PROSEU

Prosumers for the Energy Union: mainstreaming active participation of citizens in the energy transition

Key technical findings and recommendations for prosumer communities

(Deliverable N°5.3)

Horizon 2020 (H2020-LCE-2017)

Grant Agreement N°764056

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°764056. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

Lead partner for deliverable	Institute for Ecological Economy Research (IÖW)
Document type	Report
Due date of deliverable	31.08.2020
Actual submission date	31.08.2020
Dissemination level	Public (PU)
Author(s)	Swantje Gährs, Lena Pfeifer, Nanda Naber, Borna Doračić, Jan Knoefel, Arthur Hinsch, Silvia Assalini, Reinier van der Veen, Davor Ljubas, Zoran Lulić
Reviewer(s)	Kristian Petrick (Eco Union)

Cite as: Gährs, S., Pfeifer, L., Naber, N., Doračić, B., Knoefel, J., Hinsch, A., Assalini, S., van der Veen, R., Ljubas, D., Lulić, Z. (2020). Key technical findings and recommendations for prosumer communities. PROSEU - Prosumers for the Energy Union: Mainstreaming active participation of citizens in the energy transition (Deliverable N°5.3).

Summary of PROSEU

PROSEU aims to enable the mainstreaming of the renewable energy Prosumer phenomenon into the European Energy Union. Prosumers are active energy users who both consume and produce energy from renewable sources (RES). The growth of RES Prosumerism all over Europe challenges current energy market structures and institutions. PROSEU's research focuses on collectives of RES Prosumers and will investigate new business models, market regulations, infrastructural integration, technology scenarios and energy policies across Europe. The team will work together with RES Prosumer Initiatives (Living Labs), policymakers and other stakeholders from nine countries, following a quasi-experimental approach to learn how RES Prosumer communities, start-ups and businesses are dealing with their own challenges, and to determine what incentive structures will enable the mainstreaming of RES Prosumerism, while safeguarding citizen participation, inclusiveness and transparency. Moving beyond a case by case and fragmented body of research on RE Prosumers, PROSEU will build an integrated knowledge framework for a socio-political, socioeconomic, business and financial, technological, socio-technical and socio-cultural understanding of RES Prosumerism and coalesce in a comprehensive identification and assessment of incentive structures to enable the process of mainstreaming RES Prosumers in the context of the energy transition.

Summary of PROSEU's Objectives

Eight key objectives at the foundation of the project's vision and work plan:

- **Objective 1:** Document and analyse the current state of the art with respect to (150-200) RES Prosumer initiatives in Europe.
- **Objective 2:** Identify and analyse the regulatory frameworks and policy instruments relevant for RES Prosumer initiatives in nine participating Member States.
- **Objective 3:** Identify innovative financing schemes throughout the nine participating Member States and the barriers and opportunities for RE Prosumer business models.
- **Objective 4:** Develop scenarios for 2030 and 2050 based on in-depth analysis of technological solutions for RES Prosumers under different geographical, climatic and socio-political conditions.
- **Objective 5:** Discuss the research findings with 30 relevant stakeholders in a Participatory Integrated Assessment and produce a roadmap (until 2030 and 2050) for mainstreaming RE Prosumerism.
- **Objective 6:** Synthesise the lessons learned through experimentation and co-learning within and across Living Labs.
- **Objective 7:** Develop new methodological tools and draw lessons on how the PROSEU methodology, aimed at co-creation and learning, can itself serve as an experiment with institutional innovation.
- **Objective 8:** Create an RES Prosumer Community of Interest.

PROSEU Consortium Partners

Logo	Organisation	Type	Country
	FCIENCIAS.ID	Private non-profit association	Portugal
	UPORTO	University	Portugal
	ICLEI EURO	Small and medium-sized enterprise	Germany
	CLIENTEARTH	Non-governmental organisation	United Kingdom
	UNIVLEEDS	University	United Kingdom
	DRIFT	University	the Netherlands
	UNIZAG FSB	University	Croatia
	LEUPHANA	University	Germany
	ECO-UNION	Non-governmental organisation	Spain
	IÖW	Private non-profit limited company	Germany
	CE Delft	Small and medium-sized enterprise	the Netherlands

Table of contents

List of tables

List of Figures

Executive summary

This report on key technical findings and recommendations for prosumer communities is based on technical simulations of different types of individual prosumers and prosumer communities. The overall results of these simulations are shown in a separate report (Doračić et al. 2020) which concluded that there is a **high potential for renewable energy prosumers** in Europe. For example, the share of generated electricity provided by prosumer technologies can be up to 89% in 2050 for the residential sector. Drawn from the results of the technical simulations this report presents four **key conclusions for prosumer communities**:

- **Extending from individual prosuming to energy communities**: Sharing energy in a community instead of producing the energy for just one household helps to consume more energy decentrally.
- **Choosing a suitable technology for prosuming**: Choosing the most suitable technology for prosumers depends on a lot of parameters, e.g. climate conditions, regulatory conditions or energy demand. This should be analysed in each situation before making a decision.
- **Increasing self-sufficiency mindfully**: Prosumers can achieve high shares of self-sufficiency in heating and electricity. However, this should be done mindfully since reaching higher shares of renewable self-sufficiency comes with the need of an exponentially higher need of storage capacities and is not always ideal for the energy system overall.
- **Using the most efficient way to store the energy**: Whether short or long term storage is reasonable for a prosumer depends on the renewable energy technology used to produce energy, the energy demand in the community and the conditions in the energy grid.

A closer look on prosumer technologies shows, that all suitable technologies have their advantages and disadvantages depending on the situation and conditions where the prosumer community is based. Solar energy is one of the most common technologies, especially because it can be used to produce electricity through photovoltaics as well as heat through solar thermal. However, suitable rooftops or bare land and solar irradiation must be available for implementation. Wind energy can be an efficient way to produce renewable energies, but taking the size of turbines and the required distance from buildings into account, it is only suitable for energy communities. For heating and cooling production, heat pumps are on the rise as a very efficient prosumer technology. More established technologies are boilers or combined heat and power plants that use biomass. The technologies can also be combined with thermal or battery storage on a small or large scale to raise the self-sufficiency.

The report also provides some **recommendations on mainstreaming prosumer technologies** and the changes that facilitate the prosumer concept. The key recommendations here are:

- **Enable balanced involvement of all actors and increase local acceptance**: A mainstreaming of prosumers requires a more in-depth relation between prosumers, municipal actors and market actors. This can be reached by education, facilitation and suitable business models. In addition, local communities should benefit from prosumerism in order to achieve a high level of acceptance.
- **Digitalize the energy system**: The decentralised approach of prosumers needs a more digitalized energy system in order to simplify processes but also for feedback mechanisms.
- **Increase energy efficiency and create space for innovations**: Apart from producing their own renewable energy, energy efficiency of buildings and technologies is a key element to promote active consumers.
- **Simplify system integration of prosumers**: For a spread of the prosumer idea, market barriers and technical barriers for grid integration must be overcome by simplifying and clarifying requirements and conditions.

1. Introduction

This document presents conclusions and recommendations based on the technical findings of the project PROSEU to assist prosumers to choose their suitable renewable prosumer technology depending on their need, demands, size and location. Further, it offers recommendation that can support the implementation and main-streaming of prosumer technologies. Beside this, it also gives an overview of the key prosumer technologies and their technical, economical, ecological and social parameters as well as giving some best practice examples.

To set a basis for the following recommendations, a common definition of prosumers was set in the project: a **prosumer** produces energy for his/her own use (producer + consumer), whether collectively or individually. There are many definitions of prosumers, also mentioned under other names (e.g. active customer, renewable self-consumer). Within PROSEU a "RES[1] prosumer initiative (…) is a collective energy actor that produces energy from renewable sources with the primary objective of providing its own energy needs and/or those of its members, and in some cases selling excess energy to clients, thereby actively participating in the energy markets" (Horstink et al. 2019, 24). The technical simulations of PROSEU presented in report D5.2 (Doračić et al. 2020) assumed prosumers, where production of renewable energy happened on site of the building, neighbourhood or city and therefore technologies like large onshore wind parks and offshore wind parks were excluded on building, neighbourhood and city level calculations. However, the modelling on member state level looked at a larger area that can be used to generate electricity for prosumers since apart from using their own rooftop for solar, prosumers can also be part of a collective that invests in large wind turbines and solar parks that are placed within a buffer of 5 km around the area in which the prosumer lives.

The research of the PROSEU project shows that in most modelled cases, prosumers can produce more energy than they need and feed surplus to the grid. The results are based on the modelling of prosumers on different levels (individuals, neighborhoods, cities, countries, EU). To reach the results three different models for the different levels were used. A tool at UNIZAG FSB using an optimization approach and two simulation models at CE Delft and IÖW. As the CE Delft Prosumer Model and IÖW Energy Prosumer Model are simulation models, they do not optimize. Hence, on an individual level not every possible combination of technologies was simulated but only those that seemed most promising. Nevertheless, it is possible that there are even more favourable combinations of technologies.

In this report we present the key technical conclusions based on the results of the modelling for prosumer technologies in chapter 2. In chapter 3 there is a closer look on the most important prosumer technologies, including relevant technical and economical parameters. In order to get information on how the technical potential can be raised, various ideas were discussed in a workshop with participants from science, prosumer communities and regulatory affairs, which have been incorporated into this report. The last chapter states this overall recommendations on how the system should change in order to mainstream prosumer technologies.

[1] Renewable energy systems

2. Key technical conclusions for prosumer communities

One main finding from the technical simulation is, that there is a **high technical potential for prosumer technologies** in all EU member states (for all results see Doračić et al. 2020). This was shown on different levels (individual, neighbourhood, city) as well as for the EU member states[2] and the EU as a whole. In the member states the energy that can be provided varies depending on the available space, climate conditions and demands. Without taking storage into account, in some countries an overall self-sufficiency in 2050 of 50% of electricity demand in residential buildings can be reached (Estonia). When battery storage capacities are added, the numbers vary between 50% (Malta) and 95% (Estonia and Lithuania). For heating and cooling the share of self-sufficiency through RE prosumer technologies of residential buildings in 2050 resulted between 25% (UK and Malta) and 70% (Slovenia and Romania). Adding larger thermal storage increases the self-sufficiency from 35% (UK and Malta) to 85% (Slovenia and Romania).

