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Norges forskningsråd

Prosumers' role in the future energy system

A position paper prepared by FME CenSES

CenSES Position Paper

Prosumers' role in the future energy system

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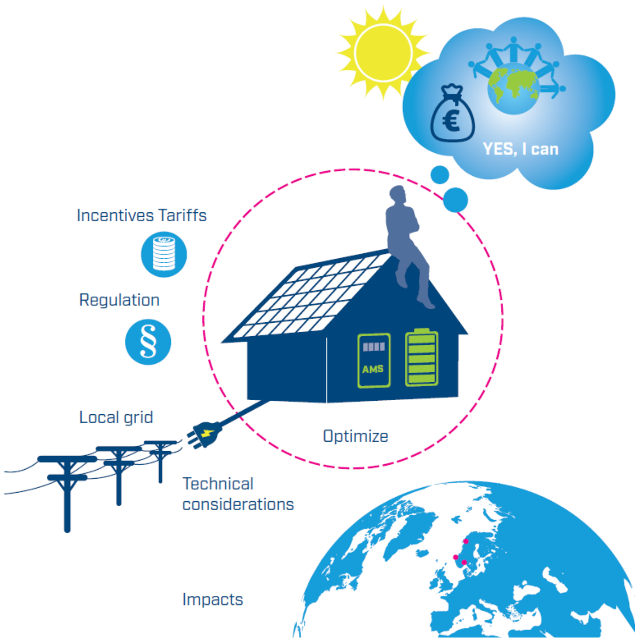
Executive summary

Prosumers are people who consume some of the goods and services that they themselves produce. The supply of electric energy and flexibility services are two distinct services needed in all power systems. The prosumers considered in this document generate at least one of type of power supply, for example through solar panels installed on the roof of their house or by a battery in their basement.

At the start of 2018 there were more than c.1000 customers supplying surplus electricity to the national grid in Norway, and the growth rate is still high. It is difficult to forecast how many prosumers there will be in the future, and at least three factors will be important for the future development:

- **Grass-roots movements** may lead to a considerable increase in the number of prosumers
- **Continued cost reductions** for solar panels and batteries
- **The EU goal to achieve nearly zero-energy buildings (NZEBs)**, especially if it were prioritized over cost-efficiency in Norwegian implementations.

This position paper presents research from a range of disciplines that mirrors the research carried out in the FME[1] CenSES. The content of the position paper is represented in the following illustration:



This document gives a historical and qualitative overview of prosumers, insights into optimization of prosumers' local energy systems, analysis of relevant regulation and incentives and tariffs, an overview of technical considerations for grid connection for own production, and quantitative simulations of energy system impacts. By contrast, the impacts of prosumers on distribution grid operations and enhancements are not the main focus of this position paper.

The main findings can be summarized as follows:

1. Existing prosumers in Norway have been motivated more by environmental concerns, technological interests, and self-consumption than by economic incentives.

[1] FME – Forskningssenter for miljøvennlig energi (research centre for environmentally friendly energy)

2. Smart meters have lowered the threshold for becoming a prosumer.
3. Return on investments has been low for prosumers.
4. Currently, batteries are not a cost-effective technology to lower peak electricity demand. It is less expensive to utilize flexibility in ventilation, electric boilers and heating. PV production (i.e. solar panels) within Oslo will reduce the need for transmission grid expansion to the city to a very little extent.
5. A capacity-based grid tariff, which has been suggested by the Norwegian Water Resources and Energy Directorate (NVE), will make it less profitable to invest in solar panels, and will give stronger incentive for flexibility. Wind power and PV as types of varying renewable generation are complementary technologies for demand response. Additional amounts of one of them will increase the value of the other. Additionally, demand response will lower the need for backup electricity generation capacity. Different types of varying renewable generation are substitutes.
6. In the EU and the EEA, national regulations for energy solutions in buildings should promote cost-efficiency. NZEBs are promoted, but it is not clear how they should be defined or how they should be handled if they do not become cost-effective should be handled.
7. The local distribution system operator (DSO) should be involved in the process when a customer wants to invest in a PV panel, to avoid instabilities in the electricity supply for the surrounding area.
8. One of the main barriers for new prosumer business models is the lack of or immature regulatory frameworks, which might be a consequence of the lack of experience of large-scale market integration of prosumers.

1 Introduction

1.1 About this document

The term *prosumer* was first introduced by futurist Alvin Toffler in 1981 [2]. He defined prosumers as people who produce some of the goods and services that they consume.

In this position paper, we focus on prosumers within the power sector. When people consume electricity and other types of power, they normally benefit from a reliable supply – a stable power system. As there must be an instantaneous balance between demand and supply of electricity at all times, stability can be ensured only by utilizing various types of flexibility services that exist within the power system. We therefore consider electrical energy and flexibility services as two distinct commodities, and an electrical prosumer will supply at least one of them. Furthermore, we discuss flexibility not only with respect to the very short term (e.g. arrangements for the disconnection of consumption when needed or the utilization of batteries) but also with respect to long-term considerations such as demand response in general or shifting demand to off-peak hours. With this relatively broad focus, we include relevant research from different research areas of FME CenSES.

This position paper summarizes findings in the case study of '*prosumers' role in the future energy system'*, mainly in non-technical language. The topic was selected together with the user partners[2] in FME CenSES. The content and conclusions in this paper are based on research conducted by the research partners in CenSES, and by the user partner Statnett. Furthermore, it has been developed in close collaboration with researchers in FME ZEN and FME CINELDI.

1.2 European policy and the growth of prosumers

The growth of prosumers should be understood in the context of the desire to avoid global warming. The Kyoto Protocol and its successor, the Paris Agreement [3], which entered into force in 2005 and 2016 respectively, are landmarks in global cooperation to combat greenhouse gas (GHG) emissions on a global scale. The goal is to limit global warming to well below 2 degrees Celsius from the 1990 level.

In the EU, a number of directives targeting the energy sector have been implemented in recent decades. The most recent directive is included in the EU's 2016 package 'Clean energy for all Europeans', also called the winter package [4]. As part of this package, the EU has committed to a decrease in CO_2 emissions by 40% by 2030, and to increase the share of renewable energy to 32% in the final energy consumption (Figure 1.1). The winter package marks the first time a strong focus has been put on the consumer side, in an effort to foster consumers' active participation in the energy sector, such that they become central players:

> consumers or communities of consumers will be entitled to produce, store or sell their electricity, allowing them to take advantage of the falling costs of rooftop solar panels and other small-scale generation units to help reduce energy bills. [5]

High feed-in tariffs for the power generation of energy from renewable sources have already fostered high increases in their share of the total generation, notably in Germany's *Energiewende* (Energy transition). From the start, the dominating technology was onshore wind power. However, As a consequence of the remarkable 80% drop in the costs of solar panels from 2008 until 2015 (Figure 1.2), there has been a take-off in distributed PV production (e.g. on the roofs of buildings). By installing PV, and sometimes batteries too, consumers become prosumers. In 2014, the share of solar power in power generation was 2–3% at the EU level. The European Commission expects that the growth of solar power will continue to increase: in its Energy Roadmap 2050, it foresees that the share of

[2] We call the stakeholders of the research centre, apart from the research partners, as user partners.

decentralized small-scale power generation will reach 6.5% in 2020, 10% in 2030, and 13.9% in 2050 under the current policy initiatives of 2010 [6].

Thus, we conclude that due to cost reductions for PVs and batteries, combined with political goals and corresponding incentives for environmentally friendly technologies, the share of share of electricity produced by prosumers in the future energy system will probably be higher than today.

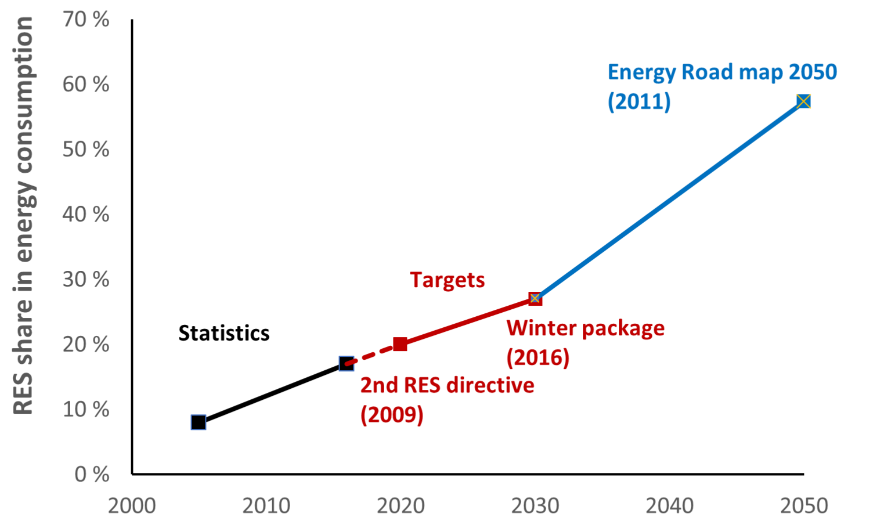


Figure 1.1: Renewable energy sources' (RES) share in total energy consumption in the EU: statistics and targets

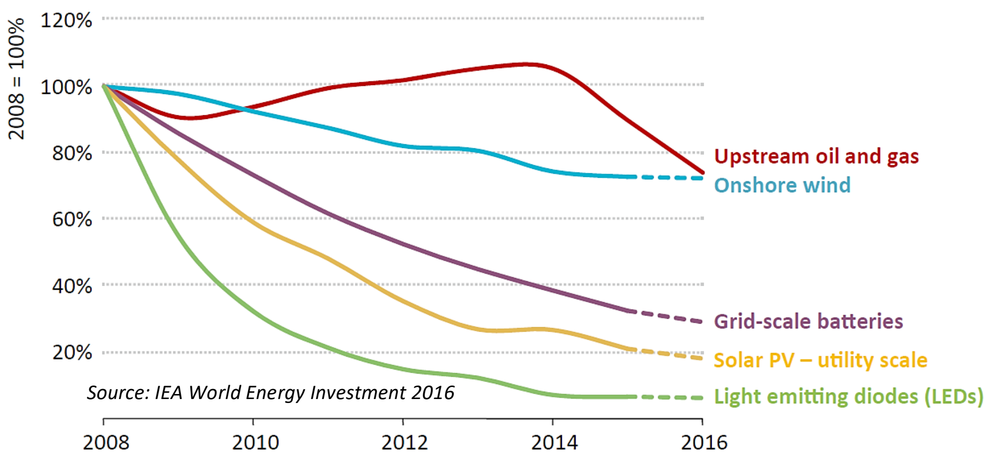


Figure 1.2: Cost reductions for green technologies

1.3 Prosumers in Norway

The circumstances of local power generation from PV and flexibility provision from prosumers in Norway are somewhat different than in other European countries. On the one side, the PV power generation profile does not match the annual demand profile. When demand is highest (in the winter), PV generation is lowest and vice versa. On the other side, there already are significant flexibility resources available in the Norwegian power system, due to the high share of reservoir-based hydropower. However, it is commonly expected that prosumers will emerge in the power sector in Norway. In 2016, the share of solar power in installed power generation capacity in Norway was below

0.1% [7]. In the same year there was a remarkable increase in the grid-connected solar power capacity compared with previously. According to the Norwegian Solar Energy Society's estimates, that growth continued in 2017 [8]. At the start of 2018, c.1000 customers were contributing surplus electricity to the national grid.

Even with the higher growth in solar-based power generation in recent years, prosumption is still a relatively marginal phenomenon in the Norwegian context. Intuitively, one might think it will remain that way, with moderate power prices, moderate support for renewables, and most electricity supplied by highly flexible reservoir hydropower. However, several Norwegian cities (e.g. Oslo) are experiencing higher growth rates in maximum electricity demand (i.e. peak load) than in annual consumption. There are several reasons for this, including an increase in the use of various electrical appliances and electric vehicle (EV) charging. Since grid companies ensure that there is always sufficient capacity in the grid, increasing peak loads will necessarily lead to grid enhancements, with corresponding costs and higher grid tariffs. Some of these costs may be avoided if local generation, batteries, or other resources for demand flexibility reduce the required capacity during the peak load times. Hence, demand flexibility such as short-term response to a price signal or a systematic shift in consumption from typical high-load hours to low-load hours can be of value to the system. The structure of tariffs charged for the distribution grid will affect the profitability of demand flexibility. In 2018, NVE suggested a mandatory structure for the grid tariff to incentivize lower peak loads [9].

1.4 Prosumers and societal transformation

While the EU and other key actors have strongly pushed the idea that consumers in the future will be 'the active hearts' of the energy system, enabling a low carbon transition through prosumption and flexible consumption, it should be highlighted that practical results have been sobering to date. While the sales of solar panels have continued to rise, flexible consumption has been difficult to realize. This suggests that while large resources have been spent on technology and market development, too little has been done to understand the social, cultural and practical elements in the choices of ordinary consumers in this context. As recently highlighted in a research paper published in *Science*, low carbon energy transitions involve technologies and economic considerations, but just as importantly, we need to understand the 'millions of citizens who need to modify their purchase decisions, user practices, beliefs, cultural conventions, and skills' [10]. To this end, an active eye should be kept on potential unintended social consequences of technological and economic developments and it should be borne in mind that transforming key societal infrastructure involves transforming society. Therefore, as Norway continues to push forward with new power tariffs, we should not only ask how the tariffs affect the power grid, but also what are their broader social and practical consequences? Who wins and who loses through the development?

