Prosumers' role in the future energy system

Short version of a position paper prepared by FME CenSES

Prosumers' role in the future energy system

This report is based on a position paper developed in cooperation with Cineldi[1] and ZEN[2].
The multidisciplinary approach presents research from a spectrum of disciplines, ranging from a sociological understanding of prosumers to a mathematical optimization of the European power system. The combination of various research traditions provides a broad picture of the issue.
For author list, full scientific elaboration and references, we refer to the original document.

ISBN: 978-82-93198-34-5

[1] Cineldi: Centre for intelligent electricity distribution, https://www.sintef.no/cineldi
[2] Zero Emission Neighbourhoods in Smart Cities, https://fmezen.no/

Content

1 Introduction

1.1 What is a prosumer?

The futurist Alvin Toffler[3] defined prosumers as people who produce some of the goods and services entering their own consumption. We focus on prosumers in the power sector.
When people consume electricity, they benefit from a reliable supply, i.e. the stability of the power system with instantaneous balance between demand and supply at all times. That stability can only be provided by various types of flexibility in the system. Electrical energy and flexibility services are two distinct commodities of which an electrical prosumer supplies at least one.

1.2 European policy and the growth of prosumers

The goal for the global cooperation in combating greenhouse gas (GHG) emissions[4] is to limit global warming to well below 2^{o}C from a 1990 level. The growth of prosumers is closely linked to this ambition.

In the course of the past decades, the EU has implemented several directives targeting the energy sector, the latest of which is included in the EU's 2016-package "Clean energy for all Europeans", also called the winter package[5]. With this package, the EU commits to decrease CO_2 emissions by 40% by 2030, and to increase the share of renewable energy to 32% in the final energy consumption, cf. Figure 1.1. It is the first time the consumer's active participation in the energy sector is fostered:

"... 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."[6]

High feed-in tariffs for generation from renewable energy sources have already yielded high increases in their share, notably in Germany's "Energiewende". From the start, the dominating technology has been onshore wind power. However, with the remarkable 80% drop in the costs of solar panels from 2008 to 2015, cf. Figure 1.2, there has been a take-off for distributed PV production e.g. on rooftops. By installing PV, and sometimes also batteries, consumers transform themselves into prosumers. In 2014, the share of solar power in power generation in the EU was 2-3%, and it is expected to grow further. In their Energy Roadmap 2050, the EU commission foresees the share of decentralized small-scale power generation to reach 13.9% in 2050 under the policy initiatives of 2010[7]. Since then, several new policy initiatives have been adopted.

[3] Toffler, A., & Alvin, T. (1981). The third wave (pp. 32-33). New York: Bantam books. Van Lente 1993.
[4] https://unfccc.int/
[5] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans
[6] European Commission (2016), "Fact Sheet: Providing a fair deal for consumers", http://europa.eu/rapid/press-release_MEMO-16-3961_en.htm
[7] European Commission (2011), "Impact assessment, accompanying the document Energy Roadmap 2050", staff working paper.

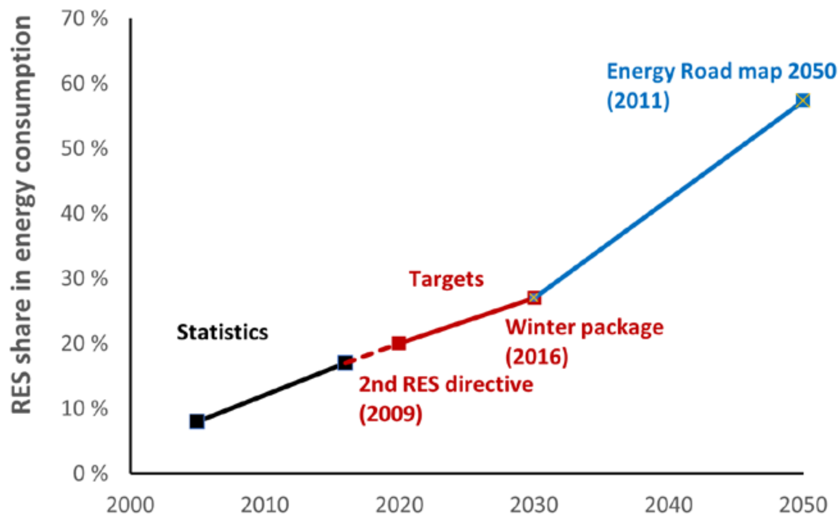

Figure 1.1: Renewables' share in total energy consumption in the EU. Statistics and targets.

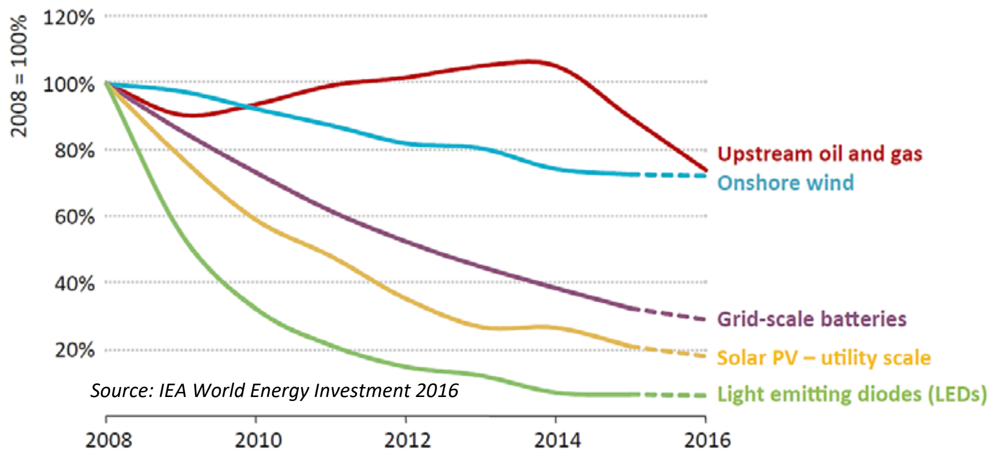

Figure 1.2: Cost reductions for green technologies

1.3 Prosumers in Norway

Circumstances for local power generation from PV and flexibility provision from prosumers in Norway differ from other European countries. On the one hand, the profile PV power generation does not match the annual profile of demand, because demand is highest in the winter when PV generation is lowest and vice versa. On the other hand, there are significant flexibility resources available in the Norwegian power system already, due to the high share of reservoir based hydro power. Yet prosumers are expected to emerge in the power sector in Norway, all the same. The share of solar in installed power generation capacity in Norway was lower than 0.1% in 2016[8], which was still a remarkable increase in the grid connected capacity that year relative to before. At the beginning of 2018 there were about 1000 surplus customers in the Norwegian electrical grid.

