internal company processes and in metering. Specifically, smart meters, platforms and remote control technologies are used. In addition, some energy communities are using or planning to use modelling tools, big data technologies, distributed ledger technology, digital twin technologies and digital tools for maintenance and repairs. The energy communities surveyed use the digital technologies for virtual power plants, for communication with customers or producers, for forecasts of production, consumption, grid and storage conditions and in some cases for trading even. The energy communities surveyed mostly use DLT for energy trading, billing and guarantees of origin. In addition to the core technologies mentioned above, some of the respondents use big data applications primarily for real-time data analysis and also for artificial intelligence or machine learning.

The analyses of conditions in the **Netherlands**, **Spain** and **Denmark** show that Germany can benefit from their experiences with implementation, especially with regard to the legal framework and market communication. The Netherlands’ postal code regulation makes possible the legal implementation of energy communities by creating the legal conditions for energy sharing. For years, Denmark has considered electricity and heat production to be common good, which is established by a non-profit rule. The regulations in Denmark on collective self-consumption correspond to the IEMD requirements and relate to buildings, like those of most EU countries. There has been draft legislation for citizen energy communities since 2021 that allows dynamic grid rates and no longer provides for supplier obligations for aggregators and citizen energy communities. The RED II definition was adopted in Spain; however, further legislative measures are needed to avoid conflicts of understanding around the definitions of market players (see Biresselioglu et al. 2021). Many EU countries have made progress in terms of the implementation of collective self-consumption at the building level as defined by the RED II. Compared to other countries, Germany does not yet have a concrete legislative proposal on energy sharing at either the building or the energy community level. The existing legal framework for citizen-led energy communities in Germany does not fully implement the requirements of the IEMD. For this to happen, a legal framework for producer-consumer communities must be created so the public grid can be used to jointly utilise the locally produced electricity (energy sharing). The landlord-to-tenant electricity model (Mieterstrommodell) that exists in Germany cannot be considered an implementation of the requirements, as tenants cannot supply themselves from their own plants without assuming full supplier obligations and no collective self-supply is possible for the tenants due to the requirement that the plant operator and self-supplier be the same person. This slows down expansion and market access.

Regulatory sandboxes can support regulators and policy makers in developing new concepts. For example, the Dutch government created a regulatory sandbox for innovative energy communities, where pilot projects can gather experience for a period of ten years using exemptions from the grid and the market. The concept is optimal for trying out regulations (see Bridge 2021). Based on these experiences, the Netherlands wants to set up a successor regulation that enables the participation of DSOs and energy suppliers in order to expand new business models for aggregators and flexibility markets, among other things (see Schittekatte et al. 2021). Germany has already created an experimental framework for pilot projects through its SINTEG regulation, which should be extended and could involve players such as energy communities, among others, to gain comparable practical experience as in the Netherlands. Regulatory changes in the area of peer-to-peer platforms create the conditions for smaller players to benefit from these concepts and also lay the foundation for flexibility market models to develop. There are already concepts for this but their implementation needs to be tested. Digital technologies allow energy communities to take on more system responsibility together with the DSOs in future. Digital platforms can be used to align consumption and production in real time using smart meters, assuming that the capabilities are adequate.

In addition to the technical infrastructure, energy communities must be given **economic incentives** that are geared towards grid system conditions and promote grid-friendly behaviour. To this end, flexibility market models are being developed as market platforms, such as enera and NODES in Germany, GOPACS in the Netherlands and IREMEL in Spain, among others, in order to actively integrate decentralised generation plants and their flexibility. It is not possible to transfer this to the German context due to the different starting situations. Rather, further investigations in the field need to be conducted on the impact of different market structures and mechanisms, liquidity, defined products and services, metering infrastructure requirements and coordination between transmission system operators, distribution system operators, producers and consumers (see Valarezo et al. 2021).

In future, the use of digital technologies will enable **business models that require a high degree of data exchange**, such as a peer-to-peer business model with continuous change of supplier relationships between producers and users. The various countries carry out the required data exchange between the market players differently. For example, it takes up to 14 days to change suppliers in Germany, whereas in the Netherlands it takes only 24 hours. Digital solutions for the technical optimisation of market communication are available in Germany, but these require the further development of specific process regulations and market design. Germany's data exchange is not yet carried out in a standardised way across the board. Further, it can take a few pointers from countries such as the Netherlands, Spain and Denmark, which have already established digital data platforms for the highly standardised handling of communication and data exchange. Denmark has advanced, highly automated and standardised market communication with a central data hub that has been freely accessible as an open-source project since 2021.