1.5 Main research questions and methods

In Sections 2–6 we look at prosumers from different angles. An abstract is provided at the start of each section. In Section 2 we focus on understanding prosumers and their motivation through a sociological perspective. We also briefly present the history of prosumers, and we summarize CenSES studies based on interviews regarding the use of prosumer technologies. Thereafter, in Section 3, we consider practical and technical aspects such as the process and requirements for connecting prosumers to the distribution grid, and the role of advanced metering system (AMS) equipment. In Section 4 we discuss markets, incentives and regulation, and cover the important topics of support mechanisms for prosumers, the impacts of capacity-based tariffs, the impacts of EU regulations on the energy performance of buildings, and business models for prosumers. The design of prosumers' own local energy systems is discussed in Section 5. We report results from model simulation and optimization of local energy systems with different set-ups, which provides insights into the economic feasibility and physical suitability of distributed generation options such as PV, and flexibility such as battery storage optimization. In Section 6 we discuss the impact of prosumers on the energy system, both on a regional level, such as transmission to Norwegian cities, and on the overall energy system in Norway, Scandinavia, and Europe. We utilize findings from a study by the country's transmission system operator (TSO), and we report results from several quantitative simulation models on the impacts of prosumers with building-integrated PV production and prosumers with demand response (DR). Finally, we present our conclusions in Section 7.

2 Understanding prosumers

Abstract: *This section introduces the history of prosumers and outlines some relevant questions about the role of prosumers and power producing buildings in society, before briefly summarising some findings from studies of end users with prosumer technology conducted within CenSES. The role of the electricity prosumer within the framework of the energy system is new, and it may change the relationship between end users of electricity on the one hand and electricity and grid providers on the other. In general, the shift from consumer to prosumer heralds more symmetry in the traditional top-down relationship of company and customer and creates possibilities for co-production between them on services and value. Findings from interviews with end users of prosumer technology such as solar photovoltaics (PV) show that while economic incentives are currently meagre, climate concern, technological interest, and self-consumption are issues that still motivate people to become prosumers today.*

2.1 The role of the prosumer

Who are the users of prosumer technology and how can this central group of actors be understood? From a technical grid perspective, households are often simply referred to as 'loads' or in economic terms as customers. However, with the rising prominence of the smart grid, the increased importance of flexibility, and the prospects of wide diffusion of prosumer technology, efforts to understand the role of active, rather than passive, end users have gained new prominence.

Conceptually, the idea of the prosumer has existed for decades, but novel developments within the energy system have led to a revival in its relevance. As pointed out by scholars who have reviewed the field [13], the term 'prosumer' has ties to the traditional field of microgeneration, which has long been an important addition to the energy portfolios of many energy systems. The term was first coined by Alvin Toffler [2], to cover instances when people produced their own goods (not necessarily limited to energy instead of purchasing them from someone else. The classic example was the traditional housewife, whose home-based production of a range of goods (e.g. cleaning, child care) was completely without monetary value. In that sense, prosumers could be found 'making their own clothes, cooking their own food, repairing their own cars, and hanging their own wallpaper' [14, p. 519) as opposed to acquiring such goods and services in the marketplace. In the digital era, the term prosumer has been employed in fields other than the energy sector, for instance to address the consumption and production of digital content on the Internet [15].

Energy users become prosumers when they use local production capacity such as solar panels or wind turbines, individually or collectively, to produce energy for their own use or for sale in the energy market through the local grid. Some benefits are due to prosumers who either by automated means or manually offer up reduced or shifted consumption as a flexibility service to the grid. A potentially new era of prosumption is dawning, due to processes of digitalization, the introduction of the Internet of Things, and big data analytics, combined with globally falling prices of microgeneration technologies such as solar PV and batteries. Equipped with their own means to produce energy, households could radically transform social, technical, and economic conditions and relations in the energy system (e.g. [16]).

However, there are proponents and opponents of the role of power-producing buildings in society, and they have been observed employing various narratives of the disadvantages of power-producing buildings to influence policymakers and public opinion [34]. There is distrust among central actors in the industry, many of whom are generally suspicious that the actions of those who hold opposing views are simply motivated by local business interests without regard for the larger system. Kvellheim concludes that power-producing buildings need to be perceived by opponents as solving a significant problem if the concept is to become mainstream [33]. One such problem could be the challenge of peak load.

The return of the relevance of the prosumer should be considered with reference to the steady roll-out of smart meters and general smart grid development in energy systems around the world. Projects that are developing, implementing, and demonstrating the use of smart metering infrastructure are currently flourishing, with different implications for different actors (e.g. [17]-[19]). A key aspect of such trials includes efforts to make energy users engage more actively with the system through monitoring their own consumption with feedback technologies (e.g. [20]), new price tariffs [21], and automated systems [22], all of which are often aimed at reducing or shifting the timing of consumption to help balance strained grids [21]. The element of electricity production at the household level adds another layer to the modern ideal of the end users as engaged energy market participants.

According to Olkkonen et al. [23], prosumers are considered to differ from ordinary consumers in the sense that they are 'individuals-as-stakeholders' who engage in micro-production of energy by way of owning or managing some kind of local production capacity. When investigating the prosumer, the importance of looking at the changing relationships between users and energy companies is stressed, as prosumers may have radically different relationships with energy companies. Accordingly, Olkkonen et al. [23] argue that a reasonable way to analyse prosumers is by looking at how the stakeholder relationship of the user and energy system is changing. In theory, prosumers may no longer primarily see their role in relation to their energy company as important and, but cutting out the middle man, they could focus instead on negotiating a space in which to act in relation to concerns related to climate issues, for example. In other words, one way to see the changing of roles from consumer to prosumer is to see them as a process of enabling users to take on different kinds of responsibilities for their energy use. Although this way of ascribing of responsibility has been susceptible to critique [24], it has also shown to appeal to some users, as it constitutes a practical way to engender societal responsibility in the face of otherwise insurmountable challenges, such as climate change [25], [18].

By extension, it is possible to study more generally the relationships between prosumers and broader institutional and societal structures. For example, it may be of interest to probe how prosumption creates new power relations or strengthens existing ones [26] [27], or whether it might lead to new kinds of inequalities or enable exploitative relations [28] [29]. In the light of such potential challenges, it could be of concern to researchers and developers to gauge whether users are getting a better deal from becoming prosumers, and that they are not simply assigned more work and responsibility that might be better handled by institutional actors.

However, it does not necessarily follow that prosumption should lead to repressive relations. On the contrary, according to Olkkonen et al. [23], historically the concept of prosumption has been connected to ideas of grass-roots community energy projects that focus on group action [30] or energy citizenship, and that stress energy awareness and green behaviour [31]. Conversely, Wolsink [32] and Goulden et al. [33] have argued that since prosumers are energy producers who are responsible for their production capacity, the fact of personal ownership engages them as prosumers. It is mainly in this way that prosumers constitute an entirely new group of stakeholders in the energy market, since they are expected to behave differently than consumers. Even so, as Olkkonen et al. [23] argue, for much of the time, prosumers will depend on the grid administered by a grid company. While the situation might change in time (or some hypothetical models see [16]), at present most prosumers cannot rely entirely on their own production. For instance, a solar PV panel set-up without any kind of storage will provide complete coverage of electricity only intermittently, thus creating a need for some other source, such as the conventional grid, in other periods. Prosumers may also need an infrastructure to sell excess energy. Thus, another way of considering the relationship between the energy company and prosumer is as a symbiotic relationship, which Bremdal [36] has argued is an apt characterization when both parties are engaged in co-production and value creation.

2.2 Who are the Norwegian prosumers?

Research on household prosumers within CenSES has focused on interviews with demo project participants in the county of Trøndelag (TrønderEnergi, Nord-Trøndelag Elektrisitetsverk) and Hvaler Municipality in the county of Østfold (Fredrikstad Energi). Findings from research on household prosumers within CenSES have shown that often the most interested customers are in the older segment of the population. For instance, Hvaler had the largest buyer group of solar panels in the country in 2015, the year when the solar roll-out started, and the average age of the buyers was 60 years. This could have been related to cost: the cheapest PV installation in Hvaler costs around EUR 2000 (average EUR 5000, most expensive EUR 12,500). PVs appeal to the older adult buyer segment with a stable economic situation, characterized by having a decent amount of disposable income. Additionally, many people of that generation still remember the 'overconsumption meter' from the 1960s, which was a gauge usually placed in the kitchen and that would assert a maximum limit on load demand in the household. It lost its relevance after power tariffs were abandoned. However, since the regulator NVE has decided that power tariffs will be reintroduced (proposed start in 2021), the possibility of using local production to offset some of the peak demand of a household or neighbourhood may become more feasible. Additionally, some novel business models for residential solar PV are beginning to mature (discussed further in Section 4.3).

Currently, residential PV systems are still an expensive way to optimize local production and demand. Without generous subsidies, the economic motivation is not strong for most potential prosumers today. However, other motivations have been found to matter. In general, most of the people studied within CenSES and in other studies have reported that the environment is an important factor. Furthermore, there was an interest among some in owning and learning about new technology, and self-identifying as technology front-runners. The latter, combined with a concern for climate issues, was the most important motivation for most of the study participants. Among the participants in demo projects featuring prosumers, studies conducted within CenSES have identified users as commonly envisioning a future in which solar power would become increasingly important and when energy prices would rise and become more volatile. Some participants expressed that they would like to be more self-reliant and consume more of their 'own' electricity, but most of them considered it would be impossible without batteries or automation.

It is difficult for independent users to acquire a turnkey PV installation in the current market for PV. Thus, some study participants reported being engaged in PV demonstration projects simply because it there was a good purchase deal on solar panels – a technology that some had already read about quite extensively. In the case of those who had not yet invested in solar panels, some reported that they were awaiting further cost reductions, and one reported that the technology was not yet good enough (they were waiting for solar roof tiles). A few users reported participation in smart grid demonstration projects in order to learn more about smart energy monitoring because it was relevant to their professional life. Additionally, there were desires to become more self-sufficient, to be able to visualize energy (both production and consumption), to gain tools in order to pass on better attitudes to the younger generations (specifically, their own children), and a feeling of being part of something bigger. In many cases, the participants' concerns seemed to constitute a prosumer persona.

Some of the prosumers interviewed in CenSES projects provided narratives that highlighted the importance of the recruitment process for prosumers. As an example, several interviewees in demonstration project in Trøndelag highlighted that they would not have become prosumers if it had not been for the fact that they had been approached by their local electricity provider with an offer. In such instances, trusting relationships between providers and customers were highlighted as essential.

Incentivizing people to buy and install local means of power production and having them actively shift or shave their loads can make sense from a system perspective, as a way to reduce the strain on the local grid. Studies have revealed burgeoning developments within energy business models, in which the trading surplus energy at discounted prices among neighbours with some production capacity among themselves demonstrated the possibility of allocating benefits to single households. We have also seen system and user interests aligned when with regard to security of supply for the community as a whole. For instance, in the Smart Energy Hvaler project[3], study participants had a strong feeling of living with a strained and weak power supply, which became part of a greater collective consciousness of the people in the community. The feeling was evident in general scepticism towards the roll-out of EV charging infrastructure during a town meeting and subtle resentment of visitors from the mainland with carefree energy attitudes. The main success of recruitment of prosumers in Hvaler relates to their shared experience of the acuteness of energy shortage, and a common interest in increasing the robustness of their grid. This ties in with the reported motivation of many of the study participants who wanted to take part in and contribute in economic terms to a research and development project and with a local flavour rather than for the sake of personal economic gain. In this regard, the social value of placing a solar PV rig on the roof of a private house or garage in a place such as Hvaler should not be underestimated.

In conclusion, the environmental concerns that were found important for end users of solar PV are in one sense rather paradoxical, as Norway has abundant hydropower. Nevertheless, our studies revealed that participants located themselves in a larger national, international, and global context. They hoped or claimed to be early adopters and frontrunners of what they thought would be the future norm. Many considered their participation in demonstration projects as helping local companies to develop services and technologies that would positively influence the Norwegian energy situation (e.g. in new technological invention, innovative solutions). Some perceived themselves as participating directly in research and innovation projects, and that their investment would be directed toward them as much as towards their own production capacity. An overview of key drivers and barriers of Norwegian prosumers is presented in Table 2.1: .

Regarding further research, there is still a need to gain a better understanding of what might motivate customers to become prosumers, and how to determine and assign value to customer flexibility

Table 2.1: Overview of key drivers of and barriers to Norwegian prosumers

Drivers	Barriers
• **Environmental concern** • **Interest in new technology** • **Energy independence** • **Interest in smart technology** • **Inspire other people** • **Community contribution** • **Security of energy supply**	• Lack of sufficient economic incentives • Expensive investments • Lack of feasibility to change consumption patterns • Immature technology and business models • Lack of offers from suppliers

[3] Hvaler is a peninsula in the Oslofjord with a rather weak connection to the main grid. This requires either a expansion of the connection capacity or other smart measures to ensure security-of-supply.