---

[8] Ramsdal R (2016), "Solcelle-panel i Norge: Det er flere tak å ta av, vi har så vidt bare skrapt litt i overflaten", Teknisk Ukeblad, https://www.tu.no/artikler/norsk-solkraftutbygging-naer-firedoblet-i-2016-vi-har-savidt-skrapt-i-overflaten/377031

Prosumption is still a marginal phenomenon in Norway, though. Intuitively one might think it will remain that way due to moderate power prices, limited support for renewables, and electricity supplied mostly by highly flexible reservoir hydro power. Yet several Norwegian cities, e.g. Oslo, are experiencing higher growth rates for the maximum electricity demand (i.e. peak load) than for annual consumption. One of the reasons is an increase in electrical appliances and charging of EVs. Since grid companies ensure sufficient capacity in the grid at all times, increasing peak loads will lead to grid enhancements, with corresponding costs and higher grid tariffs. Some of these costs may be avoided if local generation, batteries or other demand flexibility resources reduce the required capacity during the peak load hour. Demand flexibility such as short-term response to a price-signal, or systematic shift for some consumption from typical high-load hours to low-load hours, can be valuable to the system. The structure of tariff charged for the use of the distribution grid will affect the profitability of demand flexibility. In 2018 NVE[9] suggested a mandatory structure for the grid tariff to incentivize lower peak loads.[10]

1.4 Prosumers and societal transformation

While the EU and other key actors strongly push the idea of future consumers as "the active hearts" of the energy system, enabling a low carbon transition through prosumption and flexible consumption, practical results so far are sobering. While the sales of solar panels continue to rise, flexible consumption has been difficult to realize. While large resources have been spent on technology and market development, too little has been done to understand the social, cultural and practical elements that make up the choices of ordinary consumers. We need to understand the "*millions of citizens who need to modify their purchase decisions, user practices, beliefs, cultural conventions, and skills.*"[11] We should bear in mind that transforming key societal infrastructure involves transforming society. As Norway pushes forward with new power tariffs, we should not only ask how they affect the power grid, but also consider their broader social and practical consequences. Who wins and who loses through the development?

2 Understanding prosumers

Prosumers may change the relationship between end users of electricity, and electricity and grid providers. The shift from consumer to prosumer creates possibilities for co-production of services and value between company and customer. Interviews with end users of prosumer technology show that, even though economic incentives are meagre, climate concern, technological interest and self-consumption still motivate people to become prosumers.

2.1 The role of the prosumer

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 through the local grid. End users who offer reduced or shifted consumption as flexibility to the grid can also be regarded as prosumers. Due to processes of digitalization, the introduction of the Internet of Things and big data analytics, combined with falling prices of micro generation technologies like solar PV and batteries, a new era of prosumption may be dawning. Equipped with their own means to

[9] NVE: Norges vassdrags- og energidirektorat, the Norwegian water resources and energy directorate - https://www.nve.no/english/

[10] https://www.nve.no/om-nve/regelverk/lov-og-forskriftsendringer-pa-horing-ikke-konsesjonssaker/horing-forslag-til-endringer-i-forskrift-om-kontroll-av-nettvirksomhet-tariffer/

[11] Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. Science, 357(6357), 1242-1244.

produce energy, households could radically transform social, technical and economic conditions and relations in the energy system[12].

Proponents and opponents have employed different narratives of the (dis)advantages of power-producing buildings in society to influence policymakers and public opinion[13]. Central actors in the industry suspect their adversaries of being motivated by local business interests without regard for the larger picture. If the concept is to become mainstream, power-producing buildings need to be perceived by opponents as the solution to a significant problem, for example the challenge of peak load.

The relevance of the prosumer is linked to the roll-out of smart meters and smart grid development. Smart metering infrastructure has different implications for different actors. Efforts to make energy users engage more actively with the system include monitoring their own consumption with feedback technologies, new price tariffs and automated systems. These are often aimed at reducing or shifting the timing of consumption to help balancing strained grids. Electricity production in households adds another layer to the modern ideal of end users as engaged energy market participants.

Prosumers are "individuals-as-stakeholders"[14] engaging in micro-production of energy. Skipping the middle man, prosumers might no longer find their relationship to their energy company important. The transition from consumer to prosumer enables users to take on new kinds of responsibilities over their energy use, engendering societal responsibility in the face of otherwise insurmountable challenges, like climate change.

There is a concern that prosumption might lead to new kinds of inequalities or enable exploitative relations between prosumers and broader institutional and societal structures, where prosumers wouldn't get a better deal but would simply be assigned more work and responsibility. Prosumption does not necessarily lead to repressive relations, though. The concept has historically been connected to ideas of grassroot community energy projects that focus on group action or energy citizenship, emphasising energy awareness and green behaviour. Prosumers own their production capacity, and this ownership engages them. They constitute an entirely new stakeholder in the energy market since they are expected to behave differently from consumers. Even so, most of the time prosumers will depend on the grid administered by a grid company. While this might change over time, most prosumers cannot rely completely on their own production. For instance, a solar PV panel setup without any kind of storage will only intermittently provide complete coverage of electricity. Prosumers may also need infrastructure to sell excess energy. The relationship between the energy company and the prosumer can be seen as a symbiosis where both are engaged in co-production and value creation.

2.2 Who are the Norwegian prosumers?

Research on household prosumers within CenSES has conducted interviews with demo project participants in Trøndelag (TrønderEnergi, Nord-Trøndelag Elektrisitetsverk) and Hvaler (Fredrikstad Energi). It shows that often the most interested customers are in the older segment of the

[12] Parag, Y., Sovacool, B.K. (2016). Electricity market design for the prosumer era. Nature Energy 1, 16032. doi:10.1038/nenergy.2016.32
[13] Kvellheim, A. K. (2017), "The power of buildings in climate change mitigation: The case of Norway", Energy Policy, Vol 110, pp. 653-661.
[14] Olkkonen, L., Korjonen-Kuusipuro, K., and Grönberg, I. (2016) Redefining a Stakeholder Relation: Finnish Energy 'prosumers' as Co-Producers. Environmental Innovation and Societal Transitions. doi:10.1016/j.eist.2016.10.004.

population. This could relate to cost. PVs, for example, appeal to a mature buyer segment with a stable economic situation and a decent amount of disposable income

Currently, residential PV is an expensive way to optimize local production and demand. Without generous subsidies, the economic motivation is not strong enough for most potential prosumers. Yet other motivations have been found to matter as well. There is an interest in owning and learning about new technology and self-identifying as a technology front-runner, combined with a concern for climate issues. Studies have identified users as envisioning a future in which solar power becomes increasingly important and where energy prices rise and become more volatile. Some participants say they would like to be more self-reliant and consume more of their “own” electricity.