Adding up the results for all the member states on EU level shows that prosumers can contribute a very high share to the generated energy in 2050 (see Figure 1). In the residential sector, 98% of the electricity can be generated by prosumer technologies and the heating and cooling needs can be covered by prosumer technologies completely.

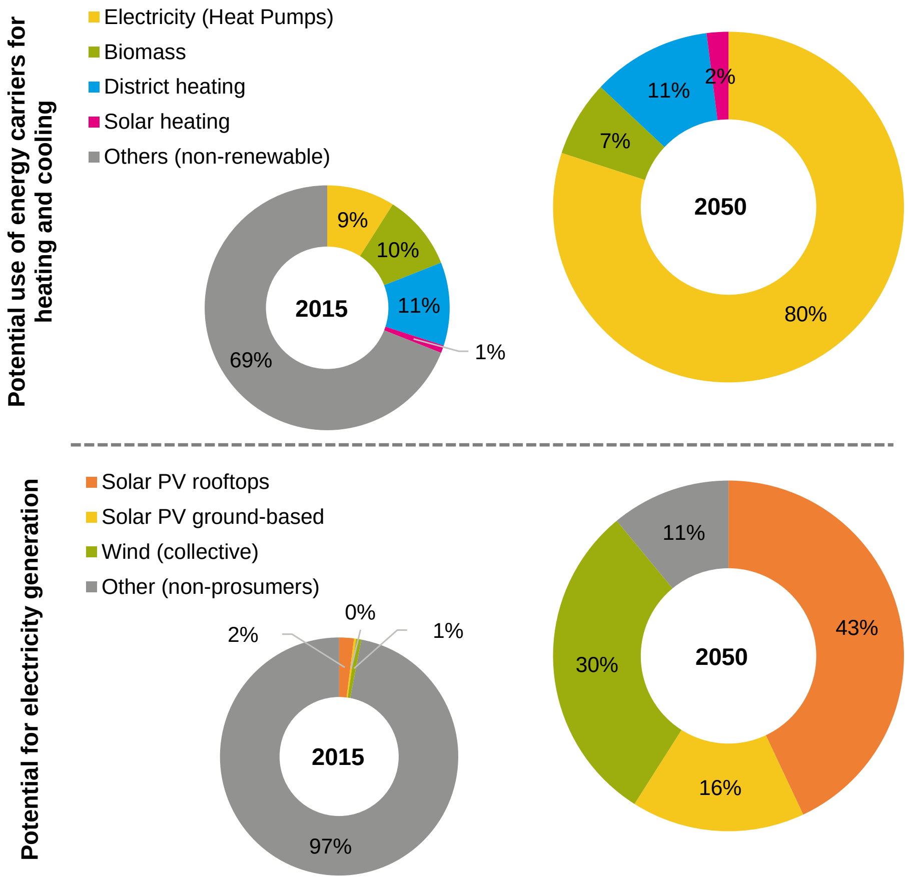

Figure 1: Share of energy sources used for generation of electricity or heating and cooling in 2050; Source: Doračić et al. (2020)

If this potential can be exploited by 2050 strongly depends on the regulations and financial support. Regulations which facilitate electricity sharing and help energy communities to benefit from prosumer technologies can lift

[2] Including the UK, since it was still a member state of the EU at the beginning of PROSEU

the prosumer potential. Investments of prosumer technologies are generally high for citizens and mostly have a payback time of 5 to 15 years, or even more. Subsidy or loans that are made available by the local or national government could support prosumers to invest in prosumer technologies. Varying social and ecological constraints and benefits, and levels of energy efficiency play a role in determining which technology is suited in which situation or location.

Since energy prices and policies are different in each member state of the EU so are the constraints. The price a prosumer gets for the generated energy fed into the grid depends highly on the policies in place. While in some countries, a prosumer feeds electricity into the grid without remuneration but only pays for the net electricity that has been taken from the grid throughout the year (e.g. the Netherlands, Spain and Belgium), in other member states a Feed-in-Tariff (e.g. Germany or UK) or a market price system (e.g. Croatia or Italy) is in place (cf. Toporek and Campos 2019). These factors have a high influence on the economic return of the electricity that can be generated, but also determines if it is profitable to use battery storage for the self-generated electricity. To acknowledge the interdependencies the following technical recommendations will touch on some regulatory and economic influences, however not make them a research object but refer to findings of previous reports of PROSEU on prosumer policy options (cf. Petrick et al. 2019) and prosumer business models (cf. Brown et al. 2020).

2.1 Extending from individual prosuming to energy communities

Sharing electricity in a community can flatten load curves and increase self-consumption, hence energy communities are a favourable group of potential prosumers. Communities should explore options for installing prosumer technologies and schemes for operation. The PROSEU research shows that it is hard to achieve complete renewable self-sufficiency on an individual level, for example due to the lack of roof space (when no collective options used) and the imbalance of supply and demand.

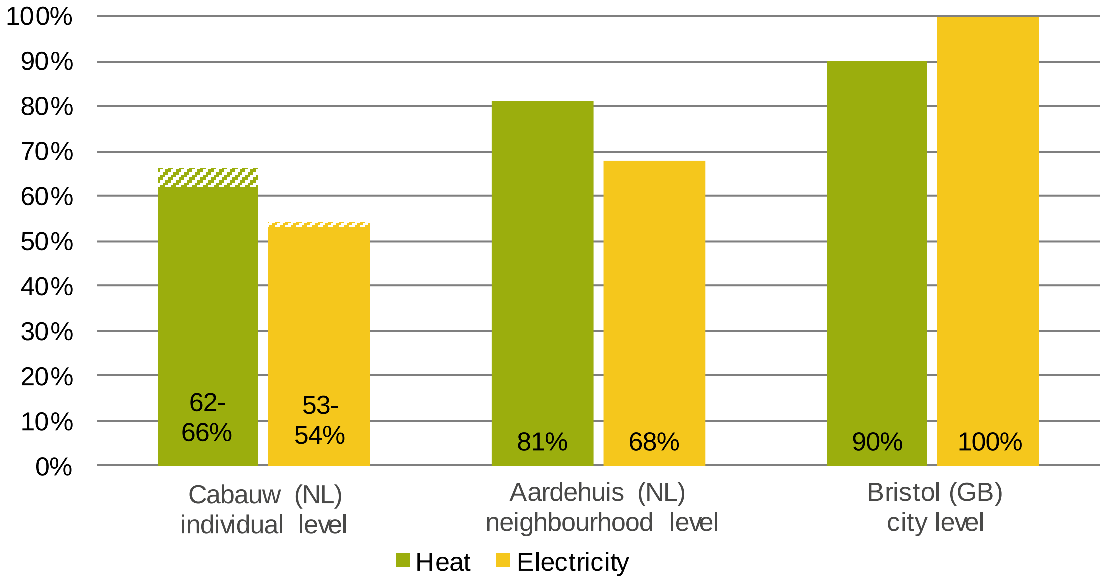

Figure 2: Modelled degrees of self-sufficiency in 2050 for location in oceanic climate zones of Northern Europe on individual, neighbourhood and city level; Source: Doračić et al. (2020)

The highest levels of self-sufficiency achieved on an individual level in the modelled scenarios were 86% for the heating and 75% for the electricity sector for a household in semi-arid climate where heating was covered with heat pumps and electricity demand with PV. However, when the prosumers are grouped in a community, higher shares of self-sufficiency can be reached. For example, for oceanic climate in the Netherlands the degree of self-sufficiency in heating and electricity increased by 15 percentage points when looking at the neighbourhood level compared to the individual level assuming the same technologies covering the energy demand (heat pumps, solar thermal and PV). On a city level, the degree of self-sufficiency was even higher in oceanic climate with 90% in heating sector and 100% in electricity sector for the city of Bristol. However, on a city level other technologies (e.g. cogeneration with biomass and wind) helped to reach higher shares of energy demand (see Figure 2). In other climate regions, similar results could be observed whereby the increase of self-sufficiency from one level to the next can vary with changing circumstances of the specific location. To reach 100% self-sufficiency both in heating and electricity, even higher storage capacities than assumed in the calculations have to be installed.

2.2 Choosing a suitable technology for prosuming

Next to economic and regulatory aspects, other factors, such as **climate conditions and energy demand**, determine which technologies are most suitable in what situation. This depends mainly on the following factors:

- amount of solar irradiation,
- amount of wind power density,
- availability of bare land to use for energy generation,
- degree of urbanisation and geographical distribution,
- biomass availability,
- energy demand and
- type of building.

In most member states of the EU, solar PV has the highest potential for prosumers to generate their own electricity. For the purpose of energy transition, the full potential of roof top area should be used. Wind technology has not shown to be a viable option in cities and neighbourhoods due to lower wind speeds in cities and space restrictions. Small wind turbines are also a lot less efficient than larger turbines. Wind technology becomes an important player only when prosumers form collectives that invest in large wind turbines. By definition, large wind turbines are only seen as prosumer option in case the turbines are placed in 5 km distance around populated areas.

Heat pumps have been proven as an efficient technology for reducing the environmental impact of the heating sector, but can in many countries not provide full self-sufficiency, mostly due to the imbalance of generation of solar energy in summer and need for heating in winter. However, integrating heat pumps with thermal storage technologies can increase the level of self-sufficiency. In both cases, a significant reduction of CO_2-emissions can be reached. The disadvantage of using solar thermal is that it decreases the available area for PV-panels, needed to generate enough electricity for the heat pump. However, it decreases the amount of electricity needed for the heat pump in winter, because of the stored heat. A solution could be to combine solar thermal with solar PV on rooftops and solar PV from solar parks. If households do not have enough rooftop area themselves to cover all energy demand, they could form a collective and invest in a solar park or wind turbine that is located close to their house. Although the energy is not generated on their own property, it could still be seen as a prosumer technology.

Technologies that use biomass, such a biomass boilers or CHP (combined heat and power) can also be used as prosumer options to generate heat and/or electricity, but only if the prosumers grow their own biomass. Because of this restriction, the potential of biomass technologies is rather low and depends highly on the biomass availability.