3 Technical considerations related to grid-connected prosumers

Abstract: *This section discusses technical aspects relevant for grid-connected prosumers and the distribution system operators (DSOs). We discuss the possibility for becoming a prosumer based on the new smart meters planned for installation for all customers in Norway by 1 January 2019, the process for a household becoming a prosumer (i.e. an involved stakeholder), and relevant requirements for connecting a PV panel to the distribution grid.*

3.1 Introduction

The ongoing digitalization in Norway is reflected in the distribution grid, with the planned installation of smart meters for all customers. In addition, a number of DSOs install remote terminal units (RTUs) in MV/LV substations for further registration of data. The new metering technologies give the DSOs new and updated information about the status and power flow in the distribution grid.

3.2 Smart meters (AMS)

In 2011, the government determined that smart meters should be installed for all customers in Norway by 1 January 2019. Before this requirement, the regulations required that meters for hourly metering of consumption should be installed for all customers with a yearly consumption higher than 100,000 kWh. Introducing new technology in the distribution grid has been a part of the digitalization process in Norway [50].

With the new smart meters, all customers have, at minimum, hourly metering of their electricity consumption. This involves the installation of c.2.9 million new meters, of which households and cabins account for c.2.5 million meters.

The regulations relating to the smart meters require that the meters should be able to [51]:

- Store the meter data with a registration frequency of a maximum of 60 minutes. It should be possible to change the registration frequency to a minimum of 15 minutes.
- Have standardized interfaces that allow for communication with external equipment, based on open standards
- Be able to connect different types of meters (e.g. gas, heat, water)
- Secure data storage in cases of voltage outage
- Disconnect or reduce (by 'electrical fuse') the total load at the customer end, except for customers who are metered with a transformer (large customers)
- Send and receive price information (from energy contracts and network tariffs) and signals for load control and earth fault detection
- Provide security against misuse of data and unwanted access to load control functionalities
- Meter both active and reactive power in both directions (in/out).

The smart meters will be an enabling technology for new grid tariffs for customers in the distribution grid. With hourly metering of the consumption, there may be a possibility for a customer to have hourly prices for the electricity (e.g. an energy contract reflecting the market prices). Energy contracts and grid tariffs on an hourly basis will incentivize customers to secure a more flexible demand. An example of flexible demand for a household is load shifting for the water heater. The peak load of a water heater is between 08:00 and 09:00, which is also the peak hour for the Nordic power system. If 50% of 2 million Norwegian households shift their water heater load away from this peak hour, the peak load could be reduced by 600 MW [38].

Since all new meters should be able to meter both active and reactive power, to and from the customer, they have been designed for customers wanting to invest in a PV panel and become a prosumer.

3.3 Practical considerations for a household becoming a prosumer

The PV market in Norway is not very developed, and is both demanding and knowledge-intensive if an end user wants to become a prosumer by installing a PV system. The local DSO is also included in the process, because the DSO needs information about the electricity fed into the grid (e.g. in order to maintain sufficient voltage quality in its grid). Most of the largest DSOs have good information on their web pages relating to how a customer can become a prosumer [35].

There can be different processes for recruiting customers to become prosumers. In Norway, several marketing campaigns by energy utilities have been directed towards helping households to become prosumers more generally, but some households have become individual prosumers.

The process for connecting prosumers to the distribution grid is much the same for all DSOs. For a customer wants to invest in a PV panel on individual basis, the process can be summarized as follows:

- The customer contacts an authorized electrician to agree about technical and economic relations for the installation of the PV panel
- The electrician sends prior notification to the DSO, with information about the installation, via the DSO's message system (e.g. Elsmart, which is used by a number of DSOs)
- The DSO considers and approves the prior notice and sends an agreement for connection to the customer. The details of the agreement, including technical requirements to the installation, can differ from DSO to DSO.
- The customer receives information from the DSO if grid investments and/or change of meter are necessary. If the customer has to increase the size of the overload protection (at the connection point to the grid), the DSO can require that the customer pays part of the potential grid investments.
- The customer enters into a connection agreement with the DSO. The electrician installs the PV system and sends over requested documentation to the DSO, such as a message with information about completed installation.
- The DSO considers and approves the message, and, if necessary, a change of the meter is performed at the prosumer's property. Either the DSOs will pay for the new meter or the customer, depending on the DSO.
- Production by the PV system starts after all formalities have been approved and the prosumer agreement has been completed. The customer is registered as a prosumer and receives a certificate. The certificate is necessary in order to receive financial support from national and municipal support schemes.

Any PV system installed without DSO approval of the installation and that does not follow the DSO's requirements can have negative consequences for the low voltage part of the distribution grid. The customer is responsible for showing the prosumer agreement to their electrician, and proving that the installation is in accordance with existing requirements. Most DSOs require that information about a completed installation is received from the electrician before the PV system can start to produce electricity, and the customer that is responsible for ensuring this is done.

3.4 Requirements for grid-connected PV panels

This subsection describes the relevant requirements for connecting PV panels to the distribution grid, based on the work presented in [35].

Grid connection of distributed generation in a low voltage distribution grid can result in new operational challenges, such as increased voltage levels. An increased number of prosumers, feeding electricity into the distribution grid, can result in a change in the direction of the power flow (i.e. the power will flow upwards in the power system instead of downwards from large power plants to the customers). This in turn can result in an increased voltage instead of voltage drop. Under the existing regulations, DSOs are obligated to deliver electricity of a certain quality to their customers, which means that the voltage should be 230 V ± 10%. Too many prosumers located in an area can result in too high voltage, depending on local conditions and the status of the grid.

In the ProAktiv project, an overview of the technical requirements for connecting prosumers to the grid was developed. The most common standards and requirements used in Norway are EN 50438 (up to 16A per phase), VDE-AR-N 4105 (up to 100 kVA), and REN-paper 0342[4] (up to 25 kW). The DSOs have not decided on one specific standard to use, and therefore the three different standards exist. It is important that the technical requirements are followed, to ensure that the installation of the PV panel will not affect the voltage quality either at the point in the grid where the prosumer is connected or where other households located in the same area as the prosumer are connected. The technical requirements relevant for DSO are summarized in Table 3.1: .

Table 3.1: Overview of technical requirements in international and national standards relevant for Norwegian DSOs

Standards **Technical requirements**	**EN 50438** (up to 16A per phase)	**VDE-AR-N 4105** (up to 100 kVA)	**REN-paper 0342*** (up to 25 kW)
Voltage change due to PV installation	$\Delta U < 3.3\%$ (EN 61000-3-3)	$\Delta U < 3\%$	$\Delta U < 3\%$
Frequency and voltage interval when the system should remain connected	$47.5\ Hz < f < 51.5\ Hz$ $< U < 1.1 \cdot U_n$	$47.5\ Hz < f < 51.5\ Hz$ $0.8 \cdot U_n < U < 1.1 \cdot U_n$	$47.5\ Hz < f < 52\ Hz$ $0.9 \cdot U_n < U < 1.1 \cdot U_n$
Maximum disconnection time irregular frequency	0.5 s	0.2 s	0.5 s
Maximum disconnection time irregular voltage*	$U < 0.85 \cdot U_n$ – 1.5 s $U > 1.1 \cdot U_n$ – 3 s $U \gg 1.15 \cdot U_n$ – 0,2 s	$U < 0.8 \cdot U_n$ – 0.2 s $U > 1.1 \cdot U_n$ – 0.2 s $U \gg 1.15 \cdot U_n$ – 0.2 s	$U \ll 0.85 \cdot U_n$ – 0.2 s $U < 0.9 \cdot U_n$ – 3 s $U > 1.1 \cdot U_n$ – 3 s $U \gg 1.15 \cdot U_n$ – 0.2 s
Interval for auto reconnection	$47.5\ Hz < f < 50.05\ Hz$ $0.85 \cdot U_n < U < 1.1 \cdot U_n$	$47.5\ Hz < f < 50.05\ Hz$ $0.85 \cdot U_n < U < 1.1 \cdot U_n$	$47.5\ Hz < f < 50.05\ Hz$ $0.9 \cdot U_n < U < 1.1 \cdot U_n$
Minimum time delay before reconnection	60 s	60 s	60 s
Unbalanced generation	No direct requirements, but the standard is only valid for installations up to 16 A per phase	Dissymmetry ≤ 4.6 kVA 1-phase converter without communication: max. 3 x 4,6 kVA	≤ 16 A with 1-phase converter
Feeding of harmonic ampere	EN 61000-3-2 up to 16 A	EN 61000-3-2 up to 16 A EN 61000-3-12 up to 75 A	IEC 61000-3-6
Short and long-term flicker	EN 61000-3-3 up to 16 A	EN 61000-3-3 up to 16 A EN 61000-3-11 up to 75 A	$P_{st} \leq 0.8$ $P_{lt} \leq 1$
Voltage regulation with reactive power	Yes*	Yes*.	No requirements
Gradual modification of active power with at high frequency	Yes*	Yes*	Yes*
Feeding of DC current	≤ 0.5% of nominal current IEC TR 61000-3-15	No requirements	PV unit shall not feed in DC current
Relay for island mode	Detection and disconnection within 2 s	Detection and disconnection within 5 s	Detection and disconnection within 0,5 s

[4] Still under development

Note: * There are different requirements for disconnection time at very low ($U \ll$) and low ($U <$) voltages. There are similarly different requirements are for very high (U≫) and high (U>) voltages.

3.5 Research needs

Distributed generation at customer level is new for the DSOs and there is a need for more experience and research is this respect. For instance, which requirements for connection will ensure the quality of supply for the first prosumer and for the last customer. Further research is also needed on the use of new information derived from the grid in order to ensure more cost-efficient operation and maintenance of the distribution grid, the use of prosumers (flexibility) as an alternative solution to grid investments, and the development of requirements to secure increased numbers of prosumers, while simultaneously maintaining quality of supply. Some of these topics will be further elaborated upon within FME CINELDI.

4 Markets, incentives and regulations

Abstract: *In this section we elaborate on the effect of markets, incentives, and regulations on prosumers. We address the question of how regulations and market developments provide incentives for prosumers, and what financial incentives exist. Additionally, we consider the impact that prosumers have on the overall energy system and whether they contribute positively to socio-economic welfare in Norway.*

4.1 Legal framework and financial support for prosumers

In Norwegian regulations, an arrangement exists for customers who contribute surplus electricity to the nation grid (*plusskundeordning*). Through this arrangement, the grid company is obliged to accept a bidirectional flow of energy but is not obliged to buy energy from the prosumer. Hence, the customer has to find a power company that both supplies power and buys the surplus power produced.

The arrangement is limited to customers who feed no more than 100 kW into the grid at their connection point. If higher amounts are sometimes fed into the grid, the customer needs to have one or more licenses (e.g. *omsetningskonsesjon*) from the Norwegian Water Resources and Energy Directorate, and will not be defined as a surplus customer. The reason for the 100 kW threshold is the advantage the surplus customer is given for not paying a tariff for selling their surplus electricity through the grid (*innmatingstariff*). There is no technical argument for the threshold in general. Furthermore, the 100 kW threshold is not a real limitation for any regular household in Norway, but for larger sites such as a school, it might limit the dimensioning of installed generation capacity.

The most significant financial incentive for becoming a 'plus customer' in Norway is the national investment support by the public enterprise Enova. Enova offers a fixed sum of NOK 10,000 in support of residential installations, plus 1250 NOK/kW of installed capacity up to 15 kW, where the support cannot exceed 35% of the cost. A 3 kW installation corresponds to NOK 13.750 and a maximum of NOK 28.750 for a 15 kW installation.[5] In addition to Enova, there are some local support schemes for renewable small-scale energy production. One example is Oslo Municipality, which offers to refund up to 30% of the costs. Financial support cannot be received for the same measure from more than one source. In principle, new renewable electricity generation also qualify for el-certificates if they are in operation before 2021. Depending on the price of el-certificates, the income from el-certificates will vary. If the price is 36 NOK/MWh and the production is 8 MWh/year, the prosumer could earn NOK 288 per year. However, due to a starting fee of NOK 15,000, el-certificates are not and incentive for small-scale producers of electricity (for a further discussion, see [40]).

[5] https://www.enova.no/privat/alle-energitiltak/solenergi/el-produksjon-/

4.2 How do the capacity-based tariffs affect 'surplus customers' (*plusskunder*)

There are ongoing discussions about future grid tariffs in the distribution grid. The current trend is for the peak load (i.e. the maximum consumption within any given year) to have a higher growth rate than that of the total yearly electricity consumption. Since the grid capacity must be dimensioned to peak load circumstances, this gives reduced average utilization for the grid. In the long term, grid tariffs will affect grid utilization and the need for costly grid enhancements. Recently, the Norwegian grid regulator (NVE) suggested that a capacity grid tariff should give customers incentives to reduce their peak load. NVE has also suggested that the energy part in the future grid tariff should only cover the costs related to marginal grid losses. Further research is needed on how electricity consumption might change if a new grid tariff is implemented. In the following, we describe the consequences for prosumers when changing from an energy-based grid tariff to a capacity-based grid tariff, based on the work done by Sæle and Bremdal [39].