A turnkey PV installation is difficult to acquire by independent users in the current market. Some users reported being engaged in PV demonstration projects because they got a good deal on solar panels. Others said they were awaiting further cost reduction, and one reported waiting for better technology (solar roof tiles). A few users reported joining in smart grid demonstration projects to learn more about smart energy monitoring because of a relation to their professional life. Adding to this a desire to become more self-sufficient, to be able to visualize production and consumption of energy, gain tools to pass on better attitudes to their children, and a feeling of being part of something bigger. The sum of these concerns seems to constitute the characteristics of a prosumer persona.

Several prosumers highlight the importance of the recruitment process. Some said they became prosumers because their local electricity provider had approached them with an offer. This shows that trusting relationships between providers and customers are essential.

Incentivizing people to buy and install local means of power production and having them actively shift or shave their loads can reduce the strain on the local grid. Burgeoning developments in business models, trading surplus energy among neighbours with some production capacity among themselves at discounted prices, show it is possible to allocate benefit to singular households, if still only in theory. System and user interests are also aligned when it comes to security of supply for the community. For instance, in the Smart Energy Hvaler project, the strong feeling of living with a strained and weak power supply became part of a greater collective consciousness. 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. Many prosumers in Hvaler participated not for the sake of personal economic gain, but to contribute economically to a research and development project.

As Norway has abundant hydropower, the environmental concerns important for end users of solar PV seem to be paradoxical, but participants locate themselves in a larger context. They see themselves as frontrunners of a possible future norm. Many consider their participation in demonstration projects as helping local companies develop services and technologies that positively influence the Norwegian energy situation. Some perceive themselves as partaking directly in research and innovation projects.

There is still need for further research to better understand what motivates customers to become prosumers, and how to determine and assign value to customer flexibility.

3 Technical considerations related to grid-connected prosumers

3.1 Introduction

The ongoing digitalization of society is reflected in the distribution grid with smart meters to be installed to all customers. In addition, several DSOs install Remote Terminal Units (RTU) in MV/LV[15] substations for further registration of data. The new metering technologies give the DSOs updated information about the status and power flow in the distribution grid.

3.2 Smart meters (AMS[16])

By 1 January 2019, all customers in Norway will have smart meters. This makes a total of 2.9 million new meters, of which households and cabins represent 2.5 million.

Regulations require that the meters should be able to[17]:

- Store the meter data with a registration frequency of maximum 60 minutes. It should be possible to change the registration frequency down to 15 minutes.
- Have standardised interfaces that allow for communication with external equipment based on open standards.
- Connect different types of meters (gas, heat, water, etc.).
- Secure data storage in case of voltage outages.
- Disconnect or reduce ("electrical fuse") the total load at the customer, except large customers metered with a transformer..
- 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).

Smart meters are an enabling technology for new grid tariffs. With hourly metering, a customer can get hourly electricity prices (for example an energy contract reflecting the market prices in Elspot). Energy contracts and grid tariffs on an hourly basis will be incentives for customers to get more flexible demand, for example load shifting of the water heater. The peak load of water heaters is between 8 and 9 in the morning, which is also the peak hour for the Nordic power system. If 50% of 2 million Norwegian households shift their water heater away from this peak hour, the peak load could be reduced with 600 MW[18].

Since all new meters should be able to meter both active and reactive power, they are ready for customers who want to invest in a PV-panel and become prosumers.

---

[15] MV/LV: Medium Voltage/Low Voltage

[16] AMS: Advanced Metering System

[17] NVE, "FOR-1999-03-11-301 Forskrift om måling, avregning, fakturering av nettjenester og elektrisk energi, nettselskapets nøytralitet mv.," https://lovdata.no/dokument/SF/forskrift/1999-03-11-301.

[18] Sæle H and Grande O. S. (2011), "Demand Response From Household Customers: Experiences From a Pilot Study in Norway", IEEE TRANSACTIONS ON SMART GRID, VOL. 2, NO. 1, MARCH 2011.

3.3 Practical considerations for a household becoming a prosumer

The PV market in Norway is not very developed. Installing a PV rig is demanding and knowledge intensive. When an end user wants to become a prosumer, the local DSO[19] is included in the process because they need information about the electricity fed into their grid to maintain sufficient voltage quality. Most of the largest DSOs have good information on their web pages on how a customer should proceed to become a prosumer[20].

There are different procedures for recruiting prosumers, like marketing campaigns where energy utilities help households become prosumers. Yet some households have performed the process individually. The procedure for connecting prosumers to the distribution grid is more or less equal for all DSOs.

The customer is responsible for the installation following requirements. If the PV system is installed without the DSO's approval and not following the DSO's requirements, this can lead to negative consequences for the low voltage part of the distribution grid.

3.4 Requirements for grid-connected PV panels

Grid connection of distributed generation in a low voltage grid can result in new operational challenges, such as increased voltage level. A larger number of prosumers feeding electricity into the distribution grid can result in a change of the direction of the power flow, i.e. upwards in the power system instead of downwards. This can result in an increased voltage instead of a voltage drop. Today's regulations require DSOs to deliver electricity to customers at a voltage of 230 V ± 10 %. Depending on local conditions and on the status of the grid, too many prosumers in the same area could result in too high voltage.

The ProAktiv project[21] developed an overview of the technical requirements for connecting prosumers to the grid. Since the DSOs have not decided on one single standard, three different standards are presented. To secure that the installation of the PV panel will not affect the voltage quality at the point in the grid where the prosumer is connected and for other households located in the same area as the prosumer, technical requirements need to be followed.

3.5 Research needs

Distributed generation from customers is new for the DSOs and more experience and research is needed. For instance, which requirements for connection should be given to secure the quality of supply for the first prosumer, and also for the last customer.
Further research is also needed related to the use of the new information from the grid for a more cost-efficient operation and maintenance of the distribution grid, the use of prosumers (flexibility) as an alternative solution to grid investments, and development of the requirements to enable an increase in the number of prosumers – at the same time as quality of supply is maintained.

---

[19] DSO: Distribution System Operator

[20] Torsæter B. N., Sæle H., Ødegården L., and Kirkeby H. (2017), " Nettilknytning av plusskunder. Erfaringer fra nettilknytning av småkraft i Norge og plusskunder internasjonalt", TR A7636 SINTEF Energy Research.