Table 1: Technical potential of prosmumer technologies; Sources:(Doračić et al. 2020; Novosel et al. 2018)

Technical potential in the EU of relevant prosumer technologies				
		2015	**2030**	**2050**
Solar (Monocrystalline PV)	Produced electricity	35 TWh	487 TWh	1090 TWh
	Efficiency	16.5-23.5%	19.8-25%	up to 25-30%
	Lifetime	20-30 years	25-40 years	30-40 years
Wind (Large Onshore)	Produced electricity	31 TWh	262 TWh	572 TWh
	Efficiency	40-50%	50%	50%
	Lifetime	20 years	25 years	25 years
Heat Pumps (Air to Water 4-10 kW)	Produced heat	278 TWh	1156 TWh	2284 TWh
	Efficiency (COP[3])	300-400	340-430	355-450
	Lifetime	18 years	18 years	18 years
Solar thermal (Thermosiphon system)	Produced heat[4]	37 TWh	39 TWh	40 TWh
	Efficiency	40%	45%	50%
	Lifetime	20 years	30 years	30 years
Battery Storage (Lithium-ion)	Efficiency	85-95%	94-97%	94-97%
	Lifetime	5-20 years	8-31 years	n.a.

2.3 Increasing self-sufficiency mindfully

If prosumer communities desire to consume a high share of their self-produced renewable energies, they can either use energy storage or vary their consumption patterns. A high share of self-sufficiency rate in itself may not be the primary goal, at least not on individual or even neighborhood level, for example due to disproportionately high costs or high costs for the energy system in general. This is rather to show technical feasibility. Nevertheless, the degree of self-sufficiency that can be reached highly depends on the energy demand throughout the year and the used technologies to generate energy in combination with the local climate conditions.

In countries with high demand for cooling, a high percentage of self-sufficiency can be reached when solar technologies are applied. In countries with a high demand for heating, which is for a large part needed during wintertime, wind energy and cogeneration technologies, which use renewable fuels, is more suited when a high percentage of self-sufficiency is pursued. If wind energy is possible as a prosumer technology, it depends on the local power density of wind, space availability and policies concerning the installation and exploitation of wind turbines.

The research of the PROSEU project shows that higher aggregation of prosumer communities increase self-sufficiency. For example, for oceanic climate the share of self-sufficiency increased from individual to neighbourhood level and even more on city level. Moreover, in most modelled cases, prosumers can achieve rather high renewable self-sufficiency, up to 100% in some cases, for both heat and the electricity. These figures correlate with the

[3] The coefficient of performance (COP) of a heat pump is the ratio of provided heating or cooling to work required.

[4] The technical potential of solar heat depends on the available roof top area. This area is limited by the amount of rooftop that is used for solar-PV. In the EU-model, solar PV is in most cases prefered over solar heat.

emission reductions and significantly depend on the technology in use and the storage capacity deployed. For example, when heat pumps were combined with solar thermal and PV in central Europe, it was not possible to achieve a high self-sufficiency rate for electricity due to a high increase of electricity consumption, if only solar PV on rooftops is used as prosumer technology to produce electricity.

Nonetheless, self-sufficiency in the heating sector was in most cases higher than 50%, as was the case in the electricity sector, when technologies other than heat pumps were used for heat production, such as cogeneration, solar thermal and electric boilers. The connection to the grid still has to be maintained since complete self-sufficiency on both electricity and heat side was not achieved in any case[5]. The assumptions made in order to model the cases are elaborated in Chapter 5 of report D5.2 (Doračić et al. 2020).

Table 2: Degrees of self-sufficiency and suitable technologies for prosumers of Northern and Southern Europe[6]; Source: Doračić et al. (2020)

	Oceanic- / Continental Climate	Mediterranean-/ Semi-arid Climate
Possible degree of self-sufficiency	Due to high heating demand in winter complete self-sufficiency in heating sector is hard to achieve. 100% self-sufficiency of electricity sector is possible with a combination of technologies. **Aardehuis neighbourhood** • 81% for heating • 68% for electricity **City of Bristol** • 90% for heating • 100% for electricity	100% self-sufficiency in electricity and heating sector possible in certain cities by PV and solar thermal on roofs (no ground-based solar needed), in case of favourable conditions. **A household in Carpentras** • 81% for heating • 70% for electricity **City of Girona** • 100% for heating • 76% for electricity (with larger battery capacity 100% is possible)
Technologies	**Aardehuis neighbourhood** • Heat pump, solar thermal, electric boiler, thermal storage for heating • PV and battery storage for electricity **City of Bristol** • Cogeneration, solar thermal and seasonal thermal storage for heating • Cogeneration, micro wind turbines, PV and battery storage for electricity	**A household in Carpentras** • Heat pump, solar thermal, electric boiler, thermal storage for heating • PV and battery storage for electricity **City of Girona** • Solar thermal and seasonal thermal storage for heating • PV and battery storage for electricity

2.4 Using the most efficient way to store the energy

The inclusion of energy storage can increase the level of self-sufficiency in the electricity and heating sector considerably and could be applied when self-sufficiency is a key motivation for prosumerism (see Figure 3). Short-term storages are yearlong applied to decouple production from consumption for a few hours and are used both

[5] Theoretically in a 100% self-sufficiency case, the prosumer(s) could disconnect but this is neither the aim nor recommended (cf. Petrick et al. 2019).

[6] A refurbishment rate has been taken into account, ranging from 0.5% to 1% depending on the case (see Doračić et al. 2020).

in the electricity as well as the heating sector. In addition, seasonal storages are used in the heating sector to shift excessive solar energy produced in the summer to heating intensive winter months.

The implementation of short-term storages could lower demand from the grid in all observed use cases considerable. In the electricity sector batteries were used to store excess electricity from parts of the day where production exceeded consumption. Nevertheless, the observed use cases showed that only in the future with expected lower battery and higher electricity costs, battery storage become economically attractive. Moreover, the environmental and social impact due to the need of scarce resources from political unstable regions to build batteries add to the argument that, if viable, first of all the demand should be as much as possible adjusted to the production when self-sufficiency is desired. For example, smart technologies or controlled loading of electric vehicles when individual mobility is needed could help to synchronize demand and production. In the heating sector heat pumps can be installed to use self-produced electricity and buffer tanks can store heat produced through solar-thermal or CHP units during the day for the night.

Moreover, PROSEU research showed that the impact of storage technologies depends also on the level of aggregation. When looking at similar circumstances like for example an individual household in Cabauw and a neighbourhood in Aardehuis it was shown that one larger battery could increase self-sufficiency to a larger extend than several individual home-storages. Contrary batteries on an even larger scale in the city of Bristol did not increase self-sufficiency by a lot because even without batteries, already high shares of self-sufficiency could be reached due to cogeneration capacities with biomass (see Figure 3).

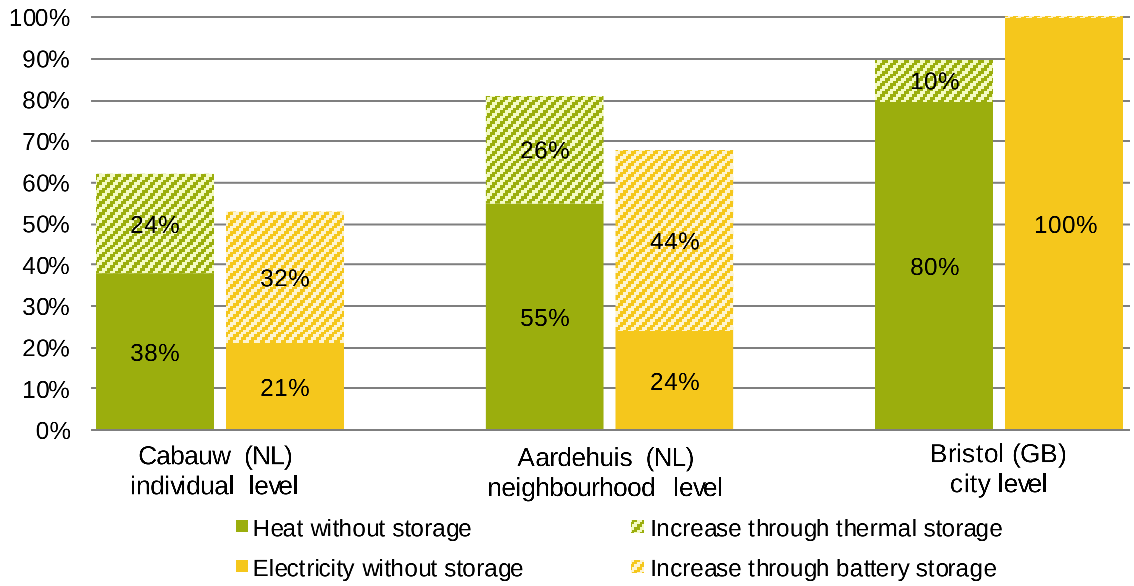

Figure 3: Modelled degrees of self-sufficeny in 2050 with and without storage; Source: Doračić et al. (2020)

Full self-sufficiency is hard to reach and needs many resources. Only the implementation of seasonal storages could provide complete self-sufficiency in some use cases. In Southern Europe, complete renewable self-sufficiency of the heating sector was possible for certain cities by utilizing solar thermal in combination with larger underground thermal storage systems. However, a more optimal solution for areas with high cooling demands would be heat pumps, which could be used for both heating and cooling depending on the need, as was shown in the simulations done for the whole EU. This has especially high potential when PV supplies electricity for the heat pumps.

3. A closer look on prosumer technologies

3.1 Solar energy

Solar technologies are the most important prosumer technology. Solar collectors convert sunlight in form of radiation into energy. They can be based on rooftops or on the ground. While solar collectors based on the ground are cheaper to install, roof top PV conflicts less with other uses of needed space and can also be implemented by prosumers without large areas of available land. The two predominant solar technologies for prosumers are:

- **Photovoltaic (PV):** Converts solar energy into electricity. Costs for producing electricity became cost competitive in recent years and hence, PV is not only for prosumers but also for energy suppliers an important technology. Prosumers can feed excess electricity into the grid that cannot be self-consumed directly or stored for later use.
- **Solar thermal:** Is primarily used to cover hot water demand, as heating is less needed at times when there is sunlight and solar energy can be produced. However, can also be coupled with thermal energy storage for covering heating demand.