A central basis for this is **digital infrastructure** with broadband network access and the country's rollout of smart meters. Germany, whose broadband access is 35 per cent at a household level and has very few smart meters, still faces major tasks compared to the Netherlands, Spain and Denmark who have national rollout rates ranging from 89 per cent to 100 per cent.

7.1 Next steps for the further development of energy communities in Germany

The expanded definition of energy communities chosen in the study allows for the establishment of new partnerships and innovative cooperation between diverse players and the increased use of digital technologies. These digital technologies are both enablers and critical success factors for numerous business models in the energy communities. In this way, they create benefit for their members and society in general and contribute to the increased expansion of renewable energies. Overall, energy communities and digital technologies can thus play an important role in the increasingly decentralised energy system and develop a new dynamic.

Three success factors would support further development in this direction:

1. Changes to the legal framework
2. (Digital) infrastructure with the rollout of smart meters and management of data flows
3. Targeted research

Regulatory framework

- Legislation for energy communities in Germany needs to be improved at national level. The implementation deadlines of the IEMD and the RED II have expired. An alliance of associations and companies have filed a complaint with the European Commission for failure to implement the RED II and is calling for infringement proceedings against Germany. Therefore, swift action is called for.
- Collective self-consumption should be made possible by removing the requirement that a self-supplier be both the operator and end consumer set out in Section 3, item 19 of the Renewable Energy Sources Act (EEG) and in the landlord-to-tenant electricity model (Sect. 21 of the EEG). German law includes a definition of citizen-led energy communities in the EEG, but so far, they have only been able to produce renewable energy collectively, but not use it jointly. Germany needs to create the legal conditions for joint use also.
- Germany must provide incentives for local energy trading and energy sharing in order to enable (on a regional level) the use of the public grid to share the locally produced electricity. To this end, grid-friendly incentive structures through the establishment of (dynamic) grid charges should also be examined.
- Supplier obligations (according to Sect. 41 of the EnWG) in Germany must be adapted to improve the conditions for peer-to-peer business models. Possible changes should increase the speed at which consumers can switch suppliers, for example. Currently, consumers need to notify the grid operator that they want to change suppliers at least seven/ten working days before the actual start of supply, and prosumers are obliged to issue a final invoice no later than six weeks after the end of the supply relationship.
- Distributed ledger technologies and smart contracts offer the possibility to automate small-scale processes such as peer-to-peer energy trading and thus to make the integration of small players such as prosumers into the market economically viable. At the moment, the market processes are still complex and in turn time- and cost-intensive. Smart contracts promise advantages in terms of transaction costs as well as speed and quality of processes. However, compatibility with the applicable legal framework must be ensured for widespread use. There is currently a lack of regulation and legal concepts in connection with smart contracts. For example, there are still questions to be clarified regarding liability and responsibilities or the applicability of general terms and conditions.

(Digital) infrastructure

- The planned rollout of smart meters should be implemented quickly in Germany, as (real-time) data is a prerequisite for many business activities of energy communities. Other EU countries have already started a large-scale rollout or are already fully equipped with smart meters.
- Adaptation of market communication and data provision: Market participants could automatically request data from other market players in a transparent and standardised manner using data hubs, either decentrally or, if necessary, also centrally, and exchange messages.
- There have been discussions on conducting a survey of smaller, decentralised flexibility potential for some time now. These flexibilities can help adapt electricity consumption to the supply of renewable energy at short notice, for example. As an alternative, they can also be used in a grid-friendly manner, in order to be available to a grid operator as an instrument for bottleneck management. For this purpose, grid operators need precise information about local grid conditions, which are usually not available in high granularity in the lower voltage levels. A mandatory prerequisite for the provision and use of flexibility is a digital upgrade of the infrastructure in the grid and at the connection user.

