Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ZERO EMISSION NEIGHBOURHOODS

Drivers and barriers towards future development

ZEN REPORT No. 22 – 2020

Stian Backe and Ann Kristin Kvellheim | NTNU and SINTEF

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Preface

Acknowledgements

This report has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The author gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Caverion, Nord-Trøndelag Elektrisitetsverk - Energi, Smart Grid Services Cluster, Statkraft Varme, Energy Norway, Norsk Fjernvarme and AFRY.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, an NRK-site in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

https://fmezen.no
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FME ZEN (page)

Norwegian Summary

Utbredelse og vekst av nullutslippsområder

Rapporten beskriver status i utviklingen av nullutslippsområder, samt drivere og barrierer for videre utbredelse. Det tas utgangspunkt i en norsk kontekst, og hovedfokus er på teknologiske, markedsrelaterte og samfunnsmessige aspekter av nullutslippsområder. Rapporten bygger i hovedsak på forskning i forskningssentrene ZEN og forløperen ZEB[4], litteraturstudier og en intern workshop.

Bygg står for en vesentlig del av total energibruk og klimagassutslipp og er derfor viktige for å nå nasjonale og internasjonale mål knyttet til avkarbonisering. Hvordan bygg og nabolag bør utvikles for å bidra til å realisere disse målene blir det fremdeles forsket på. Teknologiutvikling er viktig for valg av energisystemer i et nullutslippsområde. Energieffektive innretninger blir stadig mer utbredt. Raskt synkende kostnader gjør ny fornybar energiproduksjon økonomisk levedyktig, og særlig solceller (PV) gjør seg relevant til lokal produksjon av elektrisitet i nabolag. Tilsvarende utvikling forekommer innenfor batteriteknologi og muliggjør fleksibel energibruk gjennom smart energimåling (AMS) og styringssystemer knyttet til stasjonære og mobile batterier. Fleksibel energibruk er en kritisk faktor for å oppnå høy utnyttelse av den fornybare energien.

Hvordan samfunnet oppfatter og forholder seg til nullutslippsområder har avgjørende betydning for utviklingen fremover.

Kraftforsyning i nabolag skjer hovedsakelig via tilknytning til strømnettet. Siden kraftnettet er svært viktig for å kunne utføre sentrale samfunnsfunksjoner er markedet for strøm regulert. Lokale energisystemer i et nullutslippsområde kan bidra til økt fornybar energiproduksjon og alternativ fordeling av strøm gjennom batteriløsninger som kan være mer kostnadseffektive enn et tradisjonelt strømnett, særlig i mindre urbane strøk. Integreringen av lokale miljøvennlige energiløsninger krever marked som fanger verdien av bidragene. Slike marked kan være komplekse i drift siden mange små bidrag ofte skal fordeles innenfor korte tidsperioder. Koblingen mellom marked for materialer og energisystem vokser med utvikling av bygningsintegrert energiproduksjon.

Hvordan samfunnet oppfatter og forholder seg til nullutslippsområder har avgjørende betydning for utviklingen fremover. De innovative løsningene i slike områder møter i enkelte tilfeller begrensninger i form av et konservativt regelverk. Aktører som forvalter relevante virkemidler er sentrale for å være med og utløse samarbeid om utviklingen og videre utbredelse av nullutslippsområder.

Basert på identifiserte drivere og barrierer gir rapporten følgende anbefalinger:

Prosjekteiere og -utviklere:

- ✓ Sett ambisiøse målsettinger og utvikle bærekraftige forretningsmodeller.
- ✓ Bidra til kompetanseheving på tilbudssiden ved å bruke etterspørselsmakten.
- ✓ Engasjer beboere/brukere til å bidra til å skape attraktive nullutslippsområder
- ✓ Støtt opp under innovative prosjekt og sørg for å ha god kompetanse innen smart teknologi.

[4] The Research Centre on Zero Emission Buildings (ZEB) var et forskningssenter for utvikling av nullutslippsbygg fra 2009-2017 (www.zeb.no).

Leverandører av infrastruktur, løsninger og produkter:

- ✓ Utfordre det etablerte markedet ved bruk av innovative forretningsmodeller og effektive løsninger.
- ✓ Grip mulighetene som ligger i ny teknologi og digitalisering.
- ✓ Skap nye forretningsallianser på tvers av profesjoner og tradisjonelle markeder

Myndigheter og samfunnet forøvrig:

- ✓ Engasjer, og vær engasjerte borgere når bærekraftige løsninger skal utvikles
- ✓ Regelmessig vurdere i hvilken grad reguleringer begrenser innovasjon som er nødvendig for utvikling og utbredelse av løsninger nødvendig for et grønt skifte.
- ✓ Støtt forskning slik at mer kunnskap om nullutslippsområder kan utvikles.
- ✓ Forbildeprosjekter er vesentlig for læring og videre utvikling.

Anbefalingene er utdypet gjennom rapporten og særlig i kapittel fem. Myndigheter og forskere har et særlig ansvar når det gjelder å tydeliggjøre hvilken rolle nullutslippsområder kan spille i overgangen til et lavkarbonsamfunn. Vi håper at denne rapporten kan være et bidrag i så måte.

English Summary

Spread and growth of zero emission neighbourhoods

This report describes the development of zero emission neighbourhoods and its drivers and barriers towards further development. The Norwegian context is used as a starting point, and the main focus is on technological, market related and societal aspects of zero emission neighbourhoods. The report is mainly built upon research in The Research Centre on Zero Emission Neigbourhoods in Smart Cities (FME ZEN) and its predecessor FME ZEB[5], as well as a limited literature search and an FME ZEN internal workshop.

Buildings account for a significant share of total energy use and climate gas emissions and are therefore important to address in order to reach national and international targets on decarbonisation. How buildings and neighbourhoods should be developed in order to contribute to this, is still researched. Technological development is important for choice of energy systems in a zero emission neighbourhood. Energy efficient appliances becomes increasingly common. Rapidly decreasing costs make renewable energy production economically viable, and in particular photovoltaics (PV) is made relevant for local production of electricity in neighbourhoods. A corresponding development is evident within battery technology and makes flexible use of energy possible through advanced smart metering (AMS) and systems of operation attached to stationary and mobile batteries. Flexible use of energy is a critical factor to achieve a high utilization of the renewable energy.

How society interpret and relate to zero emission neighbourhoods is decisive for the future development

Power supply in neighbourhoods is mainly solved through the power grid. Since the power grid is incredibly important in order to perform a central function for the society, the power market is regulated. Local energy systems in a zero emission neighbourhood can contribute to increased renewable energy

[5] More information on www.zeb.no

production and alternative distribution of power through battery solutions. Such solutions can be more cost-effective than the traditional power grid, in particular in less urban areas. The integration of sustainable energy solutions on the local level requires a market that can capture the value of this contribution. Such markets can be complex in operation since several small contributions must be allocated within short timeframes. The connection between markets for materials and for energy systems is growing as a result of the development of building integrated energy production.

How society interpret and relates to zero emission neighbourhoods is decisive for the future development. The innovative solutions in such areas are sometimes hindered by conservative regulations. Actors that administer relevant measures are important in order to enable cooperation about future development and spread of zero emission neighbourhoods.

Based on identified drivers and barriers the report gives the following recommendations:

Owners and developers:

- ✓ Set ambitious objectives and develop innovative and sustainable business models.
- ✓ Create a demand (and supply) for ZEN solutions through ambitious goals and long-term value creation.
- ✓ Engage users in co-creating attractive neighbourhoods.
- ✓ Support innovative approaches and acquire competence on smart technology.

Supply and infrastructure:

- ✓ Challenge the current market with innovative business models and efficient solutions
- ✓ Grasp opportunities provided by technology development and digitalization.
- ✓ Create new business partnerships across disciplines and traditional markets (energy and building industry).

Society and policy:

- ✓ Engage, and be engaged as citizens in the development of sustainable solutions.
- ✓ Frequently evaluate regulation limiting a ZEN based on updated research and development.
- ✓ Support research to develop more knowledge on the impact of a ZEN.
- ✓ Best practice projects is essential for learning and further development.