Today, the most common grid tariff for Norwegian residential customers is an 'energy tariff' consisting of a fixed part [EUR/year] and an energy part [EURO CENT/kWh], as illustrated in the following formula:

Energy tariff = Fixed part + Energy part (1)

An alternative to the energy tariff is a capacity-based tariff. The latter can be specified in different ways. For example, it can consist of a fixed part [EUR/year], an energy part [EURO CENT/kWh] covering only the marginal losses in the grid, and a power part *[EUR/kWh/h]*, as illustrated in the following formula:

Capacity-based grid tariff =
Fixed part [EUR/year] + Energy part [EURO CENT/kWh] + Capacity part [EUR/kWh/h] (2)

The settlement of the consumption is based on hourly values from the smart meter. The capacity part can be settled by different methods, such as the average of the three maximum values during one month or the average of three maximum values in defined peak load periods. NVE's proposed capacity tariff differs from (2), and it has suggested that the fixed part should be a capacity subscription, and that the capacity part should be an additional cost per kWh whenever the consumption exceeds the subscribed amount.

A case study has evaluated the consequences for a prosumer when changing from an energy-based grid tariff to a capacity-based grid tariff as specified in (2) above. Hourly data for a typical residential customer (calculated from 100 residential customers) and hourly values for a PV model, based on solar irradiance for a specific area have been used to model a prosumer for 2015. Figure 4.1 shows the load (blue curve) and generation (orange curve). The values on the x-axis are the hourly values for one year (8760 values in total), starting on 1 January and ending on 31 December.

According to the regulations specified by NVE, the maximum allowed income for DSOs (obtained by the tariff set by NVE) should not be affected by the applied structure for the grid tariff. The calculations in the report [39] are therefore based on the assumption that an average household customer should have the same yearly costs with the alternative grid tariffs. The aforementioned average household customer has a yearly consumption of 16.659 kWh, the modelled PV panel (3.06 kWp) has a yearly generation of 1692 kWh, and the prosumer buys 14.967 kWh from the grid per year.

The calculations of grid tariff costs are based on the different alternatives of the grid tariff presented in Table 4.1: , where EUR 1 = NOK 10. The calculations have been performed for eight alternative cost combinations between the energy part and the capacity part of the capacity-based tariff. The fixed part is equal for all the alternatives. For the energy tariff, the energy part is unchanged. For the capacity-based grid tariff, the energy part increases from minimum (representing only the costs for network losses) to maximum (equal to the energy tariff), and the resulting capacity part is calculated (such that the income to the DSO is unchanged when the tariff is changed). For the last alternative (alternative 8 in Table 4.1) the capacity part of the tariff is zero, which means that in this alternative the energy tariff and the power tariff are equal.

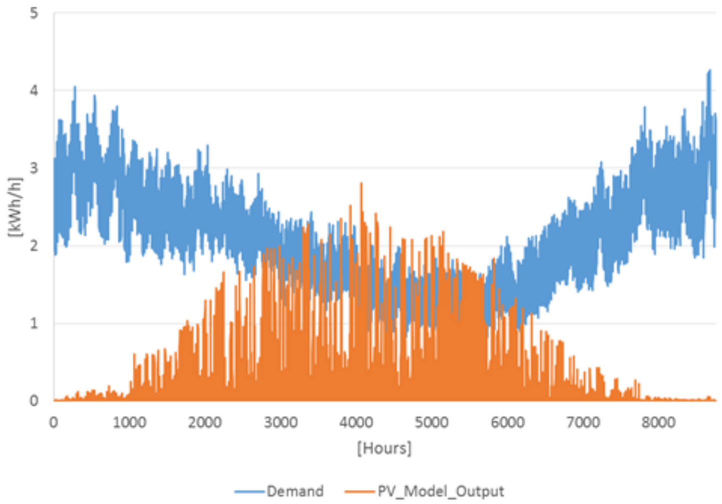


Figure 4.1: Load curve for typical residential customer and modelled PV generation [39]

Table 4.1: Alternatives in the grid tariff for the household customer and prosumer

	Energy tariff		Capacity-based tariff			Capacity part/Energy part
Alternative	**Fixed part***	**Energy part****	**Fixed part**	**Energy part****	**Capacity part*****	
1	200	4	200	0.5	17.98	35.96 (= 17.98/0.5)
2	200	4	200	1	15.42	15.42
3	200	4	200	1.5	12.85	8.56
4	200	4	200	2	10.28	5.14
5	200	4	200	2.5	7.71	3.08
6	200	4	200	3	5.14	1.71
7	200	4	200	3.5	2.57	0.73
8	200	4	200	4	0	0 (= 0/4)

* [EUR/year], ** [EURO CENT/kWh], *** [EUR/kWh/h]

The residential customer has yearly grid costs of EUR 934 (excluding VAT or other taxes, and energy costs) with the alternative grid tariffs (Table 4.1:), both for the energy-based grid tariff and the capacity-based grid tariff. For the prosumer, the changes in the different tariff elements affect the total yearly costs. The yearly costs for the prosumer are EUR 798.68 with the energy grid tariff, but with the capacity-based grid tariff the yearly costs decreases with the increasing energy part and decreasing capacity part (from left to right in Figure 4.2). For example, in alternative 6, the yearly grid costs are EUR 831.76, but in alternative 1 the corresponding value is EUR 914.10.

Figure 4.2 shows that for the energy grid tariff the yearly costs for the residential customer and the prosumer are unchanged, but the cost level for the prosumer is lower due to reduced amount of electricity bought from the grid. For the capacity-based grid tariff the yearly grid costs for the household customer are unchanged (grey bars), but the yearly costs for the prosumer are reduced with increasing energy part (from alternative 1 to 8) and decreasing capacity part. The cost reduction occurs when a larger share of the costs is moved from the capacity part to the energy part of the grid tariff. The green curve in the figure shows the value of capacity part divided by energy part (values presented in Table 4.1.)

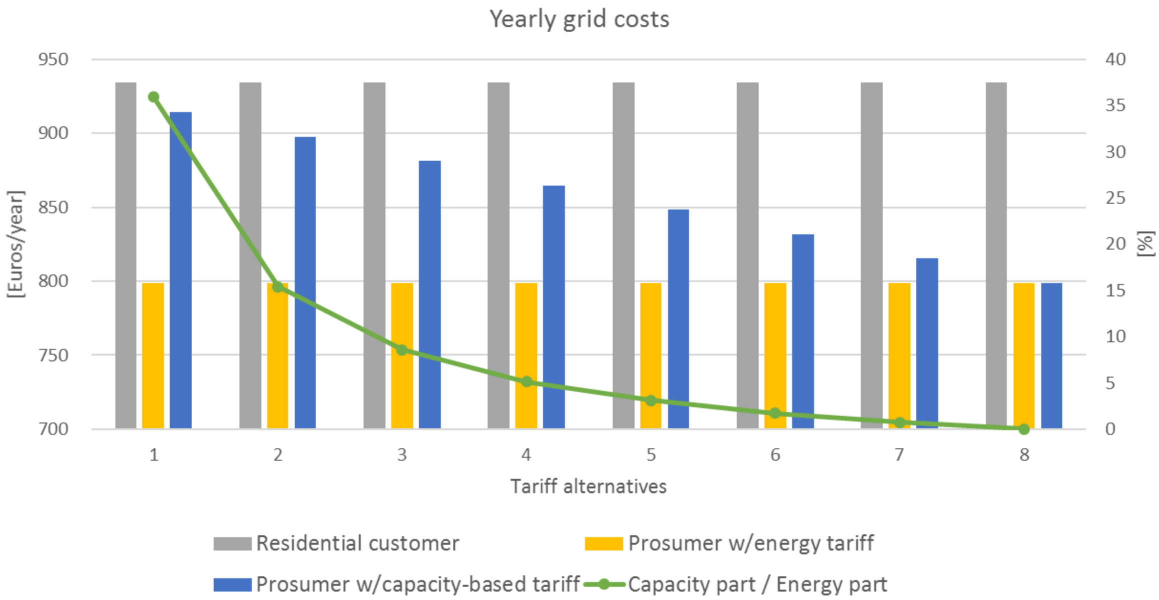


Figure 4.2: Consequences for prosumer when changing different parts in the grid tariff [39]

The calculations show that when changing from an energy-based grid tariff to a capacity-based grid tariff, the benefits for the prosumer from feeding electricity into the grid will be reduced. This will support the assumption that increased self-consumption for prosumers will be most beneficial when a capacity-based grid tariff is introduced. Self-consumption in peak load periods is most beneficial.

4.3 EU regulation on the energy performance of buildings (EPBD)

About the EPBD

The European Union has set ambitious targets through the Energy Performance of Buildings Directive (EPBD), which covers areas such as energy requirements, energy labelling, health and well-being of users, and requirements for technical systems. The first version of EPBD (Bygningsdirektiv I in Norway) was introduced in 2002 [59], and among other things included of a methodology for calculating the energy performance of buildings. The revised EPBD (Bygningsdirektiv II) in 2010 [58] built on the previous calculation methodology and introduced the idea that energy performance requirements for buildings should be cost-optimal. In addition, the concept of nearly zero-energy buildings (NZEBs) by 2020 was introduced as a target. The latest amendment to the EPBD in 2018 concerned strengthening the focus on the renovation of the building stock in addition to the targets from the previous directive [59].

Minimum requirements should be based on cost-effectiveness

According to the EPBD, member states of the European union (also including Norway through the EEA agreement) are required to set minimum energy performance requirements for buildings according to a cost-optimal calculation [60] . The goal is to define requirements to minimize global costs over the lifetime of the building. The global costs include all costs related to investment, annual cost, and disposal. These requirements are dependent on the building type and will change between regions since the global costs will depend on factors such as energy costs, climate conditions and construction costs. The following example can be used to explain the basic principle: if the energy cost were to increase and everything else were to remain constant, it would be optimal to increase investments in energy performance measures such as wall insulation. The logic is that if the discounted reductions in annual costs are larger than the increase in investment costs, the global costs can be reduced.

Nearly zero-energy buildings (NZEBs)
There is an implicit assumption in the EPBD that NZEBs will soon be cost-optimal. However, such a development is not certain and there is a lack of information on what will happen if NZEBs do not become cost-optimal. The definition of an NZEB provided in Article 2 of the EPBD is:

> a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. [58]

One interpretation of the definition is that the EPBD requires large-scale introduction of prosumers. However, the interpretation is not as straightforward as one might assume, since the exact definition is up to each EU member state to define according to the cost-optimal calculations. An overview of important features of cost-efficiency and NZEBs is presented in Table 4.2.

Table 4.2: Cost-optimal requirements versus NZEBs

Cost-optimal requirements	Near Zero-Energy Buildings (NZEBs)
• Motivated by market failures in the building sector leading to underinvestment in energy-related building measures • Member states should set requirements that minimize the global cost of the building over the building's lifetime • Revise requirements every 5 years, to adjust to market, climate and macroeconomic conditions • Member states must use a methodology that satisfies some general criteria when determining the cost-optimal requirements • Much discretion is left to the national implementation of the EPBD. • To date, the cost-optimal requirements have been tightened over time (e.g. more insulation required in the walls)	• The EPBD states that all new buildings should be nearly zero-energy buildings. • Exact definition of an NZEB is not clear • The EPBD states that policymakers should implement measures to ensure that NZEBs become cost-optimal (e.g. promote market and technology development to reach the goal) • Unclear what happens if NZEBs do not become cost-optimal • The EPBD does not strictly require on-site renewables, but they are encouraged

Flexibility in national implementation
Implementation of the EPBD varies considerably across Europe. For example, the defined values for the maximum primary energy consumption vary by a factor of 4 to 5 [61]. The following degrees of freedom for the national implementation of the EPBD will have an important impact on the number of prosumers in the energy system:

- How on-site and off-site renewable energy resources are promoted through incentives and regulations
- The definition of the primary energy factor of energy supplied to buildings
- Assumptions used in the cost-optimal calculations of energy performance.

An important aspect to consider is which energy resources are included in the building energy calculation. If the national implementation allows only on-site production to be included, it will lead to a large increase in the number of prosumers since this would be the only way to fulfil the requirement in the case that renewable energy provided through the grid or district heating is not included in the calculation. One reason to implement such a restriction would be that it is less complex, since the generated electricity would be tied to the individual building and not influenced by conditions in the aggregate power system, such as the generation mix becoming more renewable over time. However, requiring on-site generation would mean that society would miss opportunities to build the renewable energy sources elsewhere with better conditions. Such conditions could be improved economies of scale for large wind farms and solar farms or improved site-specific renewable energy conditions such as increased and more stable wind speeds.

The primary energy factor for energy supplied from the grid accounts for how much primary energy is used to produce 1 unit of final energy delivered to the end user. Currently, it is set to 2.5 in the EU [62] but member states can apply a different factor if it can be justified. It follows that if the primary energy factor is set higher than the generation mix in the power system justifies, the energy supplied from the grid will have a regulatory disadvantage in cases when the requirements for the energy performance of buildings are based on the amount of delivered primary energy. In turn, such a disadvantage for energy supplied from the grid would lead to favouring of local solutions such as increased amounts of prosumers.

As already mentioned, the EPBD states that requirements related to the energy performance of buildings should reflect the cost-optimal levels of energy-related measures. This means that the assumptions used in the calculation method have an important impact on the result. For example, if the discount rate used were lowered, it would mean that capital investments such as on-site renewable energy would be relatively more favourable.