Table 3: Fact sheet solar energy

Initial conditions	• PV panels: ~7 m² per kWp roof top area or on the ground. (Corradini et al. 2012) • Solar thermal: In Northern Europe approx. 1-1.5 m² of solar thermal covers warm water demand and an additional 1-2m² the heating demand of one person (co2online 2020)
Climate conditions	• Solar radiation (the higher the better) and temperature (the lower the better) are main factors for energy yield (Fesharaki, et al. 2011) • Solar radiation: varies between 900 kWh/(m²*a) in Northern Europe (e.g.: Stockholm ~950 kWh/(m²*a)) and 2,000 kWh/(m²*a) in Southern Europe (e.g. Madrid ~2,000 kWh/(m²*a)) (Solargis 2020)
CO_2 reduction	• PV: CO_2-impact of 45 g CO_2/kWh. (IPCC 2014) • Solar thermal: CO_2-impact of 14 g CO_2/kWh (Samweber et al. 2014)
Environmental impact	• Roof top solar competes only with few other usages • Ground-based solar competes with other possible usages like wind turbines or farming
Self-sufficiency	• PV: In Northern Europe approx. 20% of electricity demand of a typical individual household with heat pumps for heating can be covered with roof top PV. In Southern Europe the self-sufficiency in electricity can reach even 25 % • Solar thermal: In Northern Europe approx. 1-1.5 m² of solar thermal covers warm water demand and an additional 1-2m² the heating demand of one person (co2online 2020)
Investment costs	• PV: 730 €/kWp (module price for Monocrystalline PV excl. installation costs of approx. 750€/kWp) (DEA 2018a) • Solar thermal: 830 €/kW (ESTIF 2015)

LCOE / LCOH[7]	• Depends mainly on energy produced due to specific radiation • PV in residential sector: 0.10 €/kWh$_{el}$ (ESP) – 0.15 €/kWh$_{el}$ (F) (IRENA 2020) • Solar thermal: 0.04 €/kWh$_{th}$ (Southern Europe) – 0.06 €/kWh$_{th}$ (Northern Europe) (ESTIF 2015)
Cost development	• PV costs decreased from 4,000 €/kWp in 2010 to 850 €/kWp in 2019 (IRENA 2020). It is expected that prices will decrease even further to 280-800 €/kWp in 2050 (Novosel et al. 2018) • Solar thermal costs are expected to decrease from 830 €/kW in 2019 to 560 €/kW in 2050 (Novosel et al. 2018)

Social aspects / Community value

As solar energy is a considerably widespread prosumer technology, its added-value for individual citizens as well as for local communities is considerable. Depending on the specific incentive structures, solar technologies can have a comparatively quick return on investment and are well suited to facilitate electricity sharing between different households within a neighborhood. Still, visual implications (sun glare) and land-use conflicts, the latter particularly referring to ground-based solar, are sometimes cited as reasons for objections to solar plants. An inclusive consultation process should precede the siting of larger PV-plants. Joint ownership of small, but even large-scale solar plants is a great way to ensure that benefits stay within the local community. This is increasingly often being done through energy communities. Particularly local governments are well placed to lease public land, or roof space on public buildings for siting PV projects, especially when they are citizen-owned.

Interesting examples

Depending on national legislation, energy communities can foster cooperation between municipalities. The German energy cooperative *NEW-Neue Energien West eG*[8] was formed by 17 contiguous municipalities to implement renewable energy projects. Each municipality purchased shares of at least 5,000 €. To include citizens in their local photovoltaic plant, the integrated cooperative *Bürger-Energiegenossenschaft West eG*[9] has been formed. Citizens of the region can purchase shares of this separate cooperative for a minimum of 500 €. So far, more than 1,450 people have acquired over 38,000 shares. Altogether, the two cooperatives have an investment volume of 56 million Euros with 20 PV installations amounting to more than 19,000 kWp, as well as one wind park with 4.8 MW and an increased activity in providing charging stations for electric cars and district heating.

Postcoderoos-regeling (postal code regulation) is a Dutch government regulation that allows people to invest in solar panels on rooftops of large buildings, for example companies or schools, within their residential postal code and receive the rewards from it. Net metering is applied on the amount of solar energy that is generated with their solar panels and they are exempt of taxes over the amount of their consumed self-produced electricity. The cooperative *Bildtse Stroom*[10] has implemented 1,400 solar panels in the former municipality of Het Bildt, which produce approx. 340,000 kWh per year.

[7] The levelized costs of electricity or heat (LCOE/LCOH) are the costs of producing energy over the lifetime of the technology
[8] www.neue-energien-west.de/neue_energien
[9] www.neue-energien-west.de/buerger_energiegenossenschaft
[10] www.postcoderoosregeling.nl/voorbeeld-van-een-project/

3.2 Wind energy

While wind turbines can be placed both onshore as well as offshore, mainly onshore wind is considered as a prosumer option, because of the boundary condition (set by PROSEU) that technology options should be in the proximity of the prosumers. Within this definition, near coast offshore wind turbines could also be an option. The yield of a turbine highly depends on its height and rotor diameter. When the size of the rotor blades doubles, the yield quadruples. Overall, there are three types of sizes of onshore turbines:

- **Large onshore turbines (4 – 6 MW):** These type of turbines are the more efficient and mostly used in new wind parks. This option can be considered for prosumers that want to invest in a collective.
- **Small onshore turbines (< 1 MW):** Small onshore wind turbines can be placed at someone's own property. This is especially interesting for companies that want to generate their own electricity, since these turbines generate more electricity than one household uses (e.g. farms).
- **Micro onshore turbines (both horizontal and vertical) (400 W – 2 kW):** These micro onshore wind turbines can be placed on rooftops of buildings. The investment costs are generally higher than the revenues. Only at locations with very high wind speed, the micro-turbines generate more electricity than was used by their production. In almost all cases, solar panels will generate more energy than a micro turbine, therefore this option is not further examined in this factsheet.

Table 4: Fact sheet wind energy

Initial conditions	• Wind turbines have a relatively small physical ground surface and can be combined with other land uses (e.g. farming). There are, however, some aspects that need to be taken into account:
	  • certain distances between turbines and buildings, due to noise and shade from the blades
	  • height regulations due to aviation or radar
	  • possible restriction in nature reserves
	  • optimal distance between two turbines is about 5 time the rotor diameter

Climate conditions	• The higher the power density of wind, the more electricity is generated with the same wind turbine. Power density varies locally:
	  • coastal areas in most cases have higher power densities
	  • urban areas have lower power densities
	  • mountains can have a large influence on local power density of wind
	• The minimum wind speed that is needed to start the blades turning (cut in speed) is 3 m/s to 4.0 m/s for onshore turbines (DEA 2018a)

CO_2-reduction	• depends on the source[11] that is replaced by using wind turbines • CO_2-impact of wind energy: 11.5 g CO_2/kWh (IPCC 2014)
Environmental impact	• After 3 to 6 months of generating electricity with a wind turbine, the CO_2 that is emitted during production is compensated (milieu centraal 2020) • Wind turbines can have a negative effect on birds, bats and nature (milieu centraal 2020)

[11] CO_2-impact of electricity generated with fossil fuels: Solids: 820 g CO_2/kWh; natural gas: 490 g CO_2/kWh (IPCC 2014).

	• Wind turbines produce noise and create moving shadows, which could cause nuisance for people (milieu centraal 2020)
Self-sufficiency	• Degree of self-sufficiency depends on energy demand • Since wind energy supply is higher in winter than summer, it is a good source for heat pumps in winter • Wind energy can be combined with battery storage, to increase the level of self-sufficiency.
Investment costs	• Large onshore (4-6 MW): 1,070 €/kW – 1,400 €/kW (JRC 2014) • Small onshore (10 kW): 4,000 €/kW (DEA 2018a)
LCOE / LCOH	• 0.066 €/kWh to 0.067 €/kWh (IRENA 2020)
Cost development	• Wind turbines are well-established, but are still in development. The past years this has mainly let to larger turbines. • Prices for large turbines are expect to drop by almost 30% towards 2050. For smaller wind turbines this is almost 20% (Novosel et al. 2018)

Social aspects / Community value

Wind energy has a high potential for generating concrete value for local communities. Visual and noise implications are frequently cited as reasons for anti-wind protests and many wind-parks are carried primarily by external investors. Therefore, enabling participation of citizens in both the financial returns of the wind park (as shareholders/members) as well as in the overall decision-making process can highly contribute to raising acceptance for this technology. Particularly in the case of larger-scale wind parks, employment opportunities for local workers can be significant as well as land-lease payments to, ideally, a pool of landowners/municipalities in the surrounding area.

Interesting examples

Energy cooperative *Som Energia*[12] is the largest energy cooperative in Spain and actively enables financial participation of citizens in renewable energy projects. The cooperative has more than 67,000 members and over 115,000 contracts and has an annual production of 17 GWh per year of renewable energy, half of which is sourced from wind energy. Citizens can become members of the cooperative and can democratically contribute towards the processes and strategies of Som Energia. In order to become a member, a 100 € (reimbursable) contribution is required. Som Energia has just completed a wind park with an annual electricity production of 85,000 kWh/year, providing energy for around 35,000 families per year. Part of this wind park has been funded directly by Som Energia members in the Navarra region where the farm has been installed.

The Dutch concept of Winddelen (wind sharing), describes several initiatives which allow citizens to invest parts of a wind turbine and receive the revenues. Net metering is only possible when the wind turbine is situated in the investing citizen's postal code area, which is barely the case, due to the turbines' large sizes and resulting distances from dwellings. One example of Winddelen is *De Windcentrale*[13], which sold 90,000 shares of a total of 13 wind turbines with an installed capacity of 21.8 MW, providing electricity for approx. 15,000 households.

[12] www.somenergia.coop
[13] www.windcentrale.nl/molens/

3.3 Battery storage

Prosumers can store electrical energy in battery storages when there is excess electricity produced, which they want to use at a later point in time. Due to decreasing prices and greater intentions to consume self-produced electricity rather than selling them to the grid the importance of batteries increased drastically in the past years. There are two dominant battery technologies used by prosumers

- **Lead-acid battery** – mature technology that was mainly installed in the past, based on lead and sulfuric acid with efficiencies of 80-83% and investment costs of 94-423 €/kWh.
- **Lithium-ion battery** – nowadays most often applied technology in stationary storage systems, based on lithium, with efficiencies up to 95% and investment costs of 200-840 €/kWh. Further improvements are expected because lithium-ion batteries are also a key technology in the mobility sector

While batteries have a fast respond rate and high energy density the environmental impact of needed resources should not be underestimated. For individual prosumers battery storages with 5-15 kWh capacity can help to increase self-sufficiency considerably. For collective consumers, community energy storages with >100 kWh capacity can not only increase self-sufficiency but are also suitable for system and grid-services.