These recommendations are elaborated through the report and particularly in chapter five. Authorities and academia/researchers have a particular responsibility when it comes to clarifying what role a zero emission neighbourhood can play in the transition to a low carbon society. We hope that this report can be a contribution in this respect.

Table of content

1. Introduction

1.1 About this report

This report is written as part of the work in the Research Centre on Zero Emission Neighbourhoods in Smart Cities (the ZEN research centre). The aim of the report is to explore the foundations for further development and spread of Zero Emission Neighbourhoods (ZEN). Our primary focus is Norway, but developments related to the EU are highly relevant to the development in Norway and therefore included. Also, examples from outside Europe are included when appropriate.

The report endeavours to identify drivers and barriers in different areas pertinent to the development of a ZEN, such as technical, market related and institutional aspects. The report builds on research in the ZEN research centre and its precursor the Research Centre on Zero Emission Buildings (the ZEB research centre), as well as literature studies and an internal workshop.

In the rest of the report it is referred to the ZEN research centre when the research centre is addressed. Otherwise, a ZEN refers to the concept of a Zero Emission Neighbourhood (for definition, see sub-section 1.3).

1.2 Background and context

1.2.1 Climate policy

The climate is changing due to man-made greenhouse gas (GHG) emissions (Team et al., 2014). To curb emissions, policies and plans are made and actions are taken to reduce the extent of climate change. The Paris Agreement, signed in 2015, is a historic agreement that obliges the member parties to limit GHG emissions so that global temperature rise is kept within 2ºC. To achieve this ambitious goal, a range of measures are needed which includes significantly reduced GHG emissions from several sectors, including buildings, transport and energy. Other sectors are also implementing strategies to contribute to reaching climate targets (see for example Roadmap for green competitiveness in the financial sector (2018c)).

Buildings in Europe are responsible for about 40 % of total final energy requirements and 36 % of its CO_2 emissions (Sartori et al., 2009, 2016b). To achieve a significant reduction in CO_2 emissions, challenges include increasing energy efficiency and decarbonizing the power system (Jägemann et al., 2013). These developments are part of an even-larger transition towards a low-carbon society, and consequently, buildings are becoming progressively energy-efficient and power-producing. In the process of transforming the energy system in Europe, energy security is high on the agenda. Introduction of more variable renewables, such as wind and solar power, must be complemented by solutions that ensure flexibility and energy security. Grid capacity must be dimensioned for the coldest hour with the highest consumption over a year. In Norway, utility companies are planning investments in infrastructure in the magnitude of 140 billion NOK towards 2025 to ensure energy security (Bakke and Paulen, 2016a). If buildings and neighbourhoods could contribute to reduce the peak load, this is likely to be economically profitable. There is still a need for demonstrating business models through a regulatory sandbox regime, i.e. a temporary exemption from regulation, to understand the role and value of energy resources in neighbourhoods (Hentschel et al., 2019).

A push towards changing energy systems to approach a zero-emission future is present in European political goals, recently in “The Clean Energy for All Europeans legislative proposals” or “The Winter Package” (2016). Included in the Winter Package are proposed recast and revisions of several directives, of which the most relevant are the Renewable Energy Directive (RED) Council (2009) and the Energy Performance in Buildings Directive (EPBD) (2010). The RED requires an increased share of renewable energy. This implies that either the renewable energy production must increase, and/or the energy consumption must be reduced. The EPBD is regulating the energy performance of buildings through measures such as energy requirements for buildings, building elements and technical systems.

Through the European Economic Area (EEA) agreement, Norway is obliged to implement EU regulation. The EPBD is still not fully adopted into Norwegian legislation; one of the issues to be settled is how the concept of “nearly zero energy” and how the “renewable sources produced on-site or nearby” objective in the EPBD are defined in the Norwegian context. The building sector in Norway uses a large share of electricity due to the extensive and, so far, cheap access to this energy carrier. The European objective to decarbonize the power sector has less-obvious implications for Norway than for most other countries, since nearly all power generation in Norway is based on hydropower. However, there are other reasons for extending the range of energy sources, such as increasing energy flexibility.

1.2.2 Distribution of emissions

Norway has committed itself to reducing its greenhouse gas emissions by 40% by year 2030 with respect to 1990 (2017b). The measures needed to achieve this target are, however, different than elsewhere. The Norwegian power system is dominated by hydropower which is a flexible renewable power source. In 2016, the energy supply made up about 1.7 million tonnes out of the total yearly greenhouse gas emissions of 53.3 million tonnes of CO_2 equivalent (SSB, 2019) or about 10 tonnes per inhabitant[6]. The greatest contributors to this value are the oil and gas industry and other industries, followed by transport.

1.3 Definition of Zero Emission Neighbourhoods

The European approach has been focused on nearly zero energy buildings (nZEB) through the EPBD (2010). It is generally acknowledged that a zero energy building (ZEB) is a building that has a calculated balance between energy requirement and -production over a given time period, usually one year. What is meant by an nZEB has not been clearly defined in the directive, and hence it is up to the nation states to make their own interpretations. As a consequence, a range of definitions, solutions and concepts are made. The European Commission has funded reports where nZEB principles have been elaborated upon, for example the BPIE report "Principles for nearly zero-energy buildings"(Europe;, 2015) and the ECOFYS report "Towards nearly zero energy buildings. Definition of common principles under the EPBD"(Hermelink et al., 2012). In the latter, an overview of known definitions, calculation methodologies and labels for nZEB is presented.

In Norway, the focus has been on *emissions* in addition to energy. Both the ZEN Research Centre and its predecessor, The Research Centre on Zero Emission Buildings (ZEB), have published definition reports (Fufa et al., 2016a, Wiik et al., 2018b). In the ZEB definition report the short version is that:
A zero emission building produces enough renewable energy to compensate for the building's greenhouse gas emissions over its life span.(Fufa et al., 2016a)

[6] Greenhouse-gas emissions in Norway: https://www.ssb.no/klimagassn/

Furthermore, the ZEB research centre has defined in total five different levels of zero emission buildings depending on how many phases of a building's lifespan that are counted in.

In this report, ZEB could mean both Zero Emission Building and Zero Energy Building. The difference will be explained if important for the understanding of the context.

The ZEN research centre has developed a first version of a definition which can be seen in the box below:

ZEN Definition[7]

In the ZEN research centre, a neighbourhood is defined as a group of interconnected buildings with associated infrastructure, located within a confined geographical area. A zero emission neighbourhood aims to reduce its direct and indirect greenhouse gas (GHG) emissions towards zero over the analysis period, in line with a chosen ambition level with respect to which life cycle modules and building and infrastructure elements to include. The neighbourhood should focus the following, where the first four points have direct consequences for energy and emissions:

a. Plan, design and operate buildings and associated infrastructure components towards zero life cycle GHG emissions.
b. Become highly energy efficient and powered by a high share of new renewable energy in the neighbourhood energy supply system.
c. Manage energy flows (within and between buildings) and exchanges with the surrounding energy system in a smart and flexible way.
d. Promote sustainable transport patterns and smart mobility systems.
e. Plan, design and operate with respect to economic sustainability, by minimising total life cycle costs.
f. Plan and locate amenities in the neighbourhood to provide good spatial qualities and stimulate sustainable behaviour.
g. Development of the area is characterised by innovative processes based on new forms of cooperation between the involved partners leading to innovative solutions.

It is important to note the difference between a ZEN and nZEB/ZEB (nearly zero energy buildings). Whereas EU policy primarily focuses on energy, in Norway the focus is on emissions and the life-cycle of the buildings and neighbourhoods. An important reason for this difference is the energy mix which in Norway is dominated by hydropower as well as a high degree of (domestic) electrification (Bøeng and Holstad, 2013).