To date, the requirements for the energy performance of buildings have been focused on reducing the energy needs of buildings. The introduction of NZEBs in the EPBD is closely related to the issue of distributed renewables and could influence the number of prosumers in the energy system, although such an outcome would depend largely on the national implementation of the directive. A high degree of flexibility is left to the national implementation in order to facilitate a reasonable policy from a socio-economic point of view. For some member states, requiring on-site or nearby renewable energy sources could be a viable option to increase the share of renewable energy in the energy system if other options are scarce. However, this would ideally be seen in conjunction with opportunities for large-scale deployment of renewable energy sources elsewhere in the energy system.

In Norway, only the first EPBD from 2002 has been implemented so far. The 2010 revision has not yet been included in the EEA agreement from Norwegian side. In this respect, the responsible governmental agency is the Ministry of Petroleum and Energy, but it has not yet developed EPBD principles for Norway [82].

4.4 Business models and examples of prosumer initiatives in Norway

With many interconnected components and stakeholders, some of the main challenges of power markets are (1) to capture accurately and allocate the value of the energy provided through business models [63] and (2) to ensure energy is reliable, affordable and sustainable (the 'energy trilemma') [64]. The introduction of prosumers makes these challenges more complex, as prosumers take the role of both supplier and consumer. In this section, we give examples of prosumer business models in general and prosumer initiatives in Norway in particular, of which three have been studied in CenSES. The Norwegian initiatives include revised business models for energy trading to facilitate prosumers and new valuable technologies.

Energy consumption has the potential to become more responsive by coordinating end-user technologies, such as solar PV, batteries and EV charging. Prosumers' participation in energy markets is therefore a promising way to facilitate the integration of variable renewable energy. End users in most current power markets are billed on the basis of energy consumption rather than power flow. Currently in Norway, only large consumers (industry and commercial sector) are billed on the basis of their peak power outtake as part of the grid tariff. Creating correct and sufficient incentives to trigger growth in valuable prosumer services and products might therefore depend on real-time metering infrastructure and revised business models and tariffs to reflect the varying price and availability of power.

Today, a typical business model for a prosumer in Norway would be to participate in the surplus customer arrangement (*plusskundeordningen*). New business models for prosumers can be subdivided into three types [16]: peer-to-peer models (P2P), prosumer-to-grid models (P2G) and organized prosumer group models (OPG):

- *Peer-to-peer models (P2P):* These models are inspired by the sharing economy and are based on the same principles as Airbnb and Uber. Consumers pay independent prosumers directly through a decentralized market platform. The models allocate value and risk to prosumers. The main driver is knowledge of where the energy comes from, as well as better prices due to direct payment. Barriers include the challenges in designing and enforcing regulation to ensure reliable supply if single peers cannot produce power. A P2P business model is not an option within the current regulation in Norway and there are no known Norwegian examples. An example of the P2P model is Vandebron in the Netherlands.[6]
- *Prosumer-to-grid models (P2G):* In contrast to P2P, P2G models are more structured and characterized by trading between prosumers and grid operators (e.g. within smaller microgrids) [1]. Energy offers and bids are continuously matched, and the main goal is to ensure efficient use of all energy units. If the prosumer is connected to the main grid, energy can be traded externally. Allocation of value and risk is unchanged from current power markets and can vary between different examples depending on the asset ownerships. One driver is the long-term efficiency gains. However, at the core of P2G models there is a lot of real-time data, IT infrastructure, and complex algorithms. One of the greatest barriers in P2G models is making the complexity easy and affordable to deal with for the market participants. The 'surplus customer' arrangement is a version of the P2G model, as prosumers feed surplus energy back to the grid. An example of this model is Brooklyn microgrid.[7]
- *Organized prosumer group models (OPG):* Such models are characterized by communities pooling prosumers together, and thereby reaping benefits through cooperation and synergies. Trading in OPG models happens through an *aggregator*, an entity that collects energy from prosumers and trades it internally and externally. With sufficiently many prosumers, the community could grow into a virtual power plant. OPG models offer shared allocation of value and risk for the community, which is also the natural driver for such models. The question of how to fill and manage the aggregator role remains a barrier. OPG models are possible in Norway, both through the 'plus customer' arrangement for housing cooperatives and through third-party ownership of distributed production. More detailed allocation in OPG models in Norway will be possible when Elhub[8] goes live in 2019. An example of the model is the PowerMatching city.[9]

[6] https://vandebron.nl/
[7] https://www.brooklyn.energy/
[8] https://elhub.no/
[9] https://www.dnvgl.com/technology-innovation/broader-view/sustainable-future/vision-stories/power-matching-city.html

A lack of willingness to adopt a more complex operation of the power system, as well as privacy issues, is slowing down the rate of development of prosumer business models. One of the main barriers includes the lack of regulatory frameworks and immature regulatory frameworks, which might be a consequence of lack of experience of large-scale market integration of prosumers. Another barrier is the uncertainty related to reliable operation of prosumer networks, which could lead to redundant investments in generation capacity and metering infrastructure. A study by Olkkonen et al. [22] established that energy companies were mostly reactive and that end users were impatient during the development of prosumer initiatives. Without a developed market role for prosumers, ordinary citizens are facing barriers for testing, assembling and procuring local production facilities. The mandate on utilities to accept prosumer energy into the grid (the surplus customer arrangement) is only recent, and the low price of electricity in Norway delays returns on investments. Options to remove these barriers, besides waiting for prices on PV to drop further, are (1) to gain a better (1) understanding of the value of prosumer flexibility and (2) to develop business models that capture and allocate this value. The following are some examples of prosumer initiatives in Norway:

- *TrønderEnergi:* In a study conducted by Throndsen et al. [37], the local utility TrønderEnergi (hereafter abbreviated as TE) launched a questionnaire to recruit prosumers for a solar PV demo project. In that way, users were able to 'market' their motivation and suitability for becoming a prosumer. The business model was based on TE renting roofs from selected participants who paid a monthly subscription of NOK 500 (roughly EUR 45) for a solar panel system estimated to produce c.4000 kWh per year. Thus, TE took on the investment risk, whereas prosumers had a fixed rate for energy produced by their panels. While each household was given access to 4000 kWh per year of moderately cheap electricity, the utility was able to gain knowledge of the local effects of including residential solar PV, as well as valuable market knowledge in the field. The model can be classified as an OPG model, whereby TE allocated the costs of the solar installations equally among the prosumers.
- *NTE:* A similar initiative by Nord-Trøndelag Elektrisitetsverk (NTE) has been studied within CenSES. Households were selected for a demo project based on an estimated financial ability to participate and suitability of house and roof. The business model was based on prosumers taking the risk and purchasing their own solar panels, either outright or through regular down payments over 15 years. All panels were the same size and type. The participants signed a contract with NTE to become surplus customers, meaning any surplus energy generated by the PV panels would be purchased by NTE at spot price. The contract was signed for 15 years, during which time the supplier would be responsible for service and maintenance of the panel. In the spring of 2017, NTE increased their purchase price by a few øre (about .5 Eurocent). The model can be classified as a P2G model, in which individual prosumers take all risk and trade their surplus with the system.
- *Smart Energi Hvaler:* The initiative by Smart Energi Hvaler (SEH) has been studied in CenSES. Hvaler Municipality, which comprises a group of islands off the coast of Fredrikstad, is connected to the mainland grid with only one connector and this fact motivated the development of local energy supply. A type of tariff under testing was called Smart Neighborhood, which made electricity 30% cheaper if there was a surplus of solar power in the neighbourhood. The price reduction relates to the OPG model, in which the benefit of surplus power is shared by the community. SEH proved difficult to implement due to the structure of the billing services on the market. Currently, Hvaler has c.100 privately owned PV installations capable of producing about 3000–5000 kWh/year. The cost of a PV installation was originally around EUR 5000, and financial support from Enova reduced the total investment (including installation) to around EUR 3500. Revenue for owners was ensured through fixed support of EUR 0.08/kWh sold, which was in addition to the spot price. This gave a return on investment of about 10 years, but was guaranteed only until the end of 2018. Less risk on investment was dependent either on (1) rising prices or (2) a customer's ability to change loads to reduce the grid tariff. The incentive for load shifting is

dependent on the tariff structure. Since the introduction of smart meters, all residents have been subject to a capacity-based tariff, meaning that the bill for network usage is measured by peak load (see Section 4.2, Table 4.1). Thus, adding automation may benefit the usefulness of panels (e.g. water heaters are a viable way to shift demand by storing energy when the sun is shining).

- *Otovo:* The start-up company Otovo launched its business model in the market in 2016 and quickly became the market leader in sales of solar panels to Norwegian households. The company calculates the solar power potential for new customers, reduces the investment cost barrier by providing loans, and offers training to installation personnel. By handling the whole process from planning to installation of solar panels, it has removed a major barrier to the procurement of solar PV for small-scale customers. Furthermore, Otovo has established a power company offering an exchange scheme among neighbours called Nabostrøm.[10] In this model, customers can subscribe to ensure their energy consumption is balanced with as much locally produced solar power as available. This means customers indirectly buy energy from their neighbours through the retailer. When there is not enough solar power to balance consumption, Otovo buys and sells power from the spot market. The approach can be seen as a first step towards a P2P model.

4.5 Welfare effects of prosumers

A recent master's thesis from the Norwegian School of Economics [66] investigates the development and possible welfare effects of small-scale prosumers (i.e. customers with a net injection that never exceeds 100 kW) in the Norwegian power system, and particular attention is paid to customers who invested in rooftop solar panels. Currently, such customers are subsidized by direct contributions (e.g. from Enova) and favourable network tariffs (in the distribution network). Although still at a very low level, the number of prosumers has risen sharply in recent years.

In the master's thesis, Vestby and Dvergnes discuss the potential benefits described in international studies, from the perspective of an increasing number of prosumers. The benefits include: increased security of supply, more affordable electricity, improvements in sustainable power production, innovation and competition, emission reductions, more efficient land utilization, avoided or reduced grid losses, avoided or reduced investments in grid capacity, additional system flexibility, improved recovery capability, improved energy efficiency, and energy democracy (more power controlled by individuals). Vestby and Dvergnes argue that many of these benefits have lower value in the Norwegian power system than elsewhere (e.g. in Germany and the UK), since power is already relatively cheap, secure, flexible, and with low emissions in Norway. There are a number of technical and distributional challenges associated with an increasing number of prosumers in the distribution networks, and the authors maintain that a move from volumetric tariffs towards higher fixed charges, depending on load subscriptions, could provide more appropriate incentives for potential investors.

The main conclusion in Vestby and Dvergnes's master's thesis is that prosumers may be beneficial to the Norwegian power system. However, any net benefits will probably be project-specific and depend on conditions such as location and on how closely production and consumption coincide. There may be untapped potential that can be triggered by technological advances in tools such as distributed storage and demand response.

[10] https://www.otovo.no/grid/

5 Designing prosumers' energy systems

Abstract: *Modelling prosumer energy systems provides insights into the economic feasibility and physical suitability of distributed generation options. Section 5 reviews modelling efforts focused on the design of the prosumer size of solar PV, the role of battery storage on increasing flexibility, combined battery and solar PV under different conditions, and ongoing research on aggregators and other model-driven analyses.*

5.1 Introduction

Various energy modelling tools exist for the evaluation of engineering, architectural and economic aspects of prosumers' energy systems. Energy analysis tools provide insights into building design, demand profiles, the operational supply–demand energy balance, and economic feasibility. According to the United States Department of Energy [67], c.400 energy-modelling tools are available to assess buildings' energy aspects. Their main applications include physical design, calculating load profiles, estimating requirements for energy equipment, and performing cost–benefit analyses of energy system designs. Depending on the problem context and the area of expertise, the models analyse different aspects of the prosumer energy system. For example, whereas architects focus on dwelling design and insulation efficiency, engineers deal with the physical equipment feasibility of the prosumer energy system. Paradis [68] and Jebaraj and Iniyan [69] performed whole-household energy analyses in which they placed emphasis on house orientation, glazing and day lighting in order to assess the buildings' energy efficiency. Charron and Athienitis [70] present a design for a net zero-energy house in which solar technologies are used for heating and electricity consumption. Their models performed load calculations to select a customized solar-based system. In other models, such as those reported by Norton and Christensen [71] and Liping Wang et al. [72] load simulations were performed to calculate annual energy requirements, which served as basis for the energy system sizing analysis and the cash flow calculation for payback periods. Overall, for this type of energy analysis, known simulation software is used, such as TRNSYS [73] and Energy Plus [74]. These software tools allow for flexible implementation of different energy system applications, configurations and load characteristics to calculate long-term cost savings. However, for specific problems or studies, they may lack certain features or are not easily customizable.

5.2 Modelling prosumers' energy systems: aggregators and distributed generation

Roos et al. [75] have presented a model for a load aggregator that participates in the wholesale power market and the regulation capacity market. Their model represents the physical system of each consumer as part of the aggregator portfolio, and in a case study they used data from a set of Norwegian electricity consumers. The customer portfolio was composed of medium-size commercial electricity consumers, including shopping centres, food production sites, district heating sites, and greenhouses. Flexibility was acquired by reducing heating loads, substitution between electricity and oil/gas when supplying heating loads, reducing air conditioning, and energy efficiency measures for lighting. The results of Roos et al.'s study show that the aggregator's value largely depended on within-day price variations, leading to a cost reduction of c.4%. The authors highlight the importance of including both types of markets for a load aggregator. Roos et al.'s study is followed up by Ottesen et al. [76], who propose a general classification of load units according to their flexibility properties. The authors describe the implementation of a rolling horizon deterministic planning and rolling horizon stochastic planning in the case of a Norwegian university college building.