Table 5: Fact sheet battery storage

Initial conditions	• Required space depends on capacity, e.g. .4 kWh require 0,5m*0,6m*0,3m (BYD 2020)
Climate conditions	• Can be applied in every climate condition
CO_2 reduction	• Indirect: can increase share of renewable technologies like PV from small values (up to 20%) without storage to high values (up to 75%) when storage is integrated • CO_2-impact of battery storage: 59 kg CO2/kWh capacity (Emilsson and Dahllöf 2019)
Environmental impact	• Lithium mining causes depleting water tables, loss of unique extreme habitats due to land changes and the threat of endangered species (Kliem et al. 2019). • Other critical components of lithium-ion batteries such as cobalt, nickel, manganese and phosphorus are primarily mined in emerging economies where labour conditions are often highly problematic and child labour is a problem (ibid.) • Energy conversion losses of ~5% when storing electricity

Self-sufficiency	• The degree of self-sufficiency can be doubled compared to when no storage is implemented (Doračić et al. 2020), e.g. Cabauw (NL) degree of self-sufficiency:
	  ◦ electricity with storage 53-54% (21-22% without storage)
	  ◦ heating with storage 62-66% (38-45% without storage)

Investment costs	• 200-800 €/kWh (IRENA 2020; Mariaud et al. 2017; Curry 2017)
LCOE / LCOH	• n.a.

Cost development	• Further reductions in costs with increasing upscaling of production are expected. The costs per kW are expected to decrease to 65-511 €/kW in 2050 (IRENA 2020; Mariaud et al. 2017; Curry 2017).

Social aspects / Community value

Battery technologies are not only enablers of electricity storage in individual households for use during off-peak hours, they will also increasingly enable on-demand sharing of electricity between households. This can be within a set geographical area and be integrated into a local community energy storage scheme. Effective use of battery storage can additionally contribute to increasing flexibility of the grid despite an increase of electricity from intermittent renewable (prosumer) technologies. Properly implemented community energy storage coupled with community energy schemes can enable increased local consumption, contribute to better end-user prices while retaining value and governance in the hands of citizens. It also results in greater cooperation among neighbors and more energy consumption awareness. Furthermore, it possible to enable non-prosuming members of the community to access stored energy given the right technical system is in place.

Interesting examples

The European project *COMPILE*[14] is establishing a cooperatively enhanced energy community at the pilot site Luče, Slovenia, that links the expansion of renewable energies and low voltage network with the installation of a community battery (150 kW/333 kWh), five household batteries and an EV charging point. With this comprehensive approach, the project aims to test high degrees of self-sufficiency on a micro-grid level through energy management.

The German company *Sonnen*[15] offers home battery storage (Lithium-Iron Phosphate) to store self-produced but also grid supplied electricity. It allows households to use their self-produced renewable energy, draw electricity form the grid and can function as an emergency power supply during power cuts. Depending on the household size, demand and amount of self-produced energy, battery models between 10 to 50 kWh capacity or large combination cabinets can be installed. With the combination of PV with the battery storage, a single family home can cover up to 75% of its yearly electricity demand with self-produced solar energy.

[14] www.compile-project.eu/sites/pilot-site-luce/

[15] www.sonnen.de/stromspeicher/sonnenbatterie-10-performance/

3.4 Heat pump

Heat pumps are one of the highest potential technologies for prosumer, due to their high efficiency, compatibility with multiple energy sources and possible application for heating as well as cooling. They produce heat or cold by utilising a thermodynamic cycle through which they transfer heat from low temperature to high temperature by the means of the refrigerant and the mechanical work, which is used to compress the refrigerant. Their efficiency is expressed mostly through the Coefficient of Performance (COP), which can have different values depending on the temperature differences in the system, size of the system, humidity, etc.[16] Heat pumps can use different heat sources and the most common types are:

- **Air to air heat pumps** – heat is drawn from the ambient air and supplied through the local heat exchangers
- **Air to water heat pumps** – heat is drawn from the ambient air but supplied through a hydraulic heating system, using radiators, floor heating or convectors
- **Geothermal heat pumps** – Heat is drawn from the ground and is supplied through a hydraulic heating system

While heat pumps use renewable sources for heat/cold production, additional electricity (or gas) is needed to run a heat pump. Renewable electricity should be used in order to make the heat pump a zero CO_2 technology, which is why the combination of PV and heat pumps is an attractive solution for prosumers to achieve high degrees of self-sufficiency.

Table 6: Fact sheet heat pump

Initial conditions	• Geothermal heat pumps: source (underground water, lakes, etc.) in the vicinity of the building; land area availability for horizontal loop system (up to 700 m^2) • Air source systems: much lower space demand; requires only an outside unit of up to 10 m^2, depending on the size of the system
Climate conditions	• Can supply heat as well as cold and can be used in all the climate conditions • Due to significantly reduced efficiency with below zero outside temperatures, air source heat pumps are not preferable in the areas with cold winters
CO_2 reduction	• More than 90%17 for the heating sector if heat pumps are combined with PV panels (Doračić et al. 2020)
Environmental impact	• Indirect: Since the environmental effect of the heat pump depends largely on the environmental effect of used electricity, the environmental impact will be very low, if it uses renewable energy • Refrigerants have high ozone depletion and global warming potential and therefore a strong effect on the environment if leaked from the heat pump. However, leaks occur rarely and new refrigerants (e.g. natural refrigerants) are being used, which lower the aforementioned effects significantly
Self-sufficiency	• On an individual level between 50% (oceanic-/continental climate) and 85% (mediterranean/semi-arid climate) of self-sufficiency in heating can be achieved

[16] Given different parameters, the COP of the heat pump can range from as low as 1 to as high as 10, meaning that for one kWh of consumed electricity, the heat pump produces several kWh of heat/cold.

[17] 100% CO_2-emission reduction could not be reached in any PROSEU calculation, due to the increased electricity consumption by heat pumps, which could not be entirely covered by self-produced electricity by PV.

	in a typical household when the full roof top is used for PV panels (Doračić et al. 2020) • Auxiliary consumption of heat pump 1% of heat generation
Investment costs	• 450 €/kW (air to air heat pump) to 4,000 €/kW (ground source heat pump)
LCOE / LCOH	• Depending on the cost of electricity and the number of operating hours • 0.2 €/kWh to 0.9 €/kWh (Dominković 2015)
Cost development	• Depending on the type of heat pump, investment costs could decrease from 7% (air to air) up to 70% (ground source) by 2050 (Novosel et al. 2018)

Social aspects / Community value

Similar to solar thermal storage or battery storage, central heat pumps coupled with thermal storage and PV can add to the overall resilience, sustainability and flexibility of the local heat system. It therefore becomes possible to supply multiple end-users on a demand-basis. With digitalization the role of heat pumps in independent heating systems also increases allowing these systems to communicate with each other as part of a virtual community (Sugden 2020). This increases community control and interest in running such assets. Used as stand-alone, or coupled with storage technologies, however, such inter-connected solutions require a willingness on the part of residents to share building temperature data, consumption data and to give insights on comfort requirements (Lyons 2019).

Interesting examples

In the transformation of the industrial area *Vulkan*[18] in Oslo, Norway, five heat pumps with an overall capacity of 1.5 MW for heating and 1.3 MW for cooling were installed. A total of 55,000 m^2 of households and commercial buildings are heated and cooled by the combination of heat pumps and solar thermal, integrating a thermal storage system.

The hotel *Soulton Hall*[19], in Shropshire, Great Britain, installed two 62 kW ground source heat pumps, with approx. 3,800m of ground loop, powered by 200 PV panels, which satisfy the entire heating and hot water demand of the hotel with its 30 guest rooms and service facilities. By switching from oil and electricity, Soulton Hall is not only saving more than 10,000 £ each year but also substantially reducing their CO_2-emissions.

[18] www.energisentralen.no/#/om-energisentralen
[19] www.ehpa.org/technology/best-practices/heritage-buildings

3.5 Biomass technologies

There are a variety of biomass technologies for energy production, but in the context of domestic and utility sector prosumers and self-sufficient communities the following three biomass technologies are considered to be most relevant: the domestic biomass boiler, the combined heat and power system, and the district heating biomass boiler. An important restriction to the use of biomass technologies by prosumers is that the biomass feedstock needs to be grown on own territory, which requires a large area of land. Biomass feedstock can be divided into production streams and residual streams. Residual streams include residues from forests, parks and gardens, while production streams include trees and crops that are grown for the main purpose of energy production, also called ‘energy crops’. The production of energy crops is labour-intensive, but the use of residual streams also requires periodic collection efforts.

Biomass boiler: This device is similar to a conventional boiler running on fossil fuel, but burns wood pellets, logs or wood chips to provide heat. **Domestic biomass boiler** provide heat to an entire house (or flat) through a central heating system. A large **community biomass boiler** converts solid biomass from the local environment into heat, which is transported to community buildings through an underground district heating network. The transport medium is water. In the buildings, the heat is transferred to the buildings heat distribution network.

Combined heat and power system: A combined heat and power (CHP) system can be dimensioned to provide heat and power to one building or a whole community, and can be fired by solid biomass from the local environment. The biomass is fed into the boiler, where it is combusted. The hot flue gasses power a (gas or steam) turbine which drives a generator to produce electricity. The residual heat is transported by pipelines to community houses and buildings for space and water heating. Smaller CHP’s can be used for one (tertiary) building.

Table 7: Fact sheet biomass technologies

Initial conditions	• Land area: cultivation of energy crops requires less land area than the collection of biomass residues from the local environment, however uses land area more intensively and conflicts with other land uses • Storage/Boiler room: Biomass boiler are larger than conventional domestic boiler. Biomass storage and heat storage tanks require additional space in or around the building
Climate conditions	• Climate and weather influence the biomass yield on community territory • Higher temperatures, higher solar irradiation and more rainfall increase the yield
CO_2 reduction	• Depends on the source[20] that is replaced by biomass technology • CO_2-impact of biomass energy: burning of biomass is considered CO_2 neutral, due to the captured CO_2 during the period of growth of the biomass. Using local biomass will ensure minimal CO_2 emissions from biomass transport

Environmental impact	• The combustion of biomass results in the emissions of CO_2, carbon monoxide, NO_x, particulate matter, volatile organic compounds and other pollutants:
	  ◦ CO_2-emissions can be considered climate neutral
	  ◦ Other gasses can affect local air quality

[20] CO_2-impact of electricity generated with fossil fuels: Solids: 820 g CO_2/kWh; natural gas: 490 g CO_2/kWh (IPCC 2014).