1.4 Scope: primary focus on energy

This report identifies drivers and barriers towards the development of a ZEN. It focusses primarily on issues related to technological developments, how markets are developing, and what is needed from society in terms of policies, measures and citizen involvement if a ZEN is going to be more than a few demonstration projects. Energy related issues including production, efficiency, distribution and trading in the context of a ZEN, is the main, though not the only, focus. All kinds of drivers and barriers have

[7] For more information, see www.fmezen.no/what-is-a-zen/

been included if found as part of the preliminary research, literature study and workshop held on this subject. We refer to chapter 5 for recommendations and suggestions for future research.

1.5 From ZEB to ZEN: Implications of expanding the system boundary

The growing link between choice of building design and energy supply alternatives calls for a closer collaboration between stakeholders in conventional building and energy markets (Häkkinen and Belloni, 2011). Planning and developing a neighbourhood instead of single buildings offers new opportunities and challenges. The opportunities include more integrated systems for energy and transportation that could potentially reduce emissions and investment- and operational costs related to the neighbourhood. Avoiding sub-optimality related to single building- and infrastructural components will be important during the different phases of the development of a ZEN, including planning, construction, operation and decommissioning (Magent et al., 2009). The challenge arises as many stakeholders must cooperate across different sectors during all these phases to realize the ZEN benefits, and this requires process innovation (Häkkinen and Belloni, 2011). The common goal of developing a neighbourhood with zero greenhouse gas emissions should bind the suppliers and core actors together, and there is a need for developing a common sustainability index and evaluating ZEN projects at an early stage (Ding, 2008, Mhalas et al., 2013).

When moving from a building to a neighbourhood, the system boundary changes. The placement of the system boundary alters how to optimize the carbon footprint of the project. In an emission calculation, embodied energy of construction materials becomes increasingly important (Wiik et al., 2018a). The main barrier in this respect is currently access to data for embodied emissions, for instance on infrastructure for roads, water, wastewater, ditches, related areas etc., which are related to the neighbourhood (Lotteau et al., 2015). Elements of the circular economy becomes more relevant in the neighbourhood perspective, such as re-use, repairs and sharing, which can be planned as part of the project. These elements, as well as lifetime, replacement and maintenance, can be challenging to include in scenarios. When the design of energy solutions changes as they do in a neighbourhood, this will also affect the use of related materials, such as integrated photovoltaic panels and technical installations. Hence, altering the energy solutions is also affecting the emission calculations due to materials input. (Lotteau et al., 2015).

1.6 The Role of Zero Emission Neighbourhoods in European Greenhouse Gas Mitigation

1.6.1 ZEN in Europe

In the ZEN research centre a central question is: What are the policies, regulations and instruments that should be implemented to support the market uptake and spread of Zero Emission Neighbourhoods? Before this question is answered, it is important to discuss the more fundamental questions: What is the role of ZENs in society and why do Norway and Europe need zero emission neighbourhoods?

Naturally, the main motivation for a ZEN is driven by the need to mitigate greenhouse gas (GHG) emissions. Norwegian climate policy is linked to European policy, and the ambition is to reduce yearly emission within the EU Emission Trading System with 43% before 2030 and for sectors outside the quota system with 40% (2014). One half of the EU emissions come from energy and transport, and the expected development in energy as well as transport is towards electrification. It is therefore crucial to reduce the carbon footprint of electricity generation. Emissions from residential sectors should be close to zero in 2050. Another motivation for a ZEN lies in the interaction with the rest of the energy system.

EU reference scenarios (2016b) include 25% increase in demand for electricity from 2015-2050, and in the same period, emissions are almost removed from the power system. This requires a substantially increased share of renewables, including solar and wind.

Two arguments can be made: The first is that energy efficiency measures are not an alternative to electrification, they are both needed and have substantial contributions in meeting the emission target (Chu and Majumdar, 2012). The second argument is that ZENs should not only focus on emissions, but on how to provide flexibility in a larger renewable energy dominated system (RES). This flexibility added by ZENs both enables more RES to enter the system, but also decreases the need for CO_2 intensive fuels in the power system by shaving load peaks. Examples of this type of flexibility are demand side flexibility with consumers shifting or curtailing demand. Another example is short-term fuel switching, changing dynamically between energy carriers such as heat and electricity. A third is storage, in a ZEN represented both by its batteries and its thermal storage capacity (in the heat system and in the building stock). A fourth is that coordination effects utilizing that a system of many units with partially uncorrelated demand and supply has lower mean variation than the sum of the individuals, reducing the peak capacity need. Because of these important features, ZENs may play an important role in the European decarbonisation and to increase /maintain energy security.

1.6.2 ZEN in Norway

In Norway, a major hydropower producer, some argue that a ZEN would be costly and without the intended climate effects partly because domestic electricity largely comes from hydropower. However, there are several reasons why a ZEN has a GHG emission reduction potential, also in Norway.

First, if European emission reductions are to be achieved, energy efficiency and increased renewable energy production are central measures. It is a major challenge to provide enough clean electricity to Europe, and Norway has the advantage of possessing regulatory power through its hydropower reservoirs. With a well functioning power grid, the reservoirs of Norway could work as a battery for Europe (Gullberg, 2013). This gives room for more renewable energy production also from variable sources. The last emission reductions towards 2050 will be very expensive, and Europe (including Norway) should make sure that all energy/electricity resources are used efficiently. This will be reflected in the long-term value of electricity. Energy efficiency is a part of a needed transition of society in most climate scenarios that makes it possible to meet climate mitigation targets. Therefore, if current prices for electricity and emissions do not incentivise the needed investments in energy efficiency and renewable energy production, incentives should be applied to ensure it.

Second, buildings and infrastructure have a long life. Making the wrong investments today from a short-sighted economic assessment can make it expensive to meet long-term climate mitigation targets. In a ZEN, the focus on the life cycle of a building gives a more long-term and holistic approach with a better chance of achieving GHG emission reductions. Policy instruments and regulation should support holistic approaches avoiding lock in effects by technology choice.

Third, even without considering GHG emissions, the flexibility that should be built into ZENs can play a central role in reducing grid investment costs. The capacity for balancing demand and supply within a neighbourhood is more flexible than the same capability offered from a single building, making it possible to contribute to security of supply and peak shaving. Our hypothesis is that, if designed with flexibility in mind, a ZEN may both reduce the need for grid investments and potentially provide flexibility services to the rest of the system. Today's market design may not fully remunerate these positive effects. Revised market design and business models are probably needed.

1.7 Stakeholders of the report

A range of stakeholders are relevant in the context of a ZEN. The list below is not exhaustive:

- Building owners (private or public, professional or non-professional)
- Building- and area developers (professional, both public and private)
- Property owners (private or public, professional or non-professional)
- Suppliers/ building industry (entrepreneurs, craftmen's enterprises, building materials industry)
- Utility companies (grid operators and energy companies)
- Policymakers/authorities (national, regional and local)
- Citizens/interest organizations
- Research/ academia

The different stakeholders can be depicted as such:

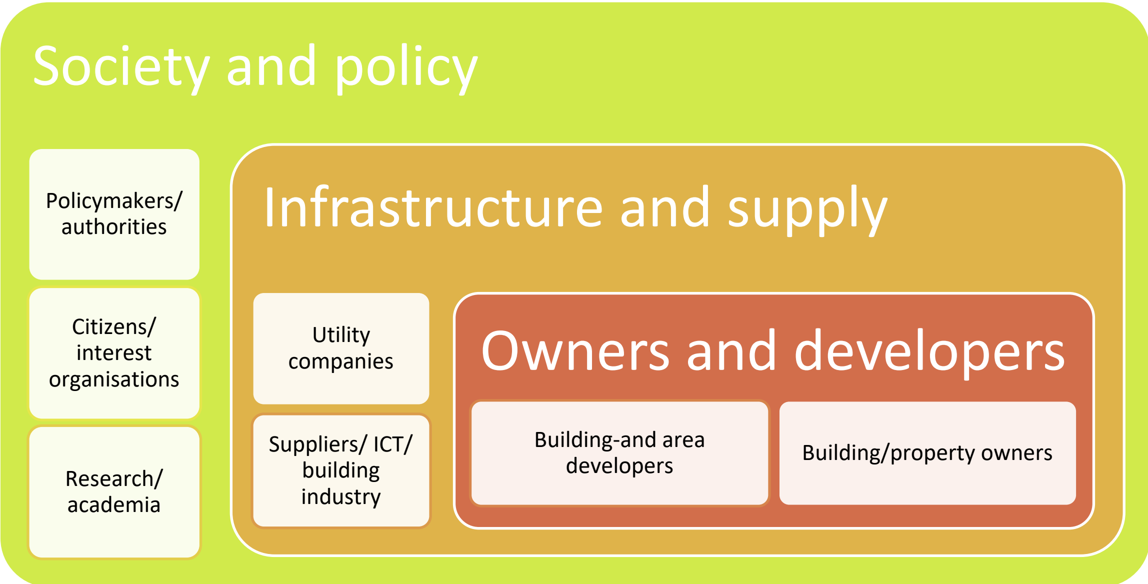

Figure 1.2: Primary stakeholders in a ZEN

Figure 1.2 aims to visualize the primary stakeholders to the development and spread of the ZEN concept. There is some degree of overlap. For example, a municipality will act as a local authority in translating the Planning and Building Act into practical use. The municipality could also be in all roles mentioned under "owners and developers" in the figure. It could also have ownership interests in actors sorted under "infrastructure and supply" which means that this is a complex picture. A regular citizen could also have several roles such as a building owner or an occupant in addition to citizen. This figure is developed primarily to help sorting the relevance of drivers and barriers and aid the forming of recommendations in section 5. Relevant actors not included in the figure are for example actors in the transport sector. It is important to keep in mind how people can commute to and from the neigbhourhood to other central locations, in particular the city centre. This is primarily a task to consider for the planning authority.

In a situation where transition is strived for, there will be opportunities for newcomers to introduce new solutions and new business models and challenge the incumbents. Therefore, new actors and perhaps also new stakeholder groups are likely to emerge in the years to come.

1.8 Methodology and structure of the report

This report is built on literature reviews and preliminary research within the ZEN research centre and its precursor, the ZEB research centre. In addition, it is built on the results of a workshop with partners in the ZEN research centre.

The structure of the rest of the report is as follows: In Section 2 the focus is on drivers and barriers to the more technical aspects of the development of a ZEN. In Section 3, drivers and barriers related to market development, value creation and business models that could be of significance to the development and diffusion of a ZEN is elaborated upon. Furthermore, Section 4 analyses how institutional framework, citizen participation and policy measures could be either drivers or barriers to the development of a ZEN. Section 5 concludes the report, and the Appendix A gives examples of state-of-the-art projects related to ZEN and more in-depth information on technical solutions particularly relevant for ZEN developments.

2 Technical developments

2.1 About this chapter

In this Section, the technical development of solar cells (PVs) as a much used technology in relation to a ZEN will be elaborated upon. Battery technology as an energy storage option is also discussed, as well as smart technologies that enable demand flexibility and control strategies for flexible demand. An overview of trending technologies for heating and residential electricity generation and storage is provided (overview in Table 2.1). The technologies in the table that are not discussed in this section can be found in Appendix B.

Table 2.1: An overview of the relevant ZEN technologies discussed in this report and their estimated capacity in Norway.

Energy generation			**Energy storage and flexibility**		
Name	**Type**	**Capacity**	**Name**	**Type**	**Capacity**
Solar cells	Electricity	68 MWp_{el} (2018)[1]	Stationary batteries	Electricity	-
Solar collectors	Heat	31 MWp_{th} (2018)[2]	Electric vehicles	Electricity	251 307 (2019)[6]
Heat pump	Heat	5 400 MW_{th} (2016)[3]	Flexible demand	Electricity	-
District heating	Heat	5 747 GWh_{th} (2018)[4]	Thermal storage	Heat	-
CHP	Co-generation	0.04 MW_{el} 0.1 MW_{th} (2017)[5]			
Fuel cells	Co-generation	-			

Sources:
[1] Installed capacity, https://www.solenergi.no/solstrm,
[2] Installed capacity, https://www.solenergi.no/nyhet/2019/3/22/stagnasjon-innen-solvarme,
[3] Installed capacity, Rapport nr 60-2016: Varmepumper i energisystemet (NVE),
[4] Delivered energy, https://www.ssb.no/energi-og-industri/statistikker/fjernvarme,
[5] Installed capacity, https://www.tekniskenyheter.no/bioenergi/bioenergi/kan-levere-700-000-kwh-varme-og-315-000-kwh-strom ,
[6] Amount of battery electric vehicles (not including plug-in hybrid), https://elbil.no/elbilstatistikk/

We categorize supply in two energy carrier categories: Electricity and heat. Figure 2.1 illustrates the energy supply chain. Note that electricity as an energy carrier can be used to provide the service of thermal comfort (e.g. heat pumps), i.e. heat is considered as an energy carrier and not as an energy demand category.

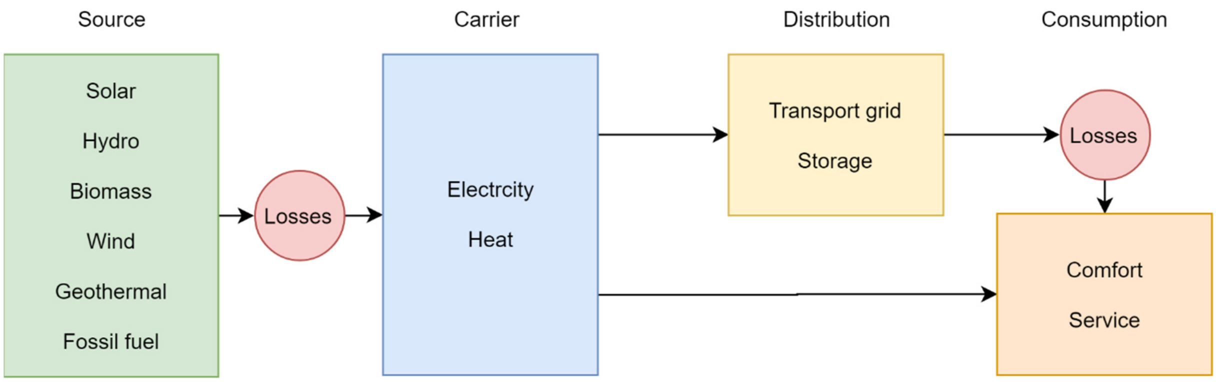

Figure 2.1: Illustration of the energy supply chain. Different sources are converted to an energy carrier. The energy is then immediately consumed for comfort or services or stored for later use. The energy can be used locally or transported through a transport grid (heat or electricity).

2.2 Solar cells

Starting from a relatively low base compared to most European countries, solar energy in Norway is experiencing very strong growth in the last years reaching a year on year growth in installed capacity of 59% in 2017 (see Figure 2.2Figure). A comparably strong trend can be observed in the development of installation prices as these, with subsidies included, have approached 14 kr/Watt in 2017 even for residential installations (see Figure2.3).