[21] https://www.energinorge .no/energiforskning/forskning-pa-fremtidens-kraftsystem2/fremtidens-smarte-nett/pagaende-prosjektersmartenett/proaktiv/

4 Markets, incentives and regulations

4.1 Legal framework and financial support for prosumers

Through the surplus customer arrangement in Norwegian regulation, the grid company is obliged to accept bi-directional flow of energy but not to buy energy from the prosumer. The customer should find a power company that is both supplying power and buying the surplus power produced.

The arrangement is limited to customers who feed maximum 100 kW into the grid. For feeding in larger quantities, the customer needs to apply for a licence (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 limit is the advantage the surplus customer gets of not paying a tariff for selling their surplus electricity through the grid ("innmatingstariff"). The 100 kW limit does not affect regular households, but for larger sites such as schools, this might be limiting the dimensioning of production capacity.

The most significant financial incentive for becoming a plus-customer in Norway is the investment support by the public enterprise Enova[22]. In addition, there are local support schemes for renewable small-scale energy production, like the municipality of Oslo which offers up to 30% of the costs as refunds. In principle, new renewable electricity generation is also entitled to el-certificates if in operation before 2021 but due to an entrance fee of 15 000 NOK, el-certificates are no incentive for small-scale producers.

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

There is an ongoing discussion about the future grid tariffs. The trend is a peak load (i.e. the maximum consumption within any given year) with a higher growth rate than the total yearly electricity consumption. Since the grid capacity must be dimensioned to peak load circumstances, this reduces average utilization of the grid. In the long term, grid tariffs affect grid utilization and the need for costly grid enhancements. Recently, the Norwegian 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 will change if a new grid tariff is implemented.

Let’s look at the consequences for prosumers when changing from an energy to a capacity-based grid tariff[23]. Today, the most common grid tariff for Norwegian residential customers is an energy tariff with a fixed part [€/year] and an energy part [Eurocent/kWh], as illustrated in (1).

Energy tariff = Fixed part + Energy part *(1)*

An alternative, capacity-based tariff can for example consist of a fixed part (€/year), an energy part (Eurocent/kWh) covering marginal losses in the grid, and a power part (€/kWh/h) as illustrated in (2).

Capacity-based grid tariff =
Fixed part [€/year] + Energy part [Eurocent/kWh] + Capacity part [€/kWh/h] *(2)*

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

[23] CIRED-paper 2017 "ECONOMIC EVALUATION OF THE GRID TARIFF FOR HOUSEHOLDS WITH SOLAR POWER INSTALLED", Hanne SÆLE (SINTEF Energy Research – Norway), Bernt A. BREMDAL (University of Tromsø (UiT)/Smart Innovation Østfold – Norway).

The settlement of the consumption is based on hourly values from the smart meter. The power part can be settled based on the average of the three maximum values during a month, the average of three maximum values in defined peak load periods, etc. NVE have proposed a capacity where the fixed part is a capacity subscription and the capacity part is an additional cost per kWh whenever the consumption exceeds the subscribed amount.

A case study has evaluated consequences for a prosumer when changing from an energy to a capacity-based grid tariff as specified in (2). According to the regulations specified by NVE, the maximum allowed income for DSOs (obtained by the tariff they set) shall not be affected by the applied structure for the grid tariff. The calculations in this case study are therefore based on the assumption that an average household customer has the same yearly costs with the alternative grid tariffs.

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, but the yearly cost for the prosumer is reduced with increasing energy part and decreasing capacity part. This 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 calculations in this case study show that when changing from an energy to a capacity-based grid tariff, the benefits for the prosumer from feeding electricity into the grid will be reduced. This supports 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 are the most beneficial.

4.3 EU regulation on Energy Performance of Buildings (EPBD)

<u>About EPBD</u>

The European union sets ambitious targets through the Energy Performance of Buildings Directive (EPBD) which covers requirements for technical systems and areas such as energy requirements, energy labelling, and health and well-being of users. The first version from 2002[24] (no: "Bygningsdirektiv I") included the definition of a methodology for calculating the energy performance of buildings. The recast of 2010[25] (no: "Bygningsdirektiv II") included the idea that energy performance requirements for buildings should be cost-optimal and introduced the target of nearly zero-energy buildings (NZEBs) by 2020. The latest amendment of the EPBD in 2018[26] strengthens the focus on renovation of the building stock.

<u>Minimum requirements shall be based on cost-effectiveness</u>

Member states of the European Union (including Norway through the EEA agreement) shall set minimum energy performance requirements for buildings according to a cost-optimal calculation[27]. The goal is to define requirements to minimize global costs over the lifetime of the building. Global

---

[24] "Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings," Off. J. Eur. Union, pp. 65–71, 2002.

[25] "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings," Off. J. Eur. Union, 2010.

[26] "Directive (EU) 2018/ of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency," Off. J. Eur. Union, 2018.

[27] EuroACE, "Factsheet on Cost-Optimality." 2011.

costs include investment, annual cost and disposal. These requirements are dependent on the building type and will vary between regions because of different climate conditions and different energy and construction costs. If, for example, the energy cost were to increase and everything else kept constant, it would be optimal to increase investments in energy performance measures such as insulation in the walls. The logic is that if the (discounted) reductions in annual cost would be larger than the increase in investment costs, the global cost would be reduced.

Nearly zero-energy buildings (NZEB)
There is an implicit assumption in the EPBD that NZEBs will be cost optimal soon. However, such a development is not certain and there is a lack of information on what will happen if this does not occur. The definition of 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"[28].

It is up to every member state to give their own interpretation of this definition according to cost optimal calculations. One possible interpretation is that the EPBD requires a large-scale introduction of prosumers.

Table 4.1 Cost-optimal requirements versus NZEB

Cost-optimal requirements	Near Zero Energy Buildings (NZEB)
• Motivated by market failures in the building sector leading to under-investment in energy-related building measures. • Member states shall 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 which satisfies general criteria when determining the cost optimal requirements. • There is a lot of discretion left to the national implementation of the EPBD. • Cost-optimal requirements have been tightened over time, e.g. more insulation in walls.	• The EPBD states all new buildings to be nearly zero-energy. • Exact definition of NZEB is not clear. • States that policy makers 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 encourages on-site renewables, but does not strictly require them.

Flexibility in national implementation
Implementation of the EPBD varies a lot across Europe. For example, the defined values for the maximum primary energy consumption vary with a factor of 4 to 5[29]. 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:

[28] "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings," Off. J. Eur. Union, 2010.
[29] Building Performance Institute Europe (BPIE), "Nearly Zero Energy Buildings Definitions Across Europe," 2015.