	• NOx and ammonia emissions may lead to soil acidification and damage the biodiversity of local ecosystems • Emission capture systems and high chimneys may reduce these effects
Self-sufficiency	• Integrating CHP in the heat and electricity production showed high potentials to increase degrees of self-sufficiency on the neighbourhood and city level (e.g. Klausner Platz; Bristol) (Doračić et al. 2020)
Investment costs	• Domestic biomass boiler: 200-550 €/kW (JRC 2017) • Community biomass boiler: 130-220 €/kW (JRC 2017) • CHP (small wood pellets 20 MW_{el}): 6,300 €/kW (DEA 2018a)
LCOE / LCOH	• Community biomass boiler (2.5 MW). 0,12 €/kWh (Koppejan 2016) • CHP 5 MW with local biomass: 0.13 €//kWh (IRENA 2012)
Cost development	• Biomass boilers are well-stablished. The expected cost development towards 2050 for the small biomass boilers is a small increase and for larger boilers a decrease of just over 10% (Novosel et al. 2018) • The larger CHP is a well-established technology, while the smaller CHP is a little bit less developed. The costs of the CHP smaller than 10 MW_{el} is expected to drop just over 10% (Novosel et al. 2018)

Social aspects / Community value

The use of biomass for heat and electricity generation can be perceived critically and is not always well received by local communities. This relates to the overall environmental impact and use of resources stated above. Still, biomass value chains are increasingly integrated into community energy schemes and provide clear value to local communities. If the biomass is sourced locally and e.g. from waste wood created during local maintenance works, then turned into wood chips and burned at a local biomass boiler, the increased sustainability can lead to more local acceptance of biomass boilers as renewable technologies. A good way of increasing citizen involvement is to feed the heat into a local district heating network which is owned by an energy cooperative with citizens profiting from better prices and more sustainable heat.

Interesting examples

Bioenergiegenossenschaft Kleinseelheim[21] has built a cooperatively owned district heating grid supplying CO_2-neutral biomass to the town's residents. More than 80 households have connected to the grid offering heat from a boiler which burns biomass collected by landscape management and maintenance work. In the eyes of the local community, it is great that the waste biomass material is being put to good use and it is enough in quantity to supply several surrounding towns in the long term.

Sindballegård[22] is a traditional Danish farm producing field crops and raising piglets and poultry that switched its heating source from oil to biomass. The oil burner was replaced by a 450 kW straw burner that is designed for round bales making it practical for the farmer to fill. The supply of 255 t of straw per year is covered by the farm's own production. Besides, the ash can be used as a fertilizer for the farm's fields.

[21] www.bioenergie-kleinseelheim.de/index.php/energietrager
[22] www.dbfz.de/fileadmin/Bioenergy4Business/data/pdf/Brochure_1.pdf

3.6 Thermal energy storage

While there are various forms of thermal energy storage, all most commonly use water as a heat storage medium. Thermal energy storage units can store heat on a shorter basis, i.e. daily or weekly, as well as an annual level, which enables the storage of heat produced during summer (e.g. solar thermal) and its usage during winter.

Pre-insulated steel vessels are usually used as buffer tanks to store heat on a daily or weekly basis. For the individual prosumers, small buffer tanks are suitable, since they do not take too much space (up to 10 m^3). These tanks can balance the production of households by storing the heat when the supply is higher than the demand (e.g. during the night or when solar heat is produced during daytime) for later when the heat demand is higher. Therefore, it can help avoiding the use of more expensive, fossil fuel units (e.g. natural gas boilers) and subsequently reducing the environmental impact and increasing the level of self-sufficiency of the households. They are required to achieve a high level of prosumer self- sufficiency on a household level.

Annual storage, also called seasonal thermal storage, enables heat storage during one season (usually summer) and usage in another (i.e. winter). The three main types of seasonal storage are pit, borehole and aquifer thermal energy storage. These large storage types are placed underground, in order to provide significant volume (>100.000 m^3) and hence capacity to store all the heat produced during one season, while not consuming useful ground area. Stored heat is mostly produced by solar thermal collectors, but also other units, e.g. cogeneration or waste heat from industry. Seasonal storage technology is crucial to reach a high level of prosumer self-sufficiency on city or regional levels, where it is shared by multiple prosumers forming a prosumer community.

The above mentioned systems can also be used to store **cold energy for space cooling**, in the same manner as storage for heating. Usually, cold water or ice can be stored in a vessel, pit or an aquifer. Vessels and pits for cooling storage are usually implemented separately to the heat storage systems. Aquifer on the other hand can be used for both purposes when connected to a heat pump. During the summer, water is taken from the cold well and, after being heated by the heat pump, returned to the warm well. During the winter, the opposite process happens. Therefore, these systems can be used in areas where there is a balance between heating and cooling through different seasons.

Table 8: Fact sheet thermal energy storage

Initial conditions	• Small buffer tanks: up to 10 m^3 per household • larger units should be carefully planned to be incorporated in the environment
Climate conditions	• Tank and pit thermal storage can be used in all the climate conditions, since most of Europe needs heating • Aquifer thermal storage more suitable in parts of Europe, where heating and cooling demand is largely in balance (Central or Northern Europe)
CO_2 reduction	• Indirect: can increase share of zero-CO_2 technologies like PV from small values (up to 20%) without storage to high values (up to 75%) when storage is integrated

Environmental impact	• Low impact of large seasonal thermal storage units possible, due to the lack of proper treatment and storage, e.g.:
	  • spilling of heat transfer medium/phase change material into the ground
	  • biological, hydrological and geotechnical effects on the ground

Self-sufficiency	• Prerequisite technology to achieve high degrees of self-sufficiency in heating and cooling sectors • In PROSEU scenarios thermal storage increased self-sufficiency in the range 4% to 26% • Auxiliary electricity consumption 0.2% (seasonal) up to 1% (buffer) of output
Investment costs	• 580 (seasonal) €/MWh to 3,000 (buffer) €/MWh (DEA 2018b)
LCOE / LCOH	• n. a.
Cost development	• Cost of buffer tanks stable; seasonal storage cost may decrease by 19% (DEA 2018b)

Social aspects / Community value

As the use of buffer tanks for heat storage is comparable, in its basic purpose, to battery storage, a network of heat storage units adds to the overall resilience, sustainability and flexibility of the local heat system. It therefore becomes possible to supply multiple end-users on a demand-basis.

Interesting examples

The *City of Gram*[23], Denmark installed district heating combining 44,800 m^2 of solar collectors with a 122,000 m^3 pit seasonal thermal storage, which cover 60% of the overall annual heat demand. The storage is established on a flat green field and the clayish soil is balanced by a dam around the pit. A 10 m deep pit and a 5 m high dam are resulting in a storage volume of 15 m and a total investment of 2.8 million Euro.

The *City of Braedstrup*[24], *Denmark* has installed an alternative district heating utilizing a borehole thermal storage with 48 boreholes heating approximately 19,000 m^3 underground land and steel tank storage of 7,500 m^3. The consumer owned cooperative Brædstrup Fjernvarme[25] supplies approx. 1,450 households and hence approx. 95% of the city's total heat demand with district heating.

[23] www.gram-fjernvarme.dk

[24] www.solar-district-heating.eu/wp-content/uploads/2019/10/Best-practice-Brædstrup-Marstal-Dronninglund-and-Gram-003.pdf

[25] www.braedstrup-fjernvarme.dk

4. Mainstreaming prosumer technologies

Modelling prosumers on different levels showed that prosumerism has high potential to lower CO_2-emissions, but also provide significant economic and social advantages and can facilitate the energy transition of the EU by 2050. In particular, when high degrees of self-sufficiency are desired, prosumer technologies are a good alternative to centrally produced and distributed energy. In order to foster prosumer technologies and strengthen their potential and positive effects, it is necessary to create encouraging regulative, economic, technical and social conditions. This chapter discusses recommendations of PROSEU to mainstream prosumerism in the EU. While the focus lies on technical recommendations, they are not independent of recommended economic, regulatory or social changes, which are therefore discussed in this chapter were applicable.

4.1 Enable balanced involvement of all actors and increase local acceptance

Despite an overall high technical potential, prosumer technologies might not be taken up in a certain area due to low enthusiasm from consumers/citizens, missing knowledge and acceptance issues. This means that projects cannot materialize despite favourable environmental conditions such as a high wind energy penetration or high radiation. Opposition can be reduced by promoting the idea that deploying prosumer technologies in a collective manner on a local level can have considerable benefits and to highlight that renewables are not only beneficial from an environmental point of view but also economically benefiting the end users, and fostering local pride by allowing presuming communities to have in their own energy production (BWE 2012; Bak 2012). In this way prosumer technologies can enable a more decentralized and democratic energy system that involves actors on different scales. The interaction between community actors (e.g. customers, prosumers, energy communities, social enterprises), market actors (e.g. grid operators, energy providers) and local government actors can however only be balanced and fruitful when all actors receive sufficient education, incentives and therefore options for professionalization.

The involvement of **community actors** in planning processes of energy projects and tailored education and enabling programs aim to democratize energy system knowledge and ownership, enable energy literacy and overall increase energy democracy. Policymakers can foster this development by reducing legal and administrative barriers, recognition of social value of community energy projects in planning legislation, guaranteed participation in flexibility markets for prosumers, promotion of communal self-consumption and financial incentives (e.g. financing schemes, economic benefits for presuming households) (see Brown et al. 2020, chapter 5.1). Regulation and legislation should enable the participation of citizens, prosumers and energy communities in the energy system by clear and transparent definitions of the respective stakeholders, simplified administrative procedures and education and capacity-building (see Petrick et al. 2019, chapter 3). Furthermore, prosumer representatives (e.g. specifically founded association) can serve as proficient advisors for governments, which should be actively sought and included in governmental processes (see Petrick et al. 2019, chapter 4).