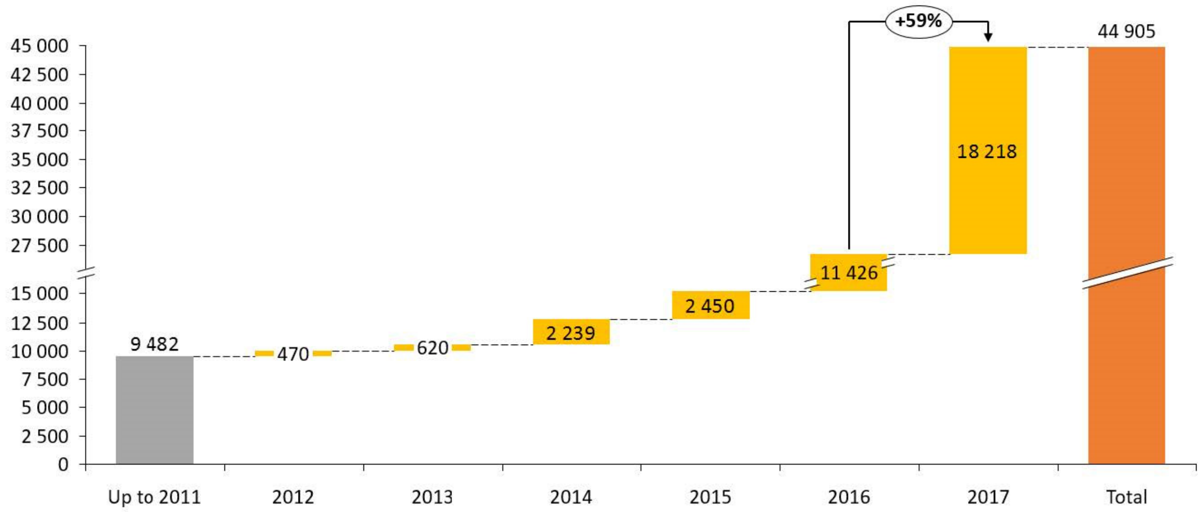

Figure 2.2: Installed PV capacity in Norway from 2011-2017. Source: (Person and Berentsen, 2018)

The predominant module technology is polycrystalline silicon cells holding 70% and monocrystalline silicon cells 24.5% of the market. Thin film cells represent 5.9% market share. The average commercial module efficiency has increased in the last 10 years from 12% to 17% with some modules reaching an efficiency of 21%.

The inverter technology (see Figure 2.4) has reached efficiency rates of 98%. Among residential, small and medium sized commercial installations the predominant technology is string inverters at 42% of the market. Central inverters with a market share of 54% are mainly used for large installations, while micro inverters, installed on individual modules, hold a 1% share. Current trends in inverter development are features for grid stabilization and optimization of self-consumption, inverters for both PV and storage.

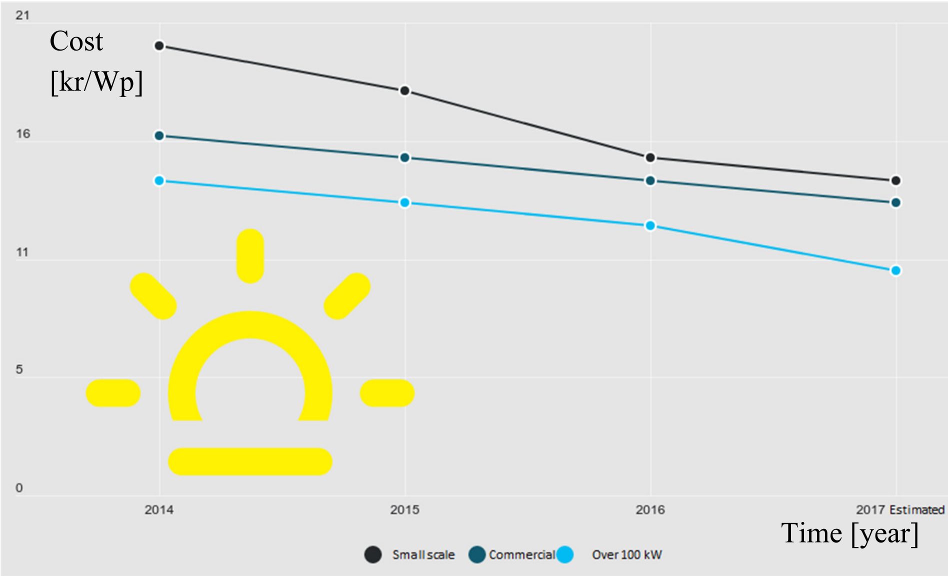

Figure 2.3: Cost of PV in Norway. Source: Multiconsult (Løvik, 2018)

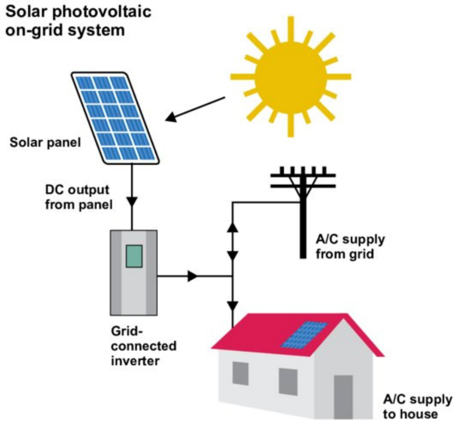

Figure 2.4: An illustration of a grid-connected PV panel. Source: (Scholtz et al., 2017)

A concept often talked about in the early years of widespread adoption of PV is the Energy Payback Time, or EPBT, that is how many years it will take before the modules generate the energy that was invested in their manufacture. This number depends on the geographical location and the technology used, mainly the silicon wafer thickness. In Norway, the EPBT is estimated to be 2,9 years for rooftop systems in Oslo (Gaiddon and Jedliczka, 2006), meaning that for around 90% of the installation lifetime the electricity produced is net production of energy (see EPBT to the right of the irradiation legend in Figure 2.5).

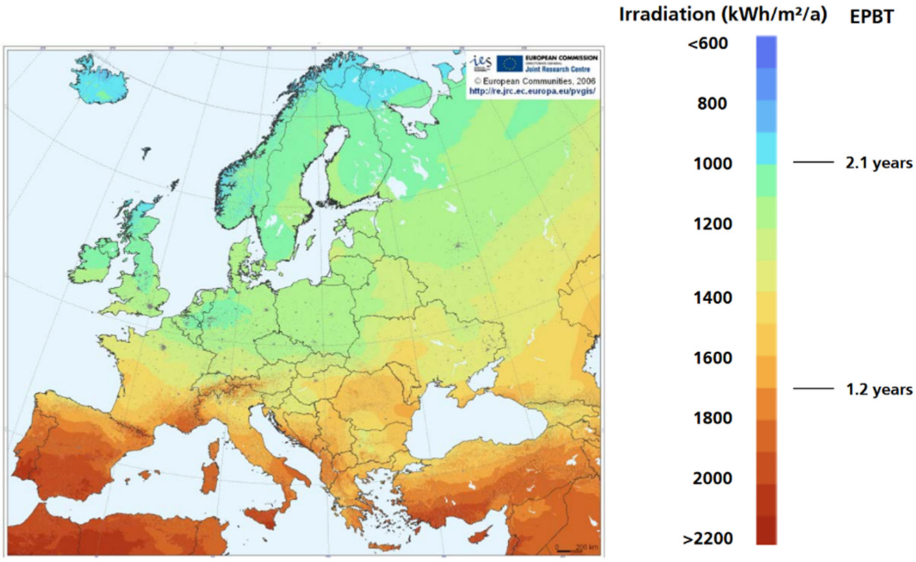

Figure 2.5: Energy Payback Time (EPBT) for PV in Europe. Source: (Philipps, 2018)

The monetary payback period of a small PV system investment in Norway has been estimated between 40 years without subsidies, and just below 20 years with the most beneficial investment support (Zaitsev et al., 2016), while more recent estimates suggest 18-19 years (Person and Berentsen, 2018). Considering a PV lifetime of 25 years, the PV investment therefore has positive present value in Norway. However, economy is not the only motivation for installing a PV system; studies have shown that private consumers are also motivated by producing their own electricity, contributing to the environment, and the interest in new technology (Throndsen et al., 2017).

There are several drivers on the development of PV in Norway (Person and Berentsen, 2018). Advanced metering systems will be installed by 2019, whereas the Elhub, the datahub for electricity consumption data starts its operation in February 2019. This will enable new business models and demand response schemes. PV producers can become energy suppliers through so-called power purchase agreements (PPA), which is basically a contract between the producer and the retailer/consumer of electricity defining terms such as prices and duration for the energy exchange. Managing electricity use to make the most out of PV supply has been launched in several pilot projects in Norway (Throndsen et al., 2017) enjoying the support of the Norwegian market regulator (NVE). PV can be a cost-effective measure to elevate a building to higher energy class. Regional electricity companies offer PV related products and services, and also independent suppliers, have entered the solar market.