- 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 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 since renewable energy provided through the grid or district heating would not be included in the calculation. One reason to implement such a restriction could 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 also means that society misses out on opportunities to build the renewable energy sources elsewhere with better conditions, such as improved economies of scale for large wind or solar farms or improved site-specific renewable energy conditions like increased and more stable wind speed.

The primary energy factor for energy supplied from the grid explains how much primary energy was used to produce 1 unit of final energy delivered to the end user. Currently it is set to 2.5 in the EU[30] but member states can apply a different factor if they can justify it. If the primary energy factor is set higher than what the generation mix in the power system justifies, the energy supplied from the grid will have a regulatory disadvantage in case the requirements for the energy performance of buildings is based on the amount of delivered primary energy. In turn, such a disadvantage for energy supplied from the grid would lead to favouring local solutions such as increased amounts of prosumers.

Since the EPBD states that requirements related to energy performance of buildings should reflect the cost optimal levels of energy related measures, the assumptions used in the calculation have an important impact on the result. For example, if the discount rate is lowered, capital investments such as on-site renewable energy will be relatively more favourable.

So far, the requirements for energy performance of buildings have been focused on reducing their energy needs. The introduction of NZEBs in the EPBD is closely related to the issue of distributed renewables and could influence the number of prosumers, but this depends largely on the national implementation of the directive. A lot of flexibility is left to the national implementation 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 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 system.

In Norway, only the first EPBD from 2002 has been implemented so far, since the 2010 recast has not been included in the EEA agreement yet. However, similar principles have been developed for Norway[31].

4.4 Business models and examples of prosumer initiatives in Norway

Two of the main challenges of power markets are:

---

[30] "Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency," Off. J. Eur. Union, 2012.

[31] Meld. St. 28 (2011-2012), Kommunal- og regionaldeptartementet, "Gode bygg for eit bedre samfunn".

(1) to accurately capture and allocate the value of the energy provided through business models[32]
(2) to ensure energy is reliable, affordable and sustainable (*the energy trilemma*)[33].
Introduction of prosumers makes these challenges more complex as prosumers take the role of both supplier and consumer.

Energy consumption has a potential to become more responsive by coordinating end-user technologies, e.g. solar PV, batteries and EV charging. Participation of prosumers 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 based on energy consumption rather than power flow. Currently in Norway, only large consumers (industry and commercial sector) are billed based on their peak power outtake as part of the grid tariff. Creating incentives to trigger growth in valuable prosumer services and products might 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 is to participate in the surplus customer arrangement ("plusskundeordningen"). New business models for prosumers can be split into three types[34]: peer-to-peer models, prosumer-to-grid models and organized prosumer group models:

- *Peer-to-peer models (P2P)* 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. These models allocate value and risk to prosumers. The main driver is knowing where the energy comes from, as well as better prices due to direct payment. Barriers include the challenge of designing and enforcing regulation to ensure reliable supply if single peers are unable to produce power. A P2P business model is not an option within the current regulation in Norway.

- *Prosumer-to-grid models (P2G)* are characterized by trading between prosumers and grid operators. 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. The long-term efficiency gains are a driver. However, at the core of P2G models lies a lot of real-time data, IT infrastructure and complex algorithms. One of the greatest barriers of P2G models is making this 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 into the grid.

- O*rganized prosumer group models (OPG)* are characterized by communities pooling prosumers together, thereby harvesting benefits through cooperation and synergies. Trading happens through an *aggregator*, an entity that collects energy from prosumers and trades it internally and externally. With enough 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 through the plus-customer arrangement for housing cooperatives or through third-party ownership of distributed production. The allocation in OPG

[32] Chesbrough, H. (2010). Business model innovation: Opportunities and barriers. Long range planning 43.2, 354-363.
[33] Heffron, R. J., McCauley, D., & Sovacool, B. K. (2015). Resolving society's energy trilemma through the Energy Justice Metric. Energy Policy 87, 168-176.
[34] Parag, Y., & Sovacool, B. K. (2016). Electricity market design for the prosumer era. Nature Energy 1, 16032.

models can become more detailed in Norway when Elhub[35] goes live in 2019. An example of this model is the PowerMatching city[36].

A lack of willingness to adopt a more complex operation of the power system, as well as privacy issues, slow down the development of prosumer business models. Lacking or immature regulatory frameworks are a main barrier. Another barrier is the uncertainty related to reliable operation of prosumer networks which could lead to redundant investments in generation capacity and metering infrastructure. Energy companies tend to be reactive and end-users tend to be impatient in the development of prosumer initiatives.[37] 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 a year old, and the low electricity price in Norway delays return on investment. Options to resolve these barriers, besides waiting for prices on PV to drop further, are (1) to better understand the value of prosumer flexibility and (2) to develop business models that capture and allocate this value.

A few examples of prosumer initiatives in Norway:

- *TrønderEnergi*: The local utility TrønderEnergi (TE) launched a questionnaire to recruit prosumers for a solar PV demo project.[38] The business model was based on TE renting roofs from selected participants. TE takes on the investment risk, whereas prosumers get a fixed rate for energy produced by the panels. While the 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. This can be classified as an OPG model where TE allocates the costs of the solar installations equally among the prosumers.

- *Nord-Trøndelag Elektrisitetsverk (NTE)*: The business model was based on prosumers taking the risk and purchasing their own solar panel rig. The participants signed a contract with NTE to become prosumers ("plus-customers") meaning any surplus energy generated by the PV panels is purchased by NTE at spot price. The contract was signed for 15 years during which time the supplier is responsible for service and maintenance of the panel. This can be classified as a P2G model where individual prosumers take all risk and trade their surplus with the system.

- *Smart Energi Hvaler*: Hvaler, a group of islands off the coast of Fredrikstad, is connected to the mainland grid with only one connector, which motivates development of local energy supply. A type of tariff that was under testing was called "Smart Neighbourhood", which made electricity 30% cheaper if there was a surplus of solar power in the neighbourhood. This relates to the OPG model where the benefit of surplus power is shared by the community. This was proven difficult to implement due to the structure of the billing services currently on the market. Financial support from Enova reduced the total investment. Revenue for owners is ensured through a feed-in tariff (FiT) in addition to the spot price. The FiT gives a return on investment of about 10 years, but is guaranteed only through 2018. Less risk on investment is dependent either on (1) rising prices or (2) the customer's ability to change loads to reduce the grid tariff. The incentive

[35] https://elhub.no/
[36] https://www.dnvgl.com/technology-innovation/broader-view/sustainable-future/vision-stories/power-matching-city.html
[37] Olkkonen, L., Korjonen-Kuusipuro, K., and Grönberg, I. (2016) Redefining a Stakeholder Relation: Finnish Energy 'prosumers' as Co-Producers. Environmental Innovation and Societal Transitions. doi:10.1016/j.eist.2016.10.004.
[38] Throndsen, W., Skjølsvold, T.M., Ryghaug, M. and Christensen, T.H., 2017. From consumer to prosumer. Enrolling users into a Norwegian PV pilot.

for load shifting depends on the tariff structure. Since the introduction of smart meters, all residents are subject to a capacity-based tariff, meaning that the bill for network usage is measured by peak load. Thus, adding automation may benefit the usefulness of panels, as e.g. water heaters are a viable way to shift demand by storing energy when the sun is shining.