Example for prosumer financing scheme

ZEF, Croatia

- Cooperative for ethical financing
- Offers financing schemes for renewable energy technologies
- As part of PROSEU financing options for prosumers are developed

Traditional **market actors**, such as energy suppliers and system operators, are currently the most dominant actors in the energy sector and are subject to change in a prosumer energy system. In order to open energy markets for prosumers, prevailing business models have to be adapted (e.g. Peer-to-Peer trading, aggregator models) and tested without restricting regulatory barriers (e.g. regulatory sandboxes), markets should be redesigned by system operators to enable access of prosumers as new market entrants and allow for small scale flexibility, and required infrastructure (e.g. smart meter) needs to be established (see Brown et al. 2020, chapter 5.3). While the previous role of traditional market actors is likely to diminish in this scenario, they would have an important role to play to support energy communities with their in-depth expertise, provide new services and manage new infrastructure. Hence, the collaboration between actors and the strengthening of new actors is key for mainstreaming prosumerism. It is still an open question whether this market actors would be willing to open up to prosumer communities and seek for cooperation.

Local governments have a key role in mainstreaming prosumerism. As owners of a significant amount of property and energy intensive services (e.g. street lighting), local governments are on one hand key energy consumers but also have on the other hand high potential for energy production (e.g. PV on roofs). Furthermore, local government's mandate for social justice and wellbeing makes them more accountable for a decarbonisation and democratisation of the energy system than the private sector. Bristol City Council has set up the "Bristol Energy Community: Catalyst Fund" as a revolving fund to help community energy projects to develop. Among others, the highly successful Bristol Energy Cooperative has made use of this fund to kick-start its activities in the city (Newbery 2012). Local governments can also have an impact by setting suitable energy targets and measures, smart urban planning and lifting taxing and legislative barriers where necessary (see Petrick et al. 2019, chapter 5.3). Being "leaders by example", they could choose to financially engage in a community energy project. In Schleswig-Holstein, the municipality of Neuenkirchen has chosen to obtain shares in the local wind park showing trust in the project (Rambelli and Hinsch 2019). In the Polish town of Kisielice, the mayor was a leading figure in promoting the idea of development of a local wind park. The council then made an amendment to the local spatial development plan to allow wind turbines to be placed on agricultural land (Rambelli and Hinsch 2019). Furthermore, local governments can shape local energy transition through education programs and grant schemes supporting the purchase of prosumer technologies for disadvantaged groups. In Gran Canaria an inter-municipal association started an effective information-campaign through posters, promotional videos as well as radio stations where the prospect of a wind park was openly discussed. The wind park was constructed and its electricity is being used to power a desalination plant on the island contributing to fresh water supply (Rambelli and Hinsch 2019). Local governments can be supported by giving them authority to tailor energy regulations to local needs, enabling them in the purchasing and operation of energy infrastructure, reducing barriers for municipal energy service companies and modifying financial constrains to municipalities (see Brown et al. 2020, chapter 5.2). In addition, when government employees are well trained and competent they can encourage (collective) prosumer initiatives. In order to ensure that prosumer technologies are accepted and backed by local citizens, the consultation process is just as important as technological arguments and financial gains.

Municipalities supporting prosumers
City of Križevci, *Croatia*

- Cooperation with the Green Energy Cooperative (ZEZ)
- Provided the cooperative with roof space on the municipally-owned Development Centre snfd Technolog Park to install a 30 kWp PV plant
- Money for the plant was raised via crowdfunding and 53 citizens have invested, investing from 135 Euro to 1000 Euro each

4.2 Digitalize the energy system

Prosumers play an important role in the energy system as a whole as they feed renewable energies into the grid (see Doračić et al. 2020) as well as being a flexible prosumer in the future energy system (IRENA 2019). This brings additional complexity to the energy system that can only be handled in a secure way when certain aspects of the system are digitized and automated. The ideally autonomous digitized energy system, which integrates smart technologies, communication networks, data management systems over several sectors (e.g. automated charging of electric vehicles; using them as energy storage), should be simple to use and is a further step to democratize the energy system for example through easier market access or virtual power plants. Apps and suitable visualizations can support the accessibility and help to reduce inhibition to use prosumer technologies. With this, digitalization of the energy system also holds potential to make prosumerism and the energy system more accessible to people that are not energy literate.

Blockchain Grid

Citizen Energy Community in Heimschuh, Austria

- Blockchain-enabled flexibility activation for distribution grid management in a region with PV prosumers
- Smart grid through dynamic distribution of network capacity, P2P trading through blockchain technology, shared battery storage
- Actors: energy retailer, Distribution System Operator (DSO), technology company, ICT company, consulting organizations/institutes

Digitalization on a decentralised level starts with the rollout of smart meter systems in the EU member states. The EU decided for a at least 80% rollout with smart meter systems in the member state originally until 2020, but some member states shifted the timeline due to negative cost-benefit analysis or missing national regulatory frameworks (cf. European Commission DG Energy 2019). The actual expansion of smart meters in the EU member states is at a very different level. By 2018, seven member states had reached the 80% expansion target. These include Finland and Sweden, which had completed the full rollout in 2013 respectively 2009, Estonia, Italy and Spain, which had over 90% of the metering points equipped with smart meters, and Denmark and Malta, which had over 80% equipped. In 2018 the installation rate for smart meters in the EU in total was 34.2% (European Commission DG Energy 2019). In all member states apart from the UK the grid operators are responsible or partners for the smart meter rollout (European Commission DG Energy 2019). Brown at al. (2020, chapter 3.2) suggest that it should be coordinated by government actors and distribution operators, rather than energy suppliers.

Looking at smart grids as a next step of digitization and prosumer integration, the focus is still on research and demonstration projects. Leading countries in this are Germany, Denmark and the UK (cf. Gangale et al. 2017) with the highest number of projects. The authors attribute this to a 'favourable national or regulatory environment' created. In addition, they state that smart grid roadmaps in the member states pushes the development.

Since digitalized energy systems operate with high volumes of data, its management, access and protection becomes a central role for the mainstreaming of prosumerism. In the EU this is subject to EU General Data Protection Regulation (GDPR) 2016/679/EC, the Energy Efficiency Directive 2012/27/EU, the Electricity Directive 2009/72/EC, the Gas Directive 2009/73/EC and further national legislation. It varies whether a central authority (e.g. ERDS in France, ATRIAS in Belgium, ElHub in Norway) or decentral service providers (e.g. Germany) will facilitate data collection and distribution (CEER 2016). The CEER report (2016) also states that the entity storing data from the smart meters varies in the member states between the DSO (e.g. Norway, Italy, Germany Spain and Belgium), a combination of DSO and supplier (e.g. the Netherlands), a combination of customer and DSO (e.g. UK) and even a DataHub (e.g. Denmark). In addition, the ownership and connected access of the data needs to be established, the responsibilities are not unified in the EU. Therefore, fair principles are needed and prosumers should be able to make use of their data. This could lead to an increase of efficiency and flexibility.

4.3 Increase energy efficiency and create space for innovations

In order to increase the share of renewable energies in a prosumer energy system, not only the expansion of technologies but furthermore the reduction of overall energy consumption and increased energy efficiency are fundamental factors. Technological breakthroughs in renewable energy technologies and energy storage will be crucial for the development of a renewable and ecological energy system.

In particular, the tuning of varying energy production and demand presents renewable energy systems with a challenge. Smart technologies can control the timing of energy consumption to some extend when implemented. Depending on the scale of the energy community[26], the geographical location, and desired degree of self-sufficiency and grid independency, storage of energy for later consumption sometimes becomes inevitable for prosumers. While thermal storage is already a feasible solution to manage varying heating demand, electric storage still proves to be expensive, not efficient (due to high losses) and the environmental impact of their production and disposal often disproportionate to their benefits (which could include less network expansion; decentralization; higher self-sufficiency). The use of electric vehicles as temporary energy storage can be a feasible solution to face flexible electricity demand, here the future development of rising car sharing concepts in place of private vehicles and their integration into the energy system should be considered. Research in options for seasonal and high capacity electricity storage should promoted.

Furthermore, energy efficiency of buildings is a factor that influences the uptake of prosumerism, especially in the heating sector where energy efficiency measures lower the demand and the temperatures required for space heating. Higher energy efficiency levels enable the use of low temperature sources like solar thermal and increases the efficiency of heat pumps due to lower temperature difference between heat source and heat sink. Therefore, measures that incentivise the retrofitting of existing buildings and high efficiency standards for new developments should be implemented. In addition, the results from PROSEU showed that with higher refurbishment in 2050 the self-sufficiency of prosumers increases.

Regulatory Sandbox
Social Energy, *UK*

- Network for energy storage and trading
- Supply of hardware, software and services
- Business model was tested in regulatory sandbox within the Ofgem Innovation Link

Even in such established technologies as wind and solar energy, there is still room for innovations and improvements. Small-scale wind turbines are still very rare as well as new forms of wind energy like airborne wind turbines. Rooftop solar is widespread but Agrivoltaics (APV) or plug-in solar panels for balconies or facades are still new. To foster innovations in the energy system it is necessary to set ambitious targets for prosumers and energy communities (see Brown et al. 2020, chapter 1), lift barriers (e.g. double taxation of stored energy; inhibitory regulation on PV installation) and give an regulatory open space for experimentation (e.g. regulatory sandboxes) in addition to advancing research.

[26] With an increasing number of prosumers, storage capacity or flexible consumption schemes are needed to balance the increased fluctuation of electricity production (especially in case of PV) (Child et al. 2019; Shivakuma et al. 2015).

4.4 Simplify system integration of prosumers

In order to make use of economies of scale it is beneficial to move beyond isolated prosumers to prosumers integrated in the local, national or even European energy context. When Prosumers are connected to the grid and have access to the energy market energy can be utilized when energy production exceeds local consumption for external consumption.

Publicly/Locally owed grid

Municipality Saerbeck, Germany

- purchased electricity grid together with citizen and local investors
- Installed two wind turbines

EWS Schönau, Germany

- First energy cooperative in Germany to purchase and operate the local grid

Beyond the fulfilment of the technical requirements (physical connection to the grid and installation of smart meter that accounts for energy withdrawal and injection), systemic factors regarding the implementation of new infrastructures and their operation need to be considered. While very active and autarky driven prosumer communities can have an active role in the implementation, ownership and operation of their local grid, it requires high degrees of investment and professionalization and is therefore not the best fit for every community. Municipality owned grids can be a feasible solution but also network operators can be useful for the facilitation of such local grids and their connection to the larger national grid to foster the interconnection of prosumer islands. High levels of communication and comprehension of needs between prosumers and operators and high levels of transparency are in any case needed to ensure a functioning energy system. Furthermore, network charges need to be revised to allow for more flexibility and avoid passing network costs disproportionally on non-prosumers (cf. Brown et al. 2020, chapter 3.3). Hence, depending on the degree of system integration and active involvement prosumers seek, grid ownership and operation can look differently and this diversity of options to choose from should be made available.