According to Multiconsult (Person and Berentsen, 2018), the barriers PV faces in Norway are a generally low competence level among consultants in the energy sector and local authorities. This is accompanied by myths such as low solar irradiation and rapid technological development that is difficult to follow. Solar irradiation in Southern Norway and Oslo area is around 1000 kWh/m2, which is comparable to many other European regions and cities including Paris, Berlin and London. Also, very little maintenance of PV installations is needed. Since they are most often fixed without moving parts there is no mechanical wear, and maintenance is limited to inspections and occasional cleaning, weather or dust. Another myth is that PV must have a negative visual impact. There are several solutions available on the market that are that are tailored for architectural integration, and some manufacturers offer modules that resemble roof tiles[8].

[8] https://www.tesla.com/solarroof

Installation is generally rather simple for small scale PV. However, for large amounts of grid connected PV, the grid operator might need more options of frequency regulation and possibly fast acting energy storage to ensure power quality (Enslin, 2010). Some grid operators have launched effective marketing campaigns for consumers. Online services, such as “Solkart”[9], make it easy for potential buyers to understand the costs, sizes and output they can expect. The price level is close to that in the mature German market, however, the profitability in Norway depends on the financial support and the output (electricity generation) of the installation. Some expect the power tariff (Hansen et al., 2017) to work in favour of PV if it could reduce the peak load of a consumer and therewith the grid cost the consumer pays. This final argument is in most cases false as load peaks are usually highest in winter when PV output is lowest. But PV prices do continue to drop, and depending on the regulatory framework, PV could be feasible at least for the individual investor in Norway. Some political opposition still exists, but as knowledge about the sector grows the opposition tends to diminish.

2.2.1 Other on-site renewable power generation

There are alternatives to PV when it comes to on-site renewable electricity generation. Among the options are micro hydro, micro wind and co-generation of heat and electricity with biofuels (see a further description in Appendix B).

Small-scale hydro power is generally powered by rivers and may not be as flexible as large-scale hydro power. The technologies for hydro power tend to favor large-scale power plants. Small-scale wind power is still very expensive partly because of limited wind resources in urban areas. There are also issues related to aerodynamic noise (Tummala et al., 2016). In contrast to solar, small-scale hydro and wind power are very dependent on the location offering good conditions, and urban areas are generally not suited for such local electricity generation. The fundamental challenge of resource availability and the need for extra space slows down the progress of other on-site renewable electricity generation than PV.

2.3 Battery storage

The most common storage technologies at customers' site are li-ion, NaS, Pb-Acid, Flywheel, Flow Batteries and Hydrogen. The cost of li-ion batteries has been dropping significantly the last years (see Figure 2.6) rendering electric vehicles more and more attractive, but also gradually becoming competitive in electricity markets. This process is likely to continue as the electric vehicle market continues to grow in China and other countries in the next years. For small consumers, behind the meter battery storage for PV self-consumption or load shifting still doesn't offer positive returns. Yet it is expected that by combining a few services, such as frequency containment reserve or congestion management at the distribution level, this could change (Divya and Østergaard, 2009).

[9] https://solkart.no/

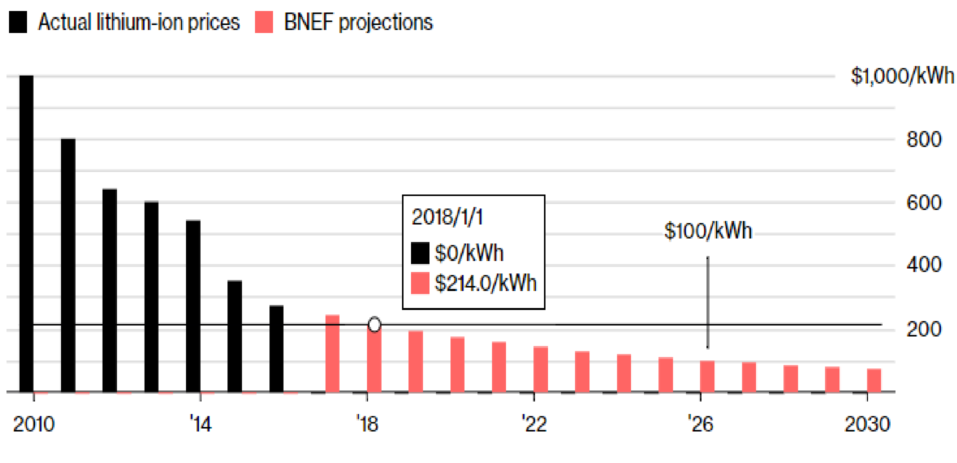

Figure 2.6: Li-ion battery cost development - historic (black) and projections (red)

One emerging concept in distribution network is the 'Community Storage' system. 'Community Storage' is a program that aggregate distributed energy storage resources that are located throughout a community, such as water heaters, electric vehicles, and interconnected storage batteries, to improve the operational efficiency of energy services to consumers (Dennis, 2016).

A utility company called Green Mountain Power (GMP) in Vermont, USA is offering consumers a Tesla Powerwall[10] fully installed for a fixed price and then provides a monthly bill credit for the customer to share access to the battery. GMP also allows consumers to simply pay a monthly fee to have a Powerwall in their home with no upfront cost, provided they share access with the utility.

In (2018b), some of the barriers of implementing community energy storage are identified. There is a lack of standards creating uncertainty and risks regarding safety and quality, and this will hinder investments in energy storage. It will be several years before standards are ready, and the market cannot wait that long. The market has come up with its own code of Recommended Practice in safety and operation.

Another barrier is remuneration. So far, it has been difficult to set the value for many storage applications, e.g. congestion management. This is leading to a passive attitude in the market, whereby compensation for services is sometimes completely lacking. Consequently, it is becoming increasingly difficult to create a comprehensive business case for storage. Examining the use of flexibility as an alternative to grid upgrades has been proposed as part of European energy legislation, which might speed up the valuation of storage services. Initiatives in this area are also ongoing through pilot projects.

When hydropower is in large supply (such as in Norway), electrification of the transport sector could contribute to a significant reduction of greenhouse gases. However, the large growth in electric vehicles (EVs) is potentially challenging to the grid particularly in neighbourhoods where charging of batteries happens simultaneously for several cars. Operational control of charging can alleviate this problem by controlling (1) when the vehicle is connected to charge and (2) the power of the charging. Also, the batteries in the car can be exploited for storage of energy to be self-consumed or sold back to the grid when prices are high (Skotland, 2016).

[10] https://greenmountainpower.com/product/powerwall/

Electric vehicle batteries have much greater capacity than home battery systems, and they represent a great potential for the future power system. The fact that these batteries are mobile means they are not always available, but it is also an advantage since they can then be used to provide system services wherever needed. Vehicle-to-Grid (V2G), Vehicle-to-Building (V2B), and Vehicle-to-Home (V2H) designate the most familiar concepts related to electric cars and batteries (see Figure 2.7):

- **Vehicle-to-Grid**; refers to services that use battery capacity in the car to charge or discharge energy to support the network or contribute as a flexible resource.
- **Vehicle-to-Building**; can be used to reduce the building's maximum load or also for V2G services.
- **Vehicle-to-Home**; refers to the use of a battery as home backup, or price response between high and low prices or other consumer flexibility services.