Ottesen et al. [77] expand the concept of flexibility from prosumers by assuming that the aggregator can control prosumers' flexible energy units. The new concept explicitly models the flexibility properties of the energy systems in the prosumers' buildings for three building groups: (1) a community consisting of public and commercial buildings, (2) households and second homes, and (3) an industrial plant. The community prosumer was Hvaler Municipality, which had 6800 electricity consumers aggregated as a single community prosumer. Every consumer had a smart meter that allowed collecting hourly consumption data. The information on the industrial plant was derived from Norske Skog Saugbrugs and Enfo Energy. The model calculated that the value of flexibility was in the order of 12% of the total costs.

Flexibility requirements for on-site balancing of supply and demand have emerged as a new feature in designs for prosumers' energy systems. Bødal et al. [78], identify and discuss four flexibility services for prosumers: (1) time-of-use price (ToU) or different tariffs, (2) kWmax control, (3) prosumer self-balancing (maximize renewable usage), and (4) islanding. These services have been actively studied and implemented in two Norwegian EU Horizon 2020 projects: INVADE and EMPOWER.

The INVADE project aims to coordinate a battery-supported system to deal with imbalances in distribution grids. Together with smart meter technologies, batteries will create prosumer flexibility (without affecting comfort) and will allow for the deployment of larger renewable capacities. Recent studies have shown that the value of storage for prosumers is in the order of 10% in savings. For example, under a time-of-use price regime, the prosumer is exposed to tariffs that vary in time dynamically (hourly) or in pre-defined periods (night versus day). Figure 5.1 shows an example in which the battery operations determine an optimal consumption pattern for a prosumer in Great Britain, based on expected intertemporal price variations throughout the day [79]. At the beginning of the day (Figure 5.1, panel i), the battery is charged in the morning (when demand and prices are low) and discharged in peak times to reduce grid consumption. In Figure 5.1 panel ii, the dotted blue line represents the actual consumption pattern in the house, and the solid red line shows the new demand pattern (seen by the grid) created by charging the battery in off-peak times and discharging the battery in the morning and evening peak times. In the modelled house (annual demand for electricity: 3.8 MWh, no PV considered), three battery sizes were tested, 1.4 kWh, 2.9 kWh, and 4.3 kWh, which produced cost savings (reduction in the electricity bill) in the magnitude of 7%, 11% and 15% respectively, compared with not having the battery in the house.

If other flexibility services for the national grid are included for battery operations, the value of the flexibility sources from prosumers will increase. This has been the case in an analysis of a large household in Trondheim [80]. The study comparesd the economic gains of a house battery for both PV and an EV battery, under three different grid tariffs. The results of the study showed cost reductions of 12–19% for EV batteries, while a home battery installation decreased cost by 9–14%. In other words, utilizing an EV battery leads to larger savings, whereas a home battery would need significant subsidies to achieve a positive net present value.

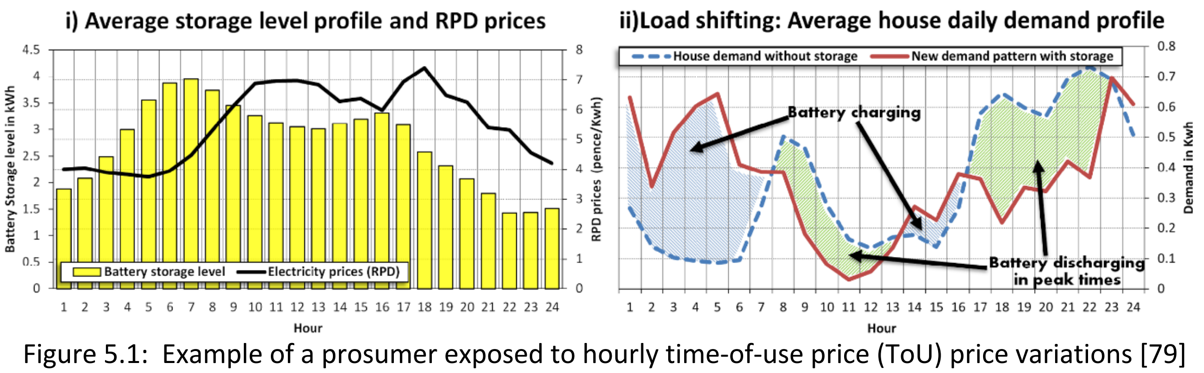


Figure 5.1: Example of a prosumer exposed to hourly time-of-use price (ToU) price variations [79]

5.3 Design and cost analysis of prosumer energy systems for peak shaving – case studies

This section describes technology components for a prosumer, together with costs and payback time for Norwegian conditions for two case studies: the retail sector and the agricultural sector. In both cases, the profitability of local PV and batteries with electricity grid tariffs rewarding peak-shaving were examined. The studies concluded that: (1) there are cases today that could benefit from an optimally sized battery for peak-shaving; (2) assuming cost reductions in PV and batteries, prosumer systems will be more affordable than business-as-usual, and (3) application of smart controls that are based on forecasting, demand response, and autonomous operation could further improve cost-efficiency.

Case study – retail sector
The case study used TRNSYS simulation software. The hourly electricity demand was met locally by PV production and a Li-ion battery, and/or from electricity supplied by the power grid. Excess electricity production was curtailed. Three different retail buildings were investigated by using hourly data from 2016.

The grid tariff structure used by Hafslund, which has a higher cost during winter (150 NOK/kW), a medium cost in spring/autumn (76 NOK/kW), and a low cost in summer (11 NOK/kW). The investment cost of PV and battery was set to 15,000 NOK/kW and 6440 NOK/kWh respectively, for a high-cost scenario, and to 9500 NOK/kW and 3220 NOK/kWh for a low-cost scenario. The case assumed a component lifetime of 25 years for PV and 15 years for battery. Two battery sizes, 33 kWh and 66 kWh, were used to test the effect of battery size on payback time.

The study results showed that the payback time varied between 3 years and 25+ years, depending on system conditions and configurations. We conclude that it is not profitable for a retailer to invest in a PV and battery with the current electricity prices and grid tariffs. However, the retail building with largest electricity demand variation might benefit from deploying a battery without PV, even with current prices. In the study, the electricity consumption characteristics affected payback times. Battery cost, PV cost and grid tariff will also significantly impact payback times. Results from the simulation showed that a 50% decrease in battery cost or a 100% increase in grid tariff would yield in payback times of about seven years for two of the buildings.

Case study – agricultural sector
The case used HOMER modelling software. The model calculates life-cycle costs and includes both installation and operational costs for various system configurations.

Electricity consumption data (hourly resolution from 2017) were used as input for the load profile. The volatility in the load profile was significantly lower than found in the case of the retail sector. The system components included in the optimization were PV, battery, inverter, and power grid for peak shaving. The project life time was set to 25 years and relevant economic rate factors were applied. Installation costs were estimated to 14000 NOK/kW for PV and 3000 NOK/kWh for battery. Component life-time for PV was set to 25 years, and for battery it was set to 10 years or 6000 cycles, which ever came first.

Since the cost of PV, battery and power grid tariff have a considerable influence on optimal component size and cost of electricity, it was decided to run a sensitivity analysis on these three parameters. PV cost factor was set to 1, 0.75 and 0.5, where multiplier 1 equalled present-day prices. The same method was used for battery cost, while the power grid was set to 50, 100, 150 NOK/kW/month, and all months were handled equally.

Table 5.1: Results from HOMER prosumer in the agricultural sector

Grid rate NOK/kW/month	Battery multiplier	PV multiplier	PV kW	Battery kWh	Grid peak kW	Converter kW	LCOE cost NOK	Invest. NOK	Local energy %
50	1	1	-	-	-	-	0.80	0	0
50	1	0.5	38	-	-	29	0.64	270,000	38

100	0.5	1	-	11	13	5	0.90	20,000	0
100	1	1	-	11	13	5	0.91	30,000	0

We ran 27 cases in our sensitivity analysis, 4 of which are highlighted in Table 5.1: . First, with our business-as-usual assumptions, the most cost-efficient solution today is no investments (i.e. no PV, battery or peak shaving needed) (Table 5.1: , row 1). Second, considering full flexibility in the three sensitivity parameters, the solution resulting in lowest electricity cost is a case with low demand charge, low PV cost and battery cost today (Table 5.1: , row 2). This situation would result in 20% cheaper electricity than today. Low PV costs (multiplier 0.5) could be achieved by 2025, according to IRENA. Third, large batteries are cost-efficient when the demand charge is high and battery costs are low (Table 5.1: , row 3). Fourth and finally, peak shaving is cost-efficient in almost all cases, except at low demand charge and battery costs today (Table 5.1: , row 4). However, Bloomberg predicts that battery costs could be at 1500 NOK/kWh (multiplier 0.5) already by 2020, which implies that peak shaving is cost-efficient in all cases. It should be noted that these results are relevant for a specific load profile and grid tariff, which means that the conclusions cannot be directly extended to other consumer types.

5.4 Criteria for PVs to optimize own consumption of own generation

Different locations have distinct annual average solar radiation, which is affected by, for example, the amount of cloud coverage, shade, orientation (south/east/west/north), and the angle of the PV panel. Since the orientation of a PV panel affects both the volume and the time of the generation, a prosumer can increase their potential for self-consumption. Prosumers' potential for self-consumption have been evaluated in a case study by Sæle and Bremdal [39]. Hvaler Municipality is located at 60° N, in south-east Norway, and a number of household customers there have installed rooftop PV panels. Empirical data show that power generation with identical equipment (installed capacity of 3.1 kWp.) varies with season, geographical location, and roof orientation and inclination. The generation profile for 15 August 2016 compared with a reference consumption profile is presented in Figure 5.2.

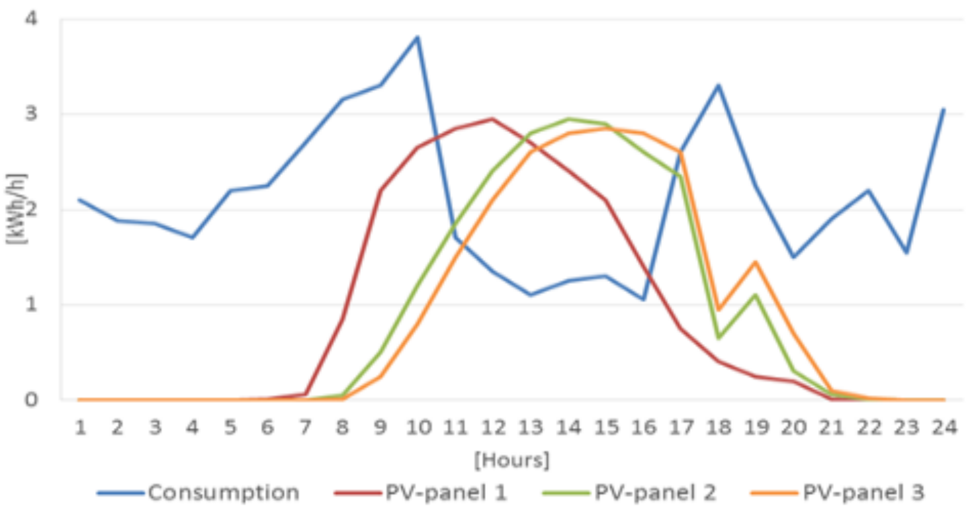


Figure 5.2: Changes in feed-in of electricity as a consequence of PV panel orientation

Figure 5.2 shows how different PV panel orientations generated different amounts of electricity at different time during the course of one day. The PV panel oriented towards south (Panel 1) had the peak generation earlier than the PV panels oriented towards west (Panels 2 and 3).

The results suggest that due considerations should be given to a household's particular consumption profile prior to installing a PV panel on their roof. Most people follow a similar daily routine that creates a power peak in the morning and in the early evening, as shown in Figure 5.2. The energy demand during the day is often much less. A south-oriented panel is likely to produce the best annual yield in terms of energy, but it may be less attractive in economic terms, since it will not eliminate or reduce the costliest part of the consumption. Consequently, an hour-by-hour analysis of the consumption before investment is recommended. The evaluation of the potential for self-consumption with different orientation of the PV panels revealed the following:

- With south orientation, the production from the PV panel covered a large share of the peak load in the morning (Figure 5.2), and very little contribution to the peak load in the afternoon.
- With west orientation, the production from the PV panel almost covered the total peak load in the afternoon during the summer, and c.50% during the autumn.

To summarize, prosumers should install their PV panel with an orientation corresponding to their consumption pattern, since the economic benefits will be larger from self-consumption of their electricity generation than from feeding the electricity into the grid.

6 Energy system impacts

Abstract: *Beside the local effects of prosumers, there are some other significant interactions with the transmission system. This section assesses the potential of prosumers to reduce necessary transmission expansion, the effects they have on the long-term development of the generation mix in the Norwegian power system, the ability of prosumers to provide flexibility and increase the system adequacy, and the impact of growing demand response on the development of the European power system.*

6.1 Introduction

A significant share of prosumers will affect the national and regional energy system. This section presents the impact of prosumers with building-integrated PV production and with demand response (DR) on the power and building sector. Since the electricity price affects the competition between electricity and other energy carriers, prosumers influence the fuel use in end-use sectors, such as industry, transport and buildings. Prosumers with local PV production reduce the competitiveness of other types of intermittent renewable electricity generation and increase the value of flexibility. However, some types of prosumers have the ability to provide flexibility services to the system, for example through DR, local energy storage and vehicle-to-grid services (V2G).