- *Otovo*: This start-up company launched their business-model in the market in 2016 and quickly became the market leader on sales of solar panels to Norwegian households. They calculate the solar power potential for new customers, reduce the investment cost barrier by providing loans, and offer training to installation personnel. By handling the whole process from planning to installation, they solve a major barrier associated with the procurement of solar PV for small scale customers. Furthermore, they have established a power company offering an exchange scheme among neighbours called "Nabostrøm"[39] where customers can subscribe to ensure energy consumption is balanced with as much locally produced solar power as available. This means customers are indirectly buying 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. This can be seen as a first step towards a P2P model.

4.5 Welfare effects of prosumers

In Norway, small-scale prosumers are subsidized by direct contributions (e.g. Enova) and favourable network tariffs. The number of prosumers has risen sharply during the last few years.

An NHH master thesis[40] discusses potential benefits from an increasing number of prosumers:

- 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
- energy democracy (more power controlled by individuals).

It is argued that many of these benefits have lower value in the Norwegian power system than elsewhere since power is already relatively cheap, secure, flexible and low in emissions. There are several technical and distributional challenges associated with an increasing number of prosumers in the distribution networks. It is maintained that a move from volumetric tariffs towards higher fixed charges depending on load subscriptions can provide more correct incentives for potential investors.

The thesis concludes that prosumers may be beneficial to the Norwegian power system, but net benefits will be project specific and depend on conditions such as location and on how well production and consumption coincide. Untapped potential can possibly be triggered by technological advances in tools such as distributed storage and demand response.

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

[40] Vestby, Line and Dvergnes, Alexander. (2017). Går samfunnet i pluss med plusskunder? Masteroppgave ved NHH.

5 Designing prosumer energy systems

5.1 Introduction

There are a lot of modelling tools available to evaluate engineering, architectural and economic aspects of prosumer energy systems and to assess the energy aspects of buildings. These tools provide insights into building design, demand profiles, the operational supply-demand energy balance and economic feasibility. These models analyse different aspects of the prosumer energy system, for example dwelling design and insulation efficiency, house orientation, glazing and daylighting and the physical equipment feasibility of the prosumer energy system.

5.2 Modelling Prosumer energy systems: Aggregators and distributed generation

A few examples of studies:

In a model[41] for a load aggregator participating in the wholesale power market and the regulation capacity market, the customer portfolio is composed of medium-size commercial electricity consumers including shopping centres, food production sites, district heating sites and greenhouses. Flexibility comes from reducing heating loads, substitution between electricity and oil/gas in satisfying heating loads, reducing air conditioning and energy efficiency measures for lighting. The study shows that the aggregator's value largely depends on within-day price variations, leading to a cost reduction of around 4%.

A further study[42] expands this concept by assuming that the aggregator can control prosumers' flexible energy units. It models the flexibility properties of the energy systems for three building groups: a community consisting of public/commercial buildings, households and cottages, and an industrial plant. The model calculated the value of flexibility to 12% of the total costs.

Flexibility requirements for on-site supply-demand balancing have emerged as a new feature on designing prosumer energy systems[43]. Four flexibility services for prosumers are identified:
1) Time-of-use pricing (ToU) or different tariffs,
2) kWmax control,
3) prosumer self-balancing (maximize renewable usage) and
4) islanding.
These services are 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 on distribution grids. Batteries together with smart meter technologies will create prosumer flexibility without affecting comfort and allow the deployment of larger renewable capacities. Studies have shown that storage yields 10% in savings for prosumers. 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 vs day). I If other flexibility services for the grid are included for battery operations, the value will increase.

---

[41] Roos, Aleksandra; Ottesen, Stig Ødegaard; Bolkesjø, Torjus Folsland. (2014) Modeling consumer flexibility of an aggregator participating in the wholesale power market and the regulation capacity market. Energy Procedia. vol. 58.
[42] Ottesen, Stig Ødegaard; Tomasgard, Asgeir. (2015) A stochastic model for scheduling energy flexibility in buildings. Energy. vol. 88.
[43] Espen Flo Bødal, Pedro Crespo del Granado, Hossein Farahmand, Magnus Korpås, Pol Olivella, Ingrid Munné, Pau Lloret (2017). Challenges in distribution grid with high penetration of renewables. Deliverable 5.1, INVADE project.

The conclusion of the analysis of a large household in Trondheim[44] is that utilizing an EV battery leads to larger savings, whereas a home battery would need significant subsidies to achieve a positive net present value.

5.3 Design and cost analysis of prosumer energy systems for peak shaving[45] – Case studies

Both cases examine the profitability of local PV and batteries with electricity grid tariffs rewarding peak-shaving.

Case study – Retail sector

For this case, 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 payback time varied between 3 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 already with current prices. So the electricity consumption characteristics affected payback times. Battery cost, PV cost and grid tariff will also significantly impact payback times. Results from the simulation show that a decrease in battery cost of 50% or an increase of 100% for grid tariff both yield in payback times of about 7 years for two of the buildings.

Case study – Agricultural sector

The volatility in the load profile in this sector is significantly lower than in the retail sector. The system components included in the optimization were PV, battery, inverter and power grid for peak shaving. With our business-as-usual assumptions, the most cost-efficient solution today is that no investments, i.e. no PV, battery or peak shaving, was needed. 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 of today. This situation would result in 20% cheaper electricity than today. Third, large batteries are cost-efficient when the demand charge is high and battery costs are low. Fourth and last, peak shaving is cost-efficient in almost all cases, except at low demand charge and battery costs of today. With battery costs down to 1500 NOK/kWh (multiplier 0.5), peak shaving would be cost-efficient in all cases.

These studies conclude that:
1) There are cases today that could benefit from an optimally sized battery for peak-shaving;
2) Assuming cost reductions of PV and battery, 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 the cost-efficiency.