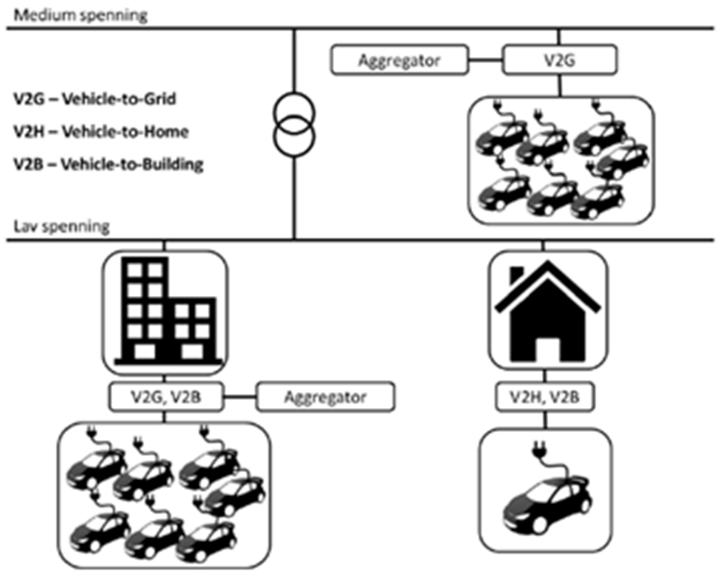

Figure 2.7: Illustration of the concepts Vehicle-to-Grid (V2G), Vehicle-to-Building (V2B) and Vehicle-to-Home (V2H)

With every charge-discharge cycle the battery is degraded. Given that the car makers guarantee for the battery performance, they have been so far reluctant to make available this functionality to the vehicle owner or grid operator. As battery prices continue to drop (see Figure 2.6) and the right business models develop, these features could in future become commonplace (Skotland et al., 2016).

Storage can improve power quality and reliability during outages as well as enable 'behind the meter' energy management practices. The grid services can be categorized in different ways, and different systems use different nomenclatures with regular overlap between services. But the underlying sources of value which can be translated into monetary value are the same. Table 2.2 summarizes these sources of value along with a classification of grid services batteries can provide.

Table 2.2: Grid related sources of value and services for battery storage

Value sources for batteries in grid	Grid services
• **Voltage stability**	• Alternative to grid reinforcement in case of congestion
• **Thermal capacity transformers and lines**	• Production shifting / curtailment
	• Load shifting
• **Frequency regulation**	• Operation in island mode / microgrid

- **Phase synchronization**
- Short circuit support
- Back-up power

In addition to grid services, batteries can provide services on the electricity markets. Starting from the level of the consumer, batteries can be used to increase consumer flexibility, integrate and control renewable energy production, optimize consumption/production with respect to time varying prices, increasing PV and wind self-consumption, and load shifting where power tariffs (e.g. Time of Use (TOU)) are used.

Alternatively, and particularly in Norway, which is introducing peak power tariffs in 2021 (Hansen et al., 2017), batteries can reduce peak consumption through peer-to-peer trading and management of power intensive loads (Lüth et al., 2018). Moving further up the chain, they can participate in the ancillary service market, day ahead- and intraday markets and improve system reliability and adequacy.

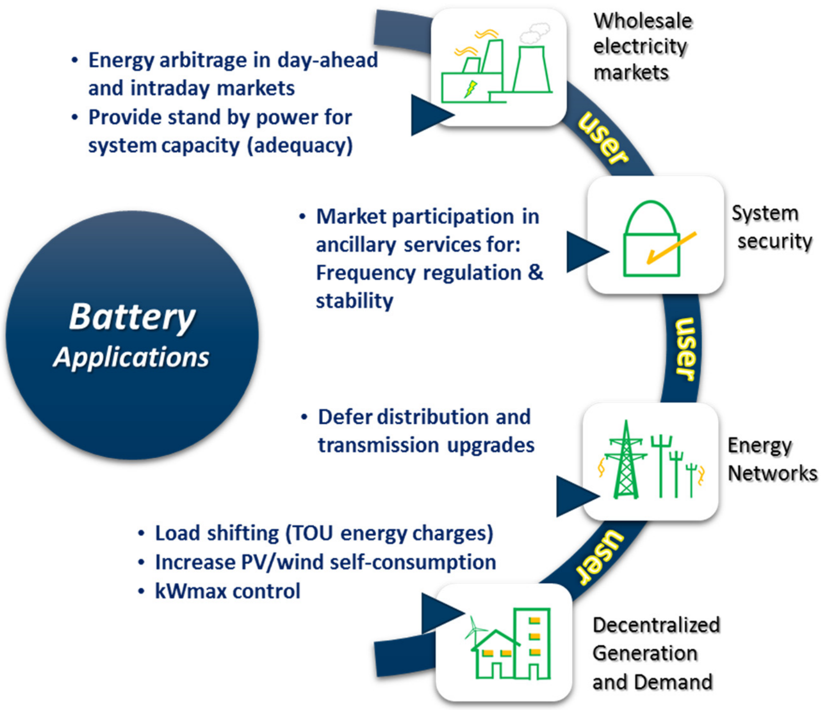

Figure 2.11: Battery storage electricity market services. Provided by Pedro Crespo del Granado based on (Crespo del Granado et al., 2018).

2.4 Energy security and smart technologies

2.4.1 Advanced Metering System (AMS)

As part of wider trends, namely smart grids, flexible electricity consumption and the internet of things, several home appliances have entered the market that can be scheduled to automatically start and stop at times when electricity prices are lower or can autonomously operate in accordance with electricity price signals.

Electricity metering in households has until the 21st century mostly been analogue, performed without a time stamp, and the meters were read by a representative of the electricity company. Smart meters are digital, they use time stamps on the energy use allowing time variable pricing and transmit consumption data directly to the DSO (or Elhub in Norway). Smart meters measure both active and reactive power and voltage levels, enabling better monitoring of the distribution grid. Smart meters can also store metered information and communicate prices and provide signals for load control. On the other hand, smart meters also pose a security risk as they could potentially be hacked to cut off supply, spread viruses or simply monitor consumers' behaviour.

Smart meters have been promoted to give customers more control over their electricity expenditures. Their three main benefits are (2011):

- **Incentives for energy savings** – customers receive immediate feedback about their electricity consumption and costs.
- **Incentives for shifting consumption** – they facilitate load and time variable tariffs therewith the incentive to shift the load towards hours of lower energy prices and loads, reducing grid congestion and improving capacity use.
- **Other operational savings** – remote collection of data reduces meter reading and invoicing costs. The availability of smart meter data enables other service providers optimized services such as PV or battery system sizing or measures that increase energy efficiency. Smart meters, however, also entail additional expenses such as increased expenses for customer support.

Smart meter roll-out in the EU is driven strongly by the EU Directives on the Internal Market for Electricity and Gas included in the Third Energy Package. Following the directive, EU countries performed cost benefit analyses (CBA) of the smart meter roll out. In countries where the CBA was positive or that have a mandatory regulatory framework (Denmark, Finland, France, Ireland, Norway, The Netherlands, Slovenia, Spain and the UK) an 80% roll out should be undertaken until 2020. In some countries, including Germany, the CBA did not come out positive, and Germany is rolling out smart meters only to selected groups of consumers. First the larger consumers, then after 2025 the installation will become compulsory for households with yearly consumption levels above 6000 kWh, whereas for those below it will remain optional. This reflects the results of the CBA which showed that the savings from smart meters depend highly on the household behaviour and type of load.

A report on the roll out progress in European countries states (2016c): *"it will be difficult to convince customers of the added value of new metering technology and the modernization of the European electricity grids, if metering data is only of use for operational changes within utilities."* The report also classifies smart meter services into three groups:

- Frequent information to consumer and feedback
- Real-time information to consumers and feedback
- Demand response

It is important to create favourable market conditions for these types of services to realize the potential benefits of smart meters, as these benefits will be compared to the costs of smart meter infrastructure, which will ultimately be borne by the consumer.

2.4.2 Practical challenges related to local flexibility

There are several practical challenges related to the use of local flexibility in a regional energy system (Strbac, 2008):

- AMS is required to identify potentials and contributions from local flexibility services.

- Contributions from single households are small in a regional network, so there needs to be an aggregation of the contributions.
- The value of flexibility is less uncertain in real-time, so there should be a sophisticated communication system that can trigger reliable flexibility response through automation.
- There is still a lot of uncertainty related to the potential and reliability of local flexibility in neighbourhoods: what contribution it can make and how it challenges the level of comfort.
- The costs of installing and administrating a complex system enabling local flexibility challenges the competitiveness of this solution.
- Procurement of local flexibility requires linking stakeholders in separate market segments.