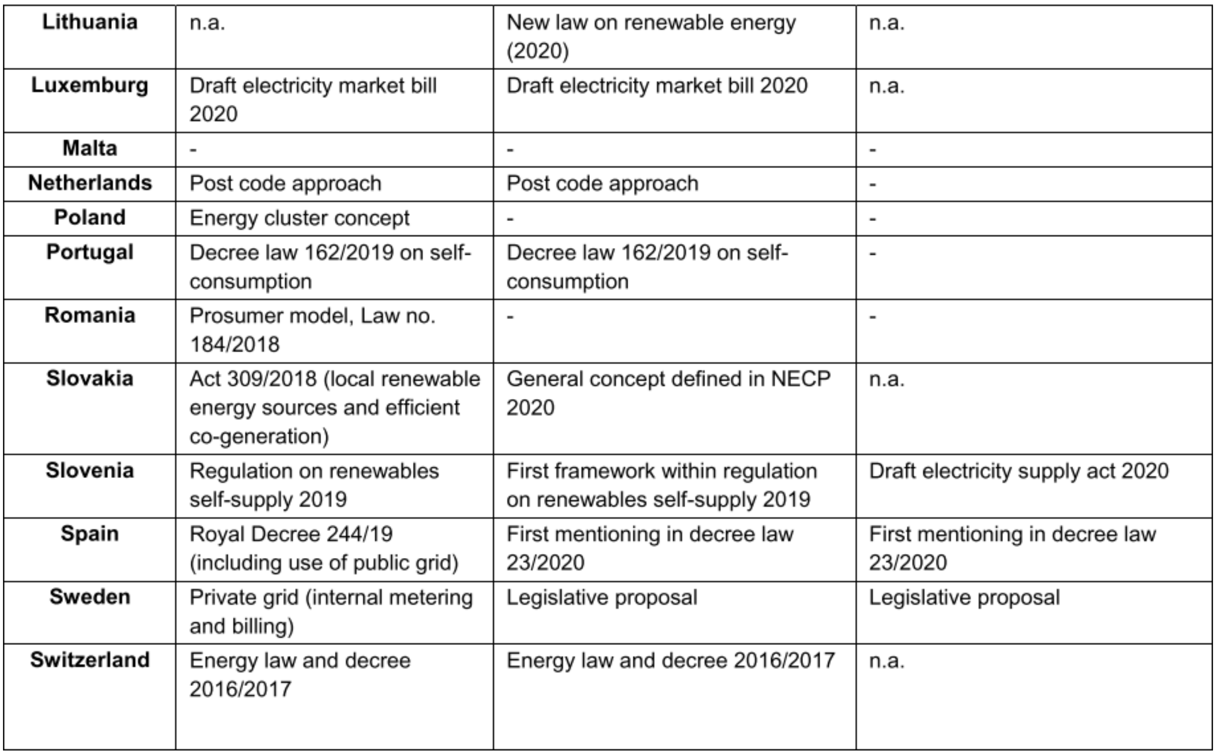
Where research is needed

- Requirements for and efficiency of new local peer-to-peer markets should be explored in more depth, taking into account aspects such as liquidity, distortion of competition, geographical expansion and efficient reduction of network bottlenecks. Pilot projects can show how local markets work.
- The situation should be evaluated continuously when further developing energy communities in how they integrate into their respective national energy markets, and what challenges and advantages arise for the energy system as a result. To this end, sandboxes for business models in which the use of digital technologies for energy communities and their different implications for the regulatory framework can be analysed should also be developed. By opening up the experimentation clause, peer-to-peer solutions can be tested without biases, for example, as has already been done successfully in the SINTEG projects.
- Questions related to the use of data to generate added value need to be further addressed. On the one hand, with regard to actual data requirements (data types, quality, temporal and plant-specific granularity, degree of aggregation, etc.) for various market players, in order to ensure the greatest possible optimisation potential for the overall system. On the other hand, with regard to the acceptance of customers towards the disclosure of their own data if they benefit from added value.
- It remains to be observed which changes in incentives arise for the players and which effects unfold through the new proportional composition of the electricity price with regard to the economic viability of various business models in view of the planned abolition of the EEG surcharge.

8 Appendix

Overview of national legislation on collective self-consumption and energy communities in selected EU Member States

Country	Collective self-consumption	Renewable energy communities	Citizen energy communities
Austria	EIWOG 2017 (electricity act)	Draft Renewables Expansion Law (EAG) presumably to enter into force beginning 2021	Draft CEC definition published as amendment of the electricity act (EIWOG)
Belgium: Wallonia	Decrees 2018, 2019	Framework legislation; decree 2019	-
Belgium: Flanders	Draft legislation, adoption of legislative framework foreseen in December 2020	Draft legislation, adoption of legislative framework foreseen in December 2020	Draft legislation, adoption of legislative framework foreseen in December 2020
Belgium: Brussels Capital Region	2018 definition	Currently exceptions, framework foreseen for early 2021	Currently exceptions, framework foreseen for early 2021
Bulgaria	Self-consumption framework	-	-
Croatia	Closed distribution grid by industrial and commercial prosumers	-	-
Cyprus	-	-	-
Czech Republic	n.a.	Draft energy act (general definition covering RECs and CECs)	Draft energy act (general definition covering RECs and CECs)
Denmark	Private grid (internal metering and billing)	n.a.	Proposed amendment of Electricity Supply Act
Estonia	Electricity Market Act	Draft legislation	Draft legislation
Finland	Private grid (industrial or real estate)	General proposals, study commissioned	General proposals, study commissioned
France	Law 2017-227, decree 2017-676	Draft legislation	Draft legislation
Germany	Tenant power model 2017	-	-
Greece	2016 law on virtual net metering	Law N4513/2018 on energy communities	Law N4513/2018 on energy communities
Hungary	Support for pilot projects	Priorities stated in NECP /Support for pilot projects	Priorities stated in NECP
Ireland	-	Renewable Electricity Support Scheme including a REC definition	-
Italy	Law N8/2020, Consultation document by Energy Authority	law N8/2020 (general framework), Consultation document by Energy Authority on detailed provisions	law N8/2020 (general framework), Consultation document by Energy Authority on detailed provisions
Latvia	-	-	-