---

[44] Bjarghov, S., Korpås, M. and Zaferanlouei, S., 2017. Value Comparison of EV and House Batteries at End-user Level under Different Grid Tariffs. Energycon 2017(forthcoming).

[45] Peak shaving: the process of reducing the amount of energy purchased from the utility company during peak demand hours.

5.4 Criteria for PVs to optimize own consumption of own generation

Since the orientation of a PV-panel affects both the volume and the time of generation, it can increase a prosumer's potential for self-consumption, as is shown in the case study of Hvaler[46]. Hvaler is an area located in south-eastern Norway where several household customers have installed roof top PV-panels. Empirical data shows how generation with equal equipment varies with season, geographical location, roof orientation and inclination. Different orientations of PV-panels yield generation of electricity at different times during the day. PV-panels oriented towards the south get peak generation earlier than PV-panels oriented towards the west.

Therefore, prior to installing a PV-panel, the household's particular consumption profile should be analysed. Most people follow a similar daily routine that creates a power peak in the morning and in the early evening. The energy demand during the day is often a lot lower. A south oriented panel is likely to produce the best annual yield in terms of energy, but it may be less attractive economically since it will not eliminate or reduce the costliest part of the consumption. Consequently, an hour-by-hour consumption analysis before investment is recommended. The evaluation of the potential for self-consumption, with different orientation of the PV-panels, shows that with

- South orientation, the production from PV-panels cover a large share of the peak load in the morning but contribute very little to the peak load in the afternoon.
- West orientation, nearly the total peak load in the afternoon is covered during the summer, and approx. 50% during the autumn.

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

6 Energy system impacts

Beside their local effects, prosumers also interact with the transmission system and a significant share of prosumers will affect the national and regional energy system.

6.1 Introduction

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. On the other hand, some types of prosumers are able to provide flexibility services to the system, for example by demand response (DR), local energy storage and vehicle to grid services (V2G).

The Norwegian energy system differs significantly from that of other European countries due to the cold climate and the large hydro reservoirs. Hence, from a social welfare perspective, the energy system adaption of prosumers differs from other European countries. In Norway, electricity consumption is highest in winter, due to electric heating, when solar radiation conditions are poor. Consequently, prosumers with local PV production have a limited potential to reduce peak electricity demand. The same effect can be observed in local production from prosumers in large cities connected to the transmission grid. In the case of Oslo, for example, the large-scale integration of prosumers, which are mainly PV-based, does not significantly reduce peak load.

---

[46] CIRED-paper 2017 "ECONOMIC EVALUATION OF THE GRID TARIFF FOR HOUSEHOLDS WITH SOLAR POWER INSTALLED", Hanne SÆLE (SINTEF Energy Research – Norway), Bernt A. BREMDAL (University of Tromsø (UiT)/Smart Innovation Østfold – Norway).

Our research demonstrates that prosumers with demand response facilitate an integration of intermittent electricity generation by lowering the need for backup electricity generation capacity and reduce the number of time periods where the electricity demand cannot be met. Further research is required on interaction and competition of demand response with other types of flexibility services provided by prosumers, 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 prosumers as 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 in 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 on how prosumers with building integrated PV and end-use flexibility will affect the peak load in the Oslo region[47]. The reason for this study is 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 PV in the future. The main results and conclusions are also valid for other urban regions in Norway.

Key message 1: Prosumers with PV and with no end-use flexibility will not impact the peak load and the required transmission grid capacity. They 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. The peak loads are mainly due to the need for electrical heating in the coldest periods of the year when 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 a larger region, there can be instances where peak demand is reduced for a single consumer, for example if the peak electricity consumption occurs when there is PV production, typically in the middle of the day.

Key message 2: An alternative for reducing the peak load isend-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, the indoor temperature provided by electric heating can be adjusted within a user specified temperature interval.
Statnett has investigated[48] how end-use flexibility can lower the need for grid expansion. They conclude that batteries are more expensive than other types of flexibility that are already available in buildings, like ventilation, electric boilers and electric heating. The cheapest flexibility comes from electric boilers in large buildings such as schools and elderly homes. Consequently, the existing flexibilities in the buildings should be used before investing in batteries. Batteries are not profitable for lowering the peak load, even in a future scenario with highly decreased battery costs.

---

[47] Statnett: Forbruksprognose Stor-Oslo. Statnett-report. 2018. Available at http://www.statnett.no/PageFiles/15366/Forbruksprognose%20Stor-Oslo%202018.pdf

[48] Haakon Vennemo, Christian Grorud, John Magne Skjelvik, Anne Maren Erlandsen: Alternativer til nettinvestering: Eksempler fra Oslo og Akershus. 2018. Report from Vista Analyse and asplan viak ordered by Statnett and Enova. Rapport nummer 2017/30. Available at http://www.statnett.no/PageFiles/14459/VA-rapport%202017-30%20Alternativer%20til%20nett%20Oslo%20og%20Akershus.pdf

6.3 Impact of prosumers with building integrated PV and no flexibility services on the Scandinavian electricity and building sector towards 2050[49]

The model in this study provides cost-optimal investments and operation related to energy supply, conversion, delivery and use of energy that is 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 study assumes that all new buildings and parts of the rehabilitated buildings from 2015 towards 2050 are prosumers. This results in 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 PV producing prosumers is addressed. The first type are prosumers in buildings that are designed according to the current building standard, hereby denoted *PRO*. The second type are prosumers in buildings that are highly energy efficient, satisfying the Norwegian passive building standard, and is hereby denoted *PRO+*. The passive building standard lowers the heating demand of the buildings, where the Scandinavian heat demand is 18% lower for *PRO+* than for *PRO* in 2050**.**

Key message 1: Of all electricity generation technologies, wind power is the most affected by the large-scale deployment of prosumers. Compared to *REF* scenario [50], the wind capacity is reduced with 28% and 43% for *PRO* and 34% and 51% for *PRO+* in 2030 and 2050 respectively. 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.

Key message 2: Thanks to large flexible hydropower plants, the Scandinavian energy system is capable of integrating significant amounts of prosumers with PV on an aggregated level, also with no local storage connected to the buildings.

Key message 3: Large integration of Scandinavian prosumers with local PV production influences the electricity trade pattern with Europe, especially when prosumers are introduced in the same order of magnitude in the rest of Europe. For *REF*, Scandinavia exports electricity at daytime when prices are high and imports at night when prices are low. This is opposed 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 during the day. 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 lowers cost-optimal investments in heat pumps and increases the cost-optimal investments in direct electric heating and electric boilers. The deployment of prosumers influences the use of heating technologies in buildings. Prosumers will influence the electricity price and thus change the competitiveness of electricity-based heating options. Heat supplied by heat pumps (HP) and from biomass boilers is reduced when prosumers enter the energy system.