The Norwegian energy system differs significantly from systems in other European countries due to the cold climate and the large hydropower reservoirs in Norway. These characteristics imply that, from a social welfare perspective, prosumers' energy system adaptations are not necessarily similar to those in other European countries. In Norway, electricity consumption is highest in winter (due to the need for electric heating), when the solar radiation conditions are poor. Consequently, prosumers with local PV production have a limited potential to reduce the peak electricity demand. The same effect can be observed when evaluating the effect of local production from prosumers living in large cities and who connect to the transmission grid. In the case of Oslo, the large-scale integration of prosumers, which mainly are PV-based, does not significantly reduce the peak load. However, the transmission capacity needs to be dimensioned on the expected peak load according to the area.

Our research demonstrates that prosumers with demand response facilitate integration of intermittent electricity generation by lowering the need for backup electricity generation capacity and by reducing the number of periods when the electricity demand cannot be met. However, further research is required to investigate the future interaction and competition of demand response with other types of flexibility services that can be provided by a prosumer, such as local batteries and vehicle-to-grid. Another important topic for further research is the optimal coordinated use of both local energy production and flexibility options for a prosumer as a part of the future energy system. The design of the energy market needs to take into account that prosumers, with both local energy production and flexibility services, can be operated independently of the power grid and the central power production and for large parts of the year.

6.2 Impact of prosumers on the transmission grid

This section is based on two studies by the Norwegian transmission system operator (TSO) Statnett. The first study assess how prosumers with building-integrated PV and end-use flexibility would affect the peak load (electricity demand) in the Oslo region [52]. The motivation for this first study was that the peak load in consumption centres determines the need for capacity in the transmission grid. In addition, it is expected that more and more buildings will have their own electricity generation from photovoltaic (PV) in the future. Although the analysis was performed for the Oslo region, the main results and conclusions are also valid for other urban regions in Norway, since the demand profiles and the generation profiles for solar production are quite similar.

Two key messages:

1. Prosumers without flexibility will not impact the peak load and the required transmission grid capacity.
2. Flexible operation of ventilation, electric boilers and electric heating should be utilized as flexibility resources before investing in batteries.

Key message 1: Prosumers with PV and with no end-use flexibility will not lower the need for capacity expansion in the transmission grid. The local production from prosumers has an insignificant impact on the aggregated peak load in the city region, as shown in Figure 6.1 by the load duration curve of the electricity demand in the Oslo region, with 0–2000 MW PV capacity. The peak loads are mainly due to the need for electrical heating in the coldest period of the year (i.e. winter), when the solar conditions are poor. Consequently, generation from PV has an insignificant impact on the peak load, independent of the installed PV capacity. Although PV generation has an insignificant effect on the peak load of large regions, there can be instances when the peak demand is reduced for a single consumer, such as if the peak electricity consumption occurs when there is PV production, typically in the middle of the day.

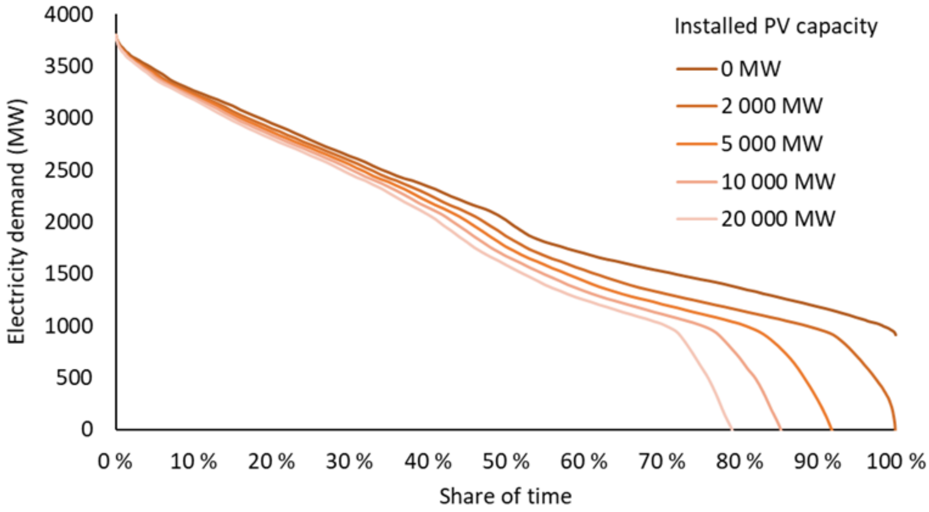


Figure 6.1: Load duration curve of the electricity demand in the region of Oslo with different levels of PV capacity

Key message 2: Based on the Key Message 1, all alternatives except local PV production are required to reduce the peak load. The alternatives include end-use flexibility provided by local batteries and flexible control of ventilation systems, electric boilers and electric heating that can move parts of the load in time. For example, indoor temperature provided by electric heating can be adjusted within a user-specified temperature interval. Statnett has further investigated how end-use flexibility can lower the need for grid expansion [53]. One conclusion reached by Statnett is that batteries are more expensive than other types of flexibility already available in buildings, including ventilation, electric boilers and electric heating. In a specific study, the cheapest flexibility was provided from electric boilers in large buildings, including schools and homes for the elderly [53]. Consequently, existing flexibilities in buildings should be used before investing in batteries. Furthermore, results show that batteries are not profitable for lowering the peak load, also within a future scenario with highly decreased battery costs.

6.3 Impact of prosumers with building-integrated PV on the Scandinavian electricity and building sector towards 2050

This section presents analyses of how a large deployment of prosumers with local PV production and no flexibility services will influence the energy system in Scandinavia (Denmark, Norway and Sweden) towards 2050, and is based on research done by Seljom et al. [41]. The analysis uses a stochastic optimization model developed with the Integrated MARKAL EFOM System (TIMES) modelling framework [42]–[45]. The model provides cost-optimal investments and operation related to energy supply, conversion, delivery, and use of energy that will be required to meet the future energy demand at a lowest possible cost. Consequently, the analysis captures the competition between various energy carriers and the interaction between supply and end-use sectors. The model is applied to gain insights into the adaption of prosumers to the energy system, from what is cost-optimal from a Scandinavian perspective, with a focus on the electricity and building sector.

In the analysis presented below, it is assumed that all new buildings and parts of the rehabilitated buildings from 2015 towards 2050 are prosumers. This gives a 25% and 50% prosumer share of the Scandinavian building stock, with a corresponding PV production at 25 TWh and 53 TWh in 2030 and 2050 respectively. Further, the impact of two types of prosumers with PV production is addressed. The first type is prosumers in buildings designed according to current building standards, hereafter denoted *PRO*. The second type is prosumers in buildings that are highly energy efficient and conform to the Norwegian passive building standard, hereafter denoted *PRO+*. The passive building standard lowers the heating demand of the buildings, and the Scandinavian heat demand is 18% lower for *PRO+* than for *PRO* in 2050. For comparison, the *REF* scenario shows the development of the energy system without any prosumers with local PV production.

Four key messages from the research are listed as follows and described in more detail below.

Prosumers with local PV production and no flexibility services:

1. Lower investments in new wind power from a socio-economic perspective
2. Can be integrated into the Scandinavian energy system due to the large flexible hydropower plants
3. Change the electricity trade pattern between Scandinavia and Northern Europe
4. Lower cost-optimal investments in heat pumps and increase the cost-optimal investments in direct electric heating and electric boilers.

Key message 1: Among the electricity generation technologies, wind power is mainly affected by the large-scale deployment of prosumers. Compared with *REF*, the wind capacity is reduced by 28% and 43% for *PRO* and 34% and 51% for *PRO+* in 2030 and 2050 respectively. It should be noted that the wind capacity is lower in *PRO+* than in *PRO*, because *PRO+* has lower electricity prices due to the lower heat demand in the passive buildings. Although PV constitutes a large part of the installed capacity, it has a smaller share of the electricity production mix. For *PRO+*, PV corresponds to 45% of the installed capacity, but only 14% of the electricity generation in 2050. Further, *REF* has no PV capacity, since PV is not considered a cost-competitive technology for the given model assumptions. Figure 6.2 shows the installed electricity generation capacity by technology, in 2010, 2030 and 2050 for the three cases, *REF*, *PRO* and *PRO+*.

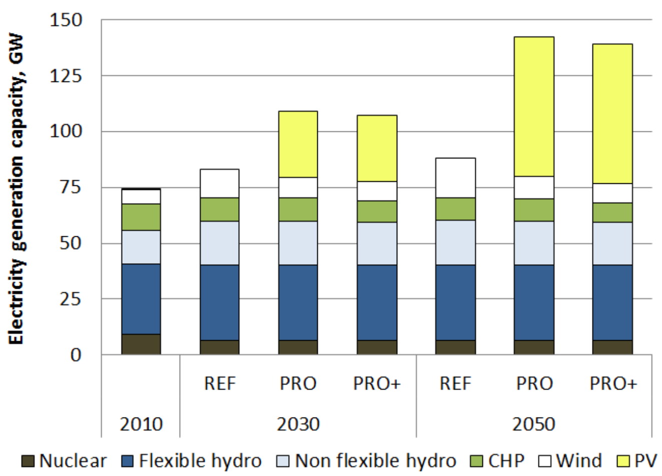


Figure 6.2: Electric generation capacity in Scandinavia by technology, for REFerence (REF), PROsumer (PRO) and PROsumer plus (PRO+) in 2010, 2030 and 2050

Key message 2: The Scandinavian energy system is capable of integrating significant numbers of prosumers with PV on an aggregated level, and with no local storage connected to the buildings. With 63 GW of PV in 2050 for *PRO+*, the energy system cannot utilize all the non-flexible electricity generation only in 3% of the time, corresponding to 2% unutilized PV production. It should be noted that the study by Seljom et al. [41] did not capture bottlenecks within the spot price regions and therefore its results cannot be used to address challenges of distribution grid level. The unutilized electricity generation is due to grid constraints and a relative low electricity demand in hours with high PV production. Figure 6.3 shows the situation on a sunny summer day in the SE3 price region in

Stockholm, in 2050 for *PRO+*. The difference between supply (regional production plus import into the region) and demand (regional consumption plus export out of the region) peaks in the middle of the day, when the solar radiation is at its highest: 7.5 GW at 14:00. At 14:00, PV contributes to 90% of the regional electricity generation, while the remaining electricity generation comes from non-flexible hydropower, nuclear power and industrial combined heat and power (CHP) plants.

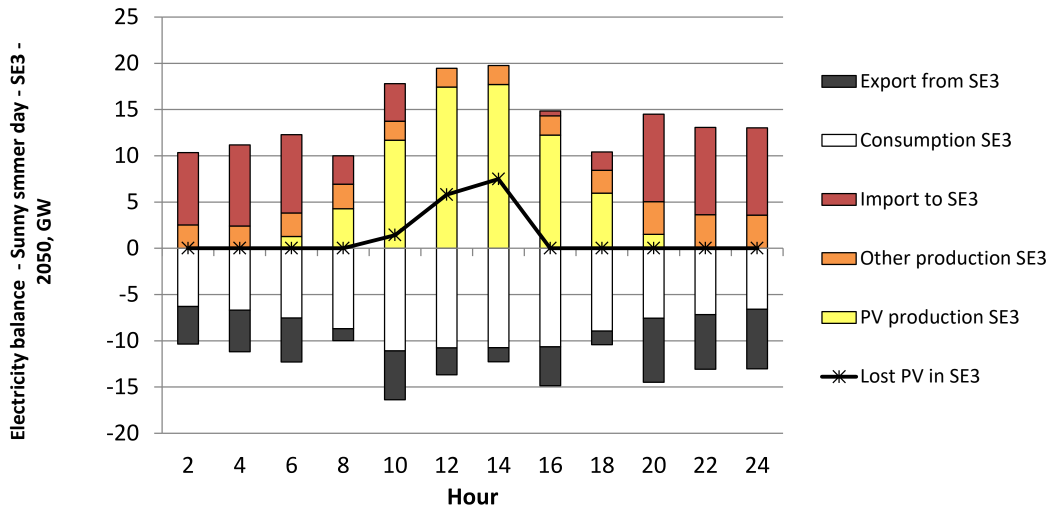


Figure 6.3: The electricity balance of a sunny summer day in 2050 for *PRO+* in the SE3 spot price region in Stockholm

Key message 3: The large integration of prosumers with local PV production influences the electricity trade pattern with Europe, in particular when prosumers are introduced in the same order of magnitude in the rest of Europe as in Scandinavia. For *REF*, Scandinavia exports electricity during daytime, when prices are high, and imports at night, when prices are low. This is in contrast to *PRO* and *PRO+*, with low European electricity prices in periods of high PV production in the middle of the day, where Scandinavia exports at night and imports electricity from Europe in daytime. Consequently, the Scandinavian energy system, with a considerable amount of flexible hydropower capacity, can adapt to substantial changes in the European energy system caused by a larger share of prosumers.