Lithuania	n.a.	New law on renewable energy (2020)	n.a.
Luxemburg	Draft electricity market bill 2020	Draft electricity market bill 2020	n.a.
Malta	-	-	-
Netherlands	Post code approach	Post code approach	-
Poland	Energy cluster concept	-	-
Portugal	Decree law 162/2019 on self-consumption	Decree law 162/2019 on self-consumption	-
Romania	Prosumer model, Law no. 184/2018	-	-
Slovakia	Act 309/2018 (local renewable energy sources and efficient co-generation)	General concept defined in NECP 2020	n.a.
Slovenia	Regulation on renewables self-supply 2019	First framework within regulation on renewables self-supply 2019	Draft electricity supply act 2020
Spain	Royal Decree 244/19 (including use of public grid)	First mentioning in decree law 23/2020	First mentioning in decree law 23/2020
Sweden	Private grid (internal metering and billing)	Legislative proposal	Legislative proposal
Switzerland	Energy law and decree 2016/2017	Energy law and decree 2016/2017	n.a.

Table 2: **Overview of national legislation on collective self-consumption and energy communities in selected EU Member States (from Frieden et al. 2020), (n.a.: information not available, NECP = National Energy and Climate Plan)**

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Abbreviations

AI	Artificial Intelligence
A. m. b. A	Limited liability company (*Andelsselskaber med begrænset ansvar* in Danish)
BMIL	Blockchain Machine Identity Ledger (a dena project)
BMWi	Federal Ministry for Economic Affairs and Energy (since Dec. 2021, Federal Ministry of Economics and Climate Protection (BMWK))
BNetzA	Federal Network Agency
BSI	German Office for Information Security
CEC	Citizen energy community
CEP	Clean Energy Package
CHP	Combined Heat and Power
CLS	Controllable Local Systems
CNMC	National Commission for Markets and Competition (*Comisión Nacional de los Mercados y la Competencia* in Spanish)
CO_2	Carbon dioxide
CSC	Collective self-consumption (CSC)
DLT	Distributed ledger technologies
DSO	Distribution system operator
EDSEP	Experiments in Decentralised Sustainable Electricity Production, regulatory innovation framework in the Netherlands
EDSN	Energie Data Services Nederland
EEG	Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz* in German)
EEX	European Energy Exchange
EnWG	Energy Industry Act (*Energiewirtschaftsgesetz*) in Germany
ESCO	Energy service company
ETPA	Energy Trading Platform Amsterdam
EU	European Union
FLECH	Flexibility clearing house
GW, MW, kW	Gigawatt, megawatt, kilowatt
HEMS	Home energy management system
ICT	Information and communications technology

IEMD	Internal Electricity Market Directive
IoT	Internet of Things
I/S	General partnership (*Interessentskab* in Danish)
i. S. d.	[not used in English]
IT	Information
iMSys	[not used in English]
kWh	Kilowatt hour
kWp	Kilowatt peak (for power measurement of PV systems)
MaStR	Market master data registry
mME	[not used in English]
OVG	Higher Administrative Court (*Oberverwaltungsgericht* in German)
P2P	Peer-to-peer energy sharing, or peer-to-peer energy trading
PoS	Proof of stake
PoW	Proof of work
PPA	Power purchase agreement
PSO	Public service obligation
PV	Photovoltaics
REC	Renewable energy community
RED II	Directive on the promotion of the use of energy from renewable sources
RES	Renewable Energy Resources
SDE	Subsidies for renewable energies in the Netherlands (*Stimulering Duurzame Energieproductie* in Dutch)
SME	Small and Medium Enterprises
SMGW	Smart meter gateway
UBA	Federal Environment Agency (*Umweltbundesamt* in German)
TSO	Transmission system operator

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