[49] Seljom, P., Lindberg, K.B., Tomasgard, A., Doorman, G., Sartori, I., 2017. The impact of Zero Energy Buildings on the Scandinavian energy system. Energy 118, 284-296.

[50] *REF* scenario shows the development of the energy system without any prosumers with local PV production.

6.4 The impact of shiftable load on the Power System

Prosumers can provide flexibility to the power system through Demand Response (DR), for example by moving the demand in time. Research[51] has been done on the impact of this type of DR on the optimal generation mix and on system adequacy.[52]

When demand response is modelled as shiftable volume with a rebound effect, consumption can be reduced by moving the demand for electricity in time for any given operational period. However, the shiftable volume is likely to increase the electricity consumption due to additional losses related to moving the electricity demand in time, the so-called rebound effect. Hence, this type of DR requires large enough price differences in the market to compensate for the cost of the associated rebound effect. For example, due to the inherent physical "cold" storage capabilities of refrigerated warehouses, their consumption can be reduced for a few hours and delayed. However, to achieve the desired temperatures later, the power consumption will be higher and at a lower efficiency, described by the rebound effect.

Key messages:

DR that shifts demand in time

1. reduces the need for back-up 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 on its own sufficient 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 illustrated in two cases.

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%. With higher demand flexibility, thermal generation capacity decreases since DR improves the utilization of the renewable electricity generation. The curtailment of renewables is reduced from about 20 TWh to 8 TWh when comparing the situation with no DR to the 5% flexibility level. In addition, DR reduces the need for peaking gas turbine capacity and lowers the CO_2 emissions.

In the second case, demand flexibility is limited to 10%, while the renewables share of the electricity demand varies from 20% to 100%. The power system needs additional capacity in the form of thermal units. With an increasing share of RES, there is a modest decrease of thermal backup capacity. The need for thermal capacity, also at high RES levels, stems from time periods with a large difference between RES generation and demand. Above 80% renewable share, the curtailment of RES and rationing increase sharply. This suggests that DR has limited capability to balance a system with high levels of RES and needs to be supplemented by other storage options.

Conclusion: 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 utilisation of the renewable energy sources.

[51] e-Highway 2050. u.d. e-Highway database per country. Funnet January 17, 2017. http://www.e-highway2050.eu/fileadmin/documents/Results/.

[52] System adequacy is a measure for 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) occurs to achieve the instantaneous balance of electricity production and consumption.

6.5 Long-term effects of demand response in the European Electricity System

The operational costs of DR depend on the type of flexible load and on the consumer type. In the residential sector, the marginal costs of load shifting are around 10€/MWh, while in the commercial sector they can vary from 5 to 150€/MWh[53]. From the prosumer's perspective, these are the reservation prices, the minimum price at which they sell their flexibility. From a supplier's perspective, it is the maximum they would pay to consumers in order 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 is optimal for the system to execute the load shifting.

Key message 1: The results show that prosumers with DR are a cost-effective solution for the European electricity sector from 2020. It is more effective in countries with high shares of intermittent renewable energy since these countries have higher variations in the electricity price. There are some types of DR that are not cost-effective, such as residential heating and AC and commercial cooling, either because they have too high costs, because they have small operational time intervals or because they cannot compete against other types of flexible demand or supply. The DR measure that is mostly utilized 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[54], household washing appliances, industrial processes, non-residential cooling and residential heating and AC.

Key message 2: Prosumers with DR increase the investments in PV since DR shifts parts of the demand to hours with high PV production and low electricity prices. The residual load, which is not covered by renewables, is changed for that 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 similarly to other energy storage options, the deployment of DR lowers the investments in battery storage capacity.

7 Conclusions

7.1 Selected main findings

a) 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.
b) Existing prosumers in Norway have been more motivated by environmental concern, technological interest and self-consumption than by economic incentives.
c) Return on investment for prosumers is very low without strengthened financial support.
d) The smart meters installed in Norway will be an enabling technology for new grid tariffs and energy contracts. They are also prepared for metering the electricity feed into the distribution grid.
e) 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.
f) Solar PV production in Oslo will only marginally reduce the need for transmission grids expansions to the city.

[53] Gils, HC, 2014. Assessment of the theoretical demand potential in Europe, Energy.
[54] HVAC: Heating, ventilation and Air Conditioning

g) A capacity-based grid tariff, as suggested by NVE, will a) make it less profitable to invest in solar panels, and b) give a stronger incentive for flexibility. However, depending on how the tariff is specified, some of the disadvantage for PV could be offset if PV panels can be installed in such a way that the production fits better with peak loads for consumption.
h) Wind power and PV, which create varying renewable generation, are complementary technologies to demand response. Additional amounts of one of them will increase the value of the other. Different types of varying renewable generation are, however, substitutes for each other.
i) In EU/EEA, national regulation for energy solutions in buildings shall promote cost-efficiency. Nearly zero-energy buildings (NZEB) are promoted, but it is not clear how they should be defined and how the case of NZEBs not becoming cost-effective should be handled.
j) To avoid instabilities in the electricity supply for the surrounding area, the local DSO should be involved in the process when a customer wants to invest in PV panels.
k) One of the main barriers for new prosumer business models is lacking or immature regulation, which might be a consequence of lacking experience of large-scale market integration of prosumers.
l) 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.

7.2 Concluding remarks

Sociological studies show that the prosumer phenomenon has a potential to transform parts of our everyday life. One possible future includes local grids connecting climate-motivated prosumers who feed in their PV generation and are active participants in the discussion of energy solutions for their neighborhoods. This could result in a reliable, fair, and environmentally friendly energy supply. For the prosumers, personal identity, self-realization and a feeling of belonging to a grass-root movement or a society working together to save the planet is important. The technologies and the organization of future prosumer activity can therefore be very different from what we can foresee today.

However, it is possible that we will not see major changes for most communities and citizens. Consumers and legislation may stay mostly focused on reliable, simple and affordable access to electricity. In that case, local solutions for generation and flexibility will connect to the overall energy system to the extent that they can compete with alternatives. This could be considerable amounts. The calculation of those cost-efficient amounts is the typical energy system analysis perspective. For flexibility services (e.g. demand shift or batteries), the largest socio-economic benefit for the Norwegian hydro-dominated power system is probably saved investment costs for the electrical grid in cities which experience higher growth rates for peak loads than for annual energy electricity consumption.

Most likely, several developments will co-exist.