Consumer Flexibility Tool

FLEXCoop, Europe

- End-to-end interoperable tool suite for energy networks, management and devices
- Demand Response optimization through monitoring and forecasting
- Negotiation of terms of flexibility activation
- Enabling energy cooperatives to become aggregators
- Market integration of prosumers through open and

The integration of prosumers requires a re-design of energy markets to allow for fair access for energy supplies (including prosumers), transparency and flexibility (cf. Brown et al. 2020, see chapter 3.6). Entry boundaries for prosumers need to be reduced through incentives (e.g. licence and legislation exemptions, feed in tariffs, export guarantees) (cf. Brown et al. 2020, chapter 3.1) and other innovative regulation have to be introduced to include new (energy and digital) technologies. A balanced integration of prosumers however also means to set a level playing field for prosumer technologies in the market and hence to abolish subsidies for fossil energy sources and ensure a fair distribution of grid costs and reflect true prices (e.g. make climate damages transparent).

References

Bak, Kasper Brejnholt (2012): Wind Energy as a Lever for Local Development in Peripheral Regions. http://wisepower-project.eu/wp-content/uploads/Wind-Energy-as-a-Lever-for-Local-Development-in-Peripheral-Regions.pdf.

Brown, Donal, Moritz Ehrtmann, Lars Holstenkamp and Steven Hall (2020): Policies for Prosumer Business Models in the EU. PROSEU - Prosumers for the Energy Union: Mainstreaming active participation of citizens in the energy transition (Deliverable N°4.2).

BWE (2012): Community Wind Power. https://www.wind-energie.de/fileadmin/redaktion/dokumente/dokumente-englisch/publications/bwe_broschuere_buergerwindparks_engl_10-2012.pdf.

BYD (2020): Technical datasheet Battery-Box Premium LVS. https://www.mg-solar-shop.de/media/pdf/c1/e3/f8/112809_Premium_Datasheet_LVS%20V2.0_EN.pdf.

CEER (2016): Review of Current and Future Data Management Models. CEER report. Brussels, Belgium: Council of European Energy Regulators. https://www.ceer.eu/documents/104400/-/-/1fbc8e21-2502-c6c8-7017-a6df5652d20b (accessed: 29. July 2020).

Child, Michael, Claudia Kemfert, Dmitrii Bogdanov and Christian Breyer (2019): Flexible electricity generation, grid exchange and storage for the transition to a 100% renewable energy system in Europe. *Renewable Energy* 139 (August): 80–101.

co2online (2020): Solarthermie: Funktionsweise, Systeme, Kosten und Förderung. https://www.co2online.de/modernisieren-und-bauen/solarthermie/ (accessed: 26. July 2020).

Corradini, Roger, Michael Beer and Tobias Schmid (2012): Energiemodell der Wohngebäude. *BWK* 64, Nr. 1/2: 48–53.

Curry, Claire (2017): Lithium-Ion Battery Costs and Market–Squeezed Margins Seek Technology Improvements & New Business Models. BNEF reports. New York: Bloomber New Energy Finance BNEF. https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf (accessed: 20. November 2018).

DEA (2018a): Technology Data for Energy Plants for Electricity and District heating generation. Danish Energy Agency. https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-generation-electricity-and (accessed: 21. November 2018).

DEA (2018b): Technology Data for Energy Storage. Danish Energy Agency. https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-energy-storage (accessed: 21. November 2018).

Dominković, Dominik Franjo (2015): The role of large scale heat pumps in future energy systems. Diplomski Rad, Zagreb: University Zagreb. https://urn.nsk.hr/urn:nbn:hr:235:888180.

Doračić, Borna, Jan Knoefel and Nanda Naber (2020): Report on local, national and EU scenarios. Prosumers for the Energy Union: Mainstreaming active participation of citizens in the energy transition (Deliverable N°5.2).

Emilsson, Erik and Lisbeth Dahllöf (2019): Lithium-Ion Vehicle Battery Production. Status 2019 on Energy Use, CO2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling. Stockholm: IVL Swedish Environmental Research Institute. https://www.ivl.se/download/18.14d7b12e16e3c5c36271070/1574923989017/C444.pdf.

ESTIF (2015): Domestic hot water for single family houses. http://www.estif.org/fileadmin/estif/content/publications/downloads/UNEP_2015/factsheet_single_family_houses_v05.pdf.

European Commission DG Energy (2019): Smart Metering Benchmark Revised Final Report. Brussels. https://www.vert.lt/SiteAssets/teises-aktai/EU28%20Smart%20Metering%20Benchmark%20Revised%20Final%20Report.pdf (accessed: 7. November 2019).

Fesharaki, V. Jafari, Majid Dehghani, J. Jafari Fesharaki and Hamed Tavasoli (2011): The Effect of Temperature on Photovoltaic Cell Efficiency. In: *Proceedings of the 1st International Conference on Emerging Trends in Energy Conservation - ETEC*. Tehran, Iran. https://pdfs.semanticscholar.org/4eb1/39ee8e2cc5d722b14ced834f35a8183b1188.pdf.

Gangale, Flavia, Julija Vasiljevska, Catalin Felix Covrig, Anna Mengolini and Fulli Gianluca (2017): Smart grid projects outlook 2017: facts, figures and trends in Europe. Luxembourg: European Commission, Joint Research Centre. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC106796/sgp_outlook_2017-online.pdf (accessed: 29. July 2020).

Horstink, L., G.P. Luz, M. Soares and K. Ng (2019): Review and characterisation of collective renewable energy prosumer initiatives. PROSEU-Prosumers for the Energy Union: Mainstreaming active participation of citizens in the energy transition. Porto, Portugal: University of Porto. https://zenodo.org/record/3560961.

IPCC (2014): *Climate Change 2014 Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. http://ebooks.cambridge.org/ref/id/CBO9781107415416.

IRENA (2012): Biomass for Power Generation. Renewable energy technologies: Cost analysis series. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-BIOMASS.pdf.

IRENA (2019): Innovation landscape brief: Behind-the-meter batteries. Abu Dhabi: International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_BTM_Batteries_2019.pdf (accessed: 21. April 2020).

IRENA (2020): Renewable Power Generation Costs in 2019. International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf (accessed: 20. July 2020).

JRC (2014): ETRI 2014: Energy Technology Reference Indicator projections for 2010-2050. Brussels: European Commission. https://setis.ec.europa.eu/system/files/ETRI_2014.pdf (accessed: 14. November 2018).

JRC (2017): Techno-economics for smaller heating and cooling technologies. European Commission, Joint Research Centre (JRC). https://data.europa.eu/euodp/en/data/dataset/jrc-etri-techno-economics-smaller-heating-cooling-technologies-2017.

Kliem, Lea, Jonas Penzien, Marco Baldauf, Anahita Bidjanbeg, Horst Fehrenbach, Andreas Auberger and Susanne Köppen (2019): Sustainable Consumption for Biodiversity and Ecosystem Services: The cases of cotton, soy and lithium. Federal Agency for Nature Conservation (BfN). https://www.bfn.de/fileadmin/BfN/internationalernaturschutz/Dokumente/Sustainable_Consumption_Biodiversity_bf.pdf.

Koppejan, Ir. J. (2016): Inventarisatie van markttoepassingen van biomassaketels en bio-wkk. Enschede: Procede Biomass BV. https://www.rvo.nl/sites/default/files/2017/04/Rapportage-Marktkansen-bioketels.pdf.

Lyons, Lorcan (2019): Digitalisation: Opportunities for heating and cooling. JRC Technical reports. Luxembourg: Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC116074/kjna29702enn.pdf.

Mariaud, Arthur, Salvador Acha, Ned Ekins-Daukes, Nilay Shah and Christos N. Markides (2017): Integrated optimisation of photovoltaic and battery storage systems for UK commercial buildings August 2017, Nr. Applied Energy: 466–478.

milieu centraal (2020): Windenergie. *Klimaat en aarde*. Website: https://www.milieucentraal.nl/klimaat-en-aarde/energiebronnen/windenergie/.

Newbery, Bridget (2012): Bristol Community Energy: Catalyst Fund. *Centre for sustainable energy*. Website: https://www.cse.org.uk/projects/view/1156.

Novosel, T., T. Pukšec, B. Kampman, T. Scholten, N. Naber, S. Gährs and J. Knoefel (2018): Prosumer technology database. 31. December. https://zenodo.org/record/2611147.

Petrick, Kristian, Jérémie Fosse and Salvador Klarwein (2019): Principles for Prosumer Policy Options. PROSEU-Prosumers for the Energy Union: Mainstreaming active participation of citizens in the energy transition. Eco Union. https://zenodo.org/record/3584746.

Rambelli, Giorgia and Arthur Hinsch (2019): Local Governments Drive Social Acceptance –Support Them! Policy Brief #3. ICLEI Local Governments for Sustainability. https://winwind-project.eu/fileadmin/user_upload/Resources/Policy_Brief__3_final.pdf.

Samweber, Florian, Manuel Sutter and Simon Köppl (2014): Solare Wärmeerzeugung durch Solarthermie und Photovoltaik. https://www.ffe.de/download/article/555/2015-02_13_Vergleich_ST_PV.pdf (accessed: 26. August 2020).

Shivakuma, A, P Dean, N Bo and A Faure (2015): *Business models for flexible production and storage: Policy Report 4*. vol. https://www.innoenergy.com/media/3668/pr-4_business-models.pdf.

Solargis (2020): Global Solar Atlas 2.0. On behalf of the World Bank Group. Website: https://globalsolaratlas.info/.

Sugden, Lindsay (2020): Why energy communities should be at the heart of your heating (and cooling) business. *Linked in*. 18. June. https://www.linkedin.com/pulse/why-energy-communities-should-heart-your-heating-cooling-sugden.

Toporek, Marta and Inês S. Campos (2019): Assessment of existing EU-wide and Member State-specific regulatory and policy frameworks of RES Prosumers (Deliverable N°3.1). PROSEU-Prosumers for the Energy Union. Brussels, Belgium: ClientEarth.

PROSEU

info@proseu.eu