Key message 4: The deployment of prosumers influences the use of heating technologies in the buildings. The prosumers will influence the electricity price, and thereby also change the competiveness of electricity based heating options. This is illustrated in Figure 6.4, which shows the annual heat supply to buildings in 2030 and 2050 for all cases. The technology group named 'Electricity' includes heat supplied from both electric boilers and direct electric heating. By comparing REF with PRO and PRO+, it is clear that the heat supplied by heat pumps and from biomass boilers is reduced as prosumers enter the energy system. Further, the heat supply low-capital electricity heat generation is increased for PRO and unchanged for PRO+ in 2050. However, since the total heat demand is lower in PRO+, the share of low-cost electric heating increases from 16% in REF to 20% in PRO+ in 2050.

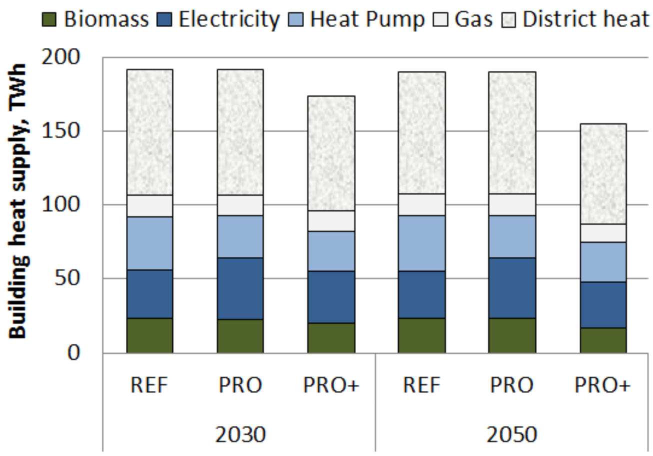


Figure 6.4: Heat supplied to buildings by different types of technology for all cases in 2030 and 2050

6.4 The impact of shiftable load on the power system

As described earlier in this report, besides local production, prosumers have the ability to provide flexibility in various forms to the power system. One type of flexibility is demand response (DR). By moving the demand in time, the impact of DR on the optimal generation mix and on system adequacy can be shown by the following example. The example comprises the power sector in Belgium, France, Germany, and the Netherlands, and is based on the results of the e-Highway 2050 project [56]. System adequacy is a measure of sufficient generation capacity available at all times in order to fulfil the demand for electricity. If there is insufficient generation capacity, involuntary load shedding (rationing) will occur to achieve an instantaneous balance of electricity production and consumption [60]. Thus, system adequacy can be used to ensure that sufficient generation capacity is available at all times to fulfil the demand for electricity.

Askeland et al. [48] modelled demand response as shiftable volume with a rebound effect, as shown in Figure 6.5. This means, that for any given operational period, the consumption can be reduced by moving the demand for electricity in time. However, the shiftable volume is likely to increase the electricity consumption due to additional losses related to moving the electricity demand in time, which is referred to as the rebound effect. Hence, a profitable use of this type of demand response requires large enough price differences in the electricity market to compensate also for the cost of the associated rebound effect. For example, due to refrigerated warehouses' inherent physical 'cold' storage capabilities, their consumption can be reduced in certain hours and delayed. However, in order to achieve the desired temperatures at a later time, the power consumption will be higher and at a lower efficiency, as described by the rebound effect.

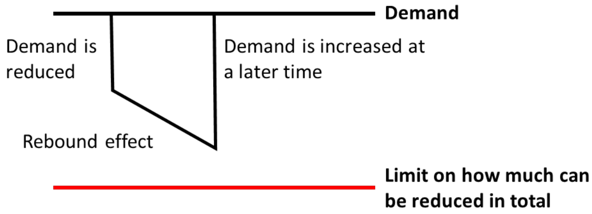


Figure 6.5: Concept of shiftable DR

Four key messages:
DR that shifts demand in time,

1. Reduces the need for backup capacity
2. Lowers the variability of electricity prices but has no impact on the average annual price
3. Reduces the amount of involuntary shedding of demand
4. Is not in sufficient on its own to ensure system adequacy and to avoid curtailment in a power system with a high share of intermittent renewables

The impact of demand response on the power sector is exemplified in two cases that are studied with an equilibrium model for the power sector. In the first case, the share of the renewable electricity generation is assumed to be 64.2% of the electricity demand in 2050, and the level of demand flexibility is varied from 0% to 20% (Table 6.1). With higher demand flexibility, thermal generation capacity decreases, since DR improves the utilization of the renewable electricity generation. When the situation with no DR is compared with the 5% flexibility level, the curtailment of renewables is reduced from about 20 TWh to about 8 TWh. In addition, DR reduces the need for peaking gas turbine capacity and lowers the CO_2 emissions. Coal is not included in the results because it is not competitive with a carbon emissions tax at 76 EUR/ton in 2050.

Table 6.1: Flexibility share sensitivity for all countries (Belgium, France, Germany, and the Netherlands)

Flexibility	0%	5%	10%	15%	20%
RES capacity [GW]	341	341	341	341	341
Thermal capacity [GW]	177	172	171	171	171
RES curtailment [GWh]	20,341	7815	7075	6875	6809
Emissions [Mton]	41	38	37	37	37
DR usage [GWh]	0	11,890	14,959	15,933	16,229
Average electricity price [EUR/MWh]	43.3	43.3	43.4	43.4	43.4
Rationing [hours]	17	11	9	9	9
Rationing [MWh]	75,124	81,875	86,204	86,199	86,197

Table 6.2: RES penetration level sensitivity assuming 10% demand flexibility

RES share	20%	40%	60%	80%	100%
RES capacity [GW]	106	213	319	425	531
Thermal capacity [GW]	186	180	172	166	162
RES curtailment [GWh]	23	46	2'474	45'448	139'079
Carbon emissions [Mton]	28	31	36	44	52
DR usage [GWh]	4624	6792	13,427	18,547	19,602
Average price [EUR/MWh]	44.1	44.0	43.6	42.5	41.5
Rationing [hours]	8	5	9	11	12

Rationing [GWh]	11	27	81	116	146

In the second case, demand flexibility is limited to 10%, while the renewables share of the electricity demand varies from 20% to 100% (Table 6.2). As the inherent variability of RES does not match the electricity demand profile, and it is assumed that there are no local energy storage solutions, the power system needs additional capacity in the form of thermal units. With an increasing share of RES, there is a modest decrease in thermal backup capacity. The need for thermal capacity, also at high RES levels, stems from periods with a large difference between RES generation and demand. Above 80% renewable share, the curtailment of RES and rationing increase sharply, which suggests that DR has limited capability to balance a system with high levels of RES and it needs to be supplemented with other storage options.

To summarize the results of the case studies, DR reduces the necessity of peaking generation capacity and is a cost-effective alternative to fast responsive gas turbines. However, even with DR, high levels of RES require thermal capacity in the system and curtailment of renewable power production. Also, with a high share of renewables, there is a need for additional storage capacity for an increased utilization of the renewable energy sources.

6.5 Long-term effects of demand response in the European electricity system

This section analyses the impact of prosumers with DR on the development of the European electricity sector towards 2050. The analysis is based on a long-term techno-economic model of the European power system, EMPIRE [54] [55], which provides for optimal investments, generation and transmission to meet the future electricity demand at least cost. Further, the investments and operation of the various DR options are made to minimize the costs of the European electricity system, and provide optimal investments, generation and transmission to meet the future electricity demand at least cost. Additionally, the investments and operation of the various DR options are made to minimize the costs of the European electricity system.

The operational costs of DR depend both on the type of flexible load and on the consumer type. In the residential sector, the marginal costs of load shifting are c.10 EUR/MWh, while in the commercial sector they can vary from 5 EUR/MWh to 150 EUR/MWh [81]. From the prosumers' perspective, these are the reservation prices, the minimum price at which they sell its flexibility. From a supplier's perspective, it is the maximum that they would pay to consumers to change their demand. If the reservation price is lower than the price differential between two short-run marginal hourly costs, or inter-hour price differential, it will be optimal for the system to execute the load shifting.

Key messages from this research are listed below.

Prosumers with DR,

1. Are a cost-effective solution for the European electricity sector
2. Increase the cost-optimal investments in PV
3. Reduce the need for peak capacity and batteries.

Key message 1: The results show cost-effective investments in DR from 2020 onwards. Investments in DR are more effective more effective in countries with high shares of intermittent renewable energy, since those countries have higher variations in their electricity prices. Some types of DR are not cost-effective, such as residential heating and air conditioning (AC), and commercial cooling, because their costs are too high costs, or they have small operational time intervals, or hey cannot compete against other types of flexible demand or supply. The most-often utilized DR measure is heat storage because it has the highest potential and can move electricity within 12 hours. Other types of DR measures, grouped by utilization, are non-residential HVAC, household washing appliances, industrial processes, non-residential cooling, and residential heating and AC.

Key message 2: The impact of prosumers increases the investments in PV, since DR shifts parts of the demand to hours with high PV production and low electricity prices. The load that is not covered by renewables, also called residual load, is changed for the same reason. However, more PV increases the amount of PV production that is curtailed in time periods when DR is not profitable. DR is therefore not a sufficient measure to avoid curtailment in regions with a high share of intermittent production.

Key message 3: With DR, peak loads are reduced and therefore less peak capacity is required by the system. Since DR operates in a similar manner to other energy storage options, the deployment of DR lowers the investments in battery storage capacity.

7 Conclusions

7.1 Summary

This document is primarily based on studies carried out by research partners of the FME CenSES. We started by focusing on the motivations of the prosumer itself. Then we zoomed out gradually, and finally we discussed the impact of prosumers on the European power system. In-between those two ends, we have discussed practical and technical aspects prosumers must deal with, markets and incentives, the optimization of prosumers' energy systems, and impacts on the need for grid capacity to/from cities.

A wide range of methods have been applied in the research we build upon, including: Reviews of existing work, qualitative analysis and interviews, collaboration and discussing with grid companies, socio-economic considerations, and mathematical optimization and simulation of energy systems locally, for Norway, and Europe.

7.2 Main findings

Our findings are highlighted as follows:

1. The growth of prosumers heralds a more symmetrical relationship between stakeholders in the power system than in the traditional, centralized, top-down relationship of power companies and end-use electricity consumer.
2. Existing prosumers in Norway have been more motivated by environmental concerns, technological interest, and self-consumption than by economic incentives.
3. Return on investment for prosumers is very low in the absence of strengthened financial support.
4. The smart meters currently being installed in Norway will be an enabling technology for new grid tariffs and energy contracts. They are also designed for metering electricity fed into the distribution grid.
5. Currently, batteries are not a cost-effective technology to lower peak electricity demand. It is less expensive to utilize flexibility in ventilation, electric boilers and heating.
6. PV production (i.e. solar panels) within Oslo will to a very little extent reduce the need for transmission grids expansions to the city.
7. A capacity-based grid tariff, which has been suggested by NVE, will (1) make it less profitable to invest in solar panels, and (2) give a stronger incentive for flexibility. However, depending on how the tariff will be specified, some of the disadvantages of PV could be offset if PV

panels can be installed in such a way that the production fits better with peak loads for consumption.

8. Wind power and PV as types of varying renewable generation are complementary technologies for demand response. Additional amounts of one of them will increase the value of the other.
9. In the EU and EEA, national regulations for energy solutions in buildings should promote cost-efficiency. Nearly-zero energy buildings (NZEBs) are being promoted, but it is not clear how they should be defined and how they should be handled if they do not prove to be cost-effective.
10. The local DSO should be involved in the process when a customer wants to invest in a PV panel, to avoid instabilities in the electricity supply for the surrounding area.
11. One of the main barriers to new prosumer business models is the lack of regulatory frameworks or immature regulatory frameworks, which might be a consequence of lack experience of large-scale market integration of prosumers.
12. Demand response, such as moving the demand in time, facilitates the integration of varying electricity generation, and lowers the need for backup electricity generation capacity.

7.3 Concluding remarks

This position paper presents research from a range of disciplines, ranging from a sociological understanding of prosumers to a mathematical optimization of the European power system. This multidisciplinary approach mirrors the research that has been carried out in FME CenSES. The blend between various research traditions gives a fruitful overview and provides a broad picture.

On the one hand, sociological studies have shown that the prosumer phenomenon has the potential to transform parts of our everyday life. In one scenario there might exist local grids connecting climate-motivated prosumers who feed their PV generation into the grid and are active participants in discussing energy solutions for their neighbourhoods. This could give a reliable, fair, and environmentally friendly energy supply. For the prosumers, personal identity, self-realization, and a feeling of belonging and contributing to a grass-roots' movement or a society working together to save the planet would be important. The technologies and the organization of prosumer activity in the future might therefore be very different from what we can foresee today.

On the other hand, it is possible that we will not see such major changes for most communities and citizens. Consumers and legislation may stay mainly focused on having reliable and simple access to electricity at an affordable cost. Local solutions for generation and flexibility will then connect to the overall energy system to the extent they can compete with alternatives with respect to both costs and other qualities, which could be considerable. The calculation of such cost-efficient amounts is typically done from an energy system analysis perspective. For flexibility services (e.g. demand shifts or batteries), the largest socio-economic benefit for the hydropower-dominated power system in Norway would probably be saved investment costs for the electrical grid in cities, which are likely to experience higher growth rates for peak loads than for annual energy electricity consumption.

Most likely, several developments will co-exist simultaneously in Norway in the future.

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