The challenges mentioned above relate to lack of knowledge on how to cost-efficiently integrate local flexibility, and it calls for more research on these issues. Another key practical challenge is to affordably realize a technically complex market for many small sources of flexibility. Whether the sources of flexibility can provide true value to the system is dependent on whether the cost of implementing and operating the market is smaller than the potential savings provided by these sources.

The flexibility some devices provide can be used to increase self-consumption of locally produced electricity. This functionality can be useful for heat pumps or water heaters that consume a relatively large share of residential electricity. In case of small consuming devices, such as refrigerators, washers and driers, the inconveniences for the user as well as the extra cost of these devices compared to conventional ones probably outweigh the benefits.

3 Market developments

3.4 About this chapter

In this section, the market developments of significance to ZEN will be elaborated upon. The captured value of developing a ZEN will be dependent on markets stimulating the promotion of environmental, economic and social objectives (Roseland, 2000).

3.5 Power markets

3.5.1 Background

The main challenge of power markets is balancing reliability, affordability and sustainability, which is often referred to as dealing with *the energy trilemma* (Heffron et al., 2015). With an increasing share of low-carbon production technologies, emissions related to electricity has the potential to become significantly reduced, and possibly even approach zero. Recent reports argue that a 60 % electrification of the EU economy by 2050 is needed to reach climate targets (Glorieux and Noyens, 2018). Improving efficient use of electricity will be a key objective to decarbonize the interconnected energy system. Norway has the highest consumption of electricity in households in the world (Bøeng and Holstad, 2013). Therefore, electricity as an energy carrier is very relevant for ZEN and Norway.

Generally, electricity is mainly traded as a product in most of today's markets, and value is assigned to the amount of electricity provided. Since the 1990s, this trading has taken place in deregulated markets around the world where producers sell to wholesale markets and end-users sign buying contracts in retail markets. The deregulated market is cleared both before and during the dispatch of electricity. The day-ahead clearing makes it possible to schedule the dispatch of slow-ramping generators, whereas the real-time clearing makes sure supply is equal to demand.

Providing electricity cannot be done without an extensive infrastructure. Therefore, the reliability of the electricity system regarding transmission and generation capacity is generally treated as a regulated utility service, and the cost of this service is normally captured through a tariff. The regulated tariff is passed on to end-users, and the allocation of the tariff generally depends on total consumption as it does in Norway. It should be noted that the value of this service for society is significantly higher than the tariff, i.e. the cost of ensuring a reliable transport network for electricity is much lower than the willingness to pay for it.

Consumption of electricity is emission free. However, the production and infrastructure making consumption of electricity possible is related to emissions. Therefore, emissions related to electricity is mainly a problem on the supply side. But since supply and demand of electricity are balanced in real-time, the demand side can be very influential on the operation of the system. With introduction of small-scale power generation, such as PV, it is also harder to classify connection points locally as supply or demand nodes.

3.5.2 Flexibility investments

The variable nature of production of electricity from wind and solar and the loss of fossil fuel based flexible production will require large investments into storage, flexible demand/supply, and/or electricity grids. Demand flexibility could involve consumers shifting and reducing load during constrained situations (Faruqui et al., 2010). Flexible demand and storage move electricity consumption in time and are not only technical enablers for PV and wind; they also stabilize electricity prices and revenues which can positively affect investment risk. Lower risk reduces the interest rate investors pay for renewables projects. Lower investment risk therefore impacts the final cost of energy much more for capital intensive renewables than for fossil fuel-based generation with high variable costs.

Covering the costs of expensive peak capacity is still a challenge in electricity markets, and several market mechanisms are being tested and discussed (Cramton et al., 2013). High peaks in demand calls for large amounts of installed capacity, however, the value of this capacity is only present during the infrequent peak demand periods. The value of reducing peak periods is related to saved investment costs in mostly idle assets. The value of local flexibility for end-users depends on the flexibility need of the system. In Norway, there is a suggestion to change the tariff structure (Hansen et al., 2017) to incentivize less load on the connection point to the grid. The value of local energy production in a ZEN will be affected by such a tariff by making it more valuable to self-consume locally produced energy (Sæle and Bremdal, 2017). This market development makes flexible electricity consumption (e.g. batteries) more attractive and variable electricity production (e.g. solar PV) potentially less attractive (unless self-consumed under a net-metering policy).

Dealing with the complexity of bi-directional flow (export from a traditional consumer to the grid) could be a barrier for integrating a ZEN in energy markets. However, there is also a potential benefit of introducing distributed resources for grid operators if they can be utilized during constrained grid situations. If the reliability of distributed resources can be guaranteed, investments in grid capacity can be reduced. Grid investments have been lagging since the market liberation and much of the equipment, with an otherwise long life measured in decades, will need to be replaced in the coming years. Norwegian electric grid companies will need to invest 140 billion NOK into their infrastructures between 2016 and 2025 (Bakke and Paulen, 2016b). Of this sum, 15 billion NOK could be saved with the introduction of smart grid enabling technologies (Kjølle and Sand, 2016). Per inhabitant that is approximately 3000 NOK, which spread over a lifetime of a few decades turns into a few hundred NOK per inhabitant per year. For comparison, the value of food waste in Norway is estimated at 20.58 billion NOK per year (Stensgård and Hanssen, 2016), which is more than the potential savings from smart grid technologies over a few decades.

Figure 3.1: The cost of batteries compared to the cost of overhead electricity distribution grid (lines) in different areas.. Source: SINTEF IntegER (2017)

Figure 3.1, taken from the Norwegian SINTEF project IntegER, depicts the concept of the substitution between storage and traditional infrastructure. The grey line represents the cost of a 1000 kWh battery. The green, red and purple lines represent the cost of a 315 kVA line in an urban, suburban and rural environment depending on the length of the line. Given a need for grid reinforcement due to a higher peak in production or load one can either replace a high voltage line or install 1000 kWh of battery storage at a cost of 5 000 000 NOK or approximately 560 000 EUR. If it is an urban environment and the line is shorter than 6 km, it will be cheaper to replace the line. If it is longer, the battery will be the cheaper alternative.

There are potentially more costs related to battery investments. Consumers need to be informed and educated, which takes time and focus from other activities. Many might also make uneconomical decisions purchasing smart grid enabling devices that can cost tens of thousands of NOK, ranging from home battery systems to smart grid ready washing machines, effectively spending more than the potential savings on the grid side.

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3.5.3 Value of power system assets

As a reference point for considering residential power supply, we make a coarse estimate of the value of assets in the traditional Norwegian power system per household. For every kW of generation capacity installed, the energy produced is in the range of 4 000-5 000 kWh per year[11]. With an average annual household consumption of 16 044 kWh it takes approximately: 16 044/4 000 = 4 kW installed capacity to supply a household with energy. Since the investment cost of hydropower is estimated at 10 000-15 000 NOK/kW in Norway (Sidelnikova et al., 2015), these generation assets represent a value of 40 000-60 000 NOK per household per year. High voltage transmission assets in Norway are valued at 58 721 MNOK (2018a), that is about 11 000 NOK per inhabitant or 33 000 NOK for a 3-member household. This value covers the nation's entire consumption (not only the residential sector), which means that the real value of the household power supply might be smaller. For value of low voltage distribution assets, we can look at Skagerak Nett AS. To supply 191 000 customers (340 000 citizens assuming an average of 2.85 citizens per household) Skagerak Nett owns assets worth 3 894 MNOK or 11 453 NOK per citizen. For a 3-member household that is about 34 000 NOK, again this includes all sectors and might be smaller for the residential sector only. The total value of assets is therefore in the order of a 100 000 NOK per household (Table 3.1).

[11] Norwegian hydropower (01.01.2017): Installed capacity: 33,2 GW, annual generation 139 TWh. 139000/33,2=4187 kWh per installed kW
https://energifaktanorge.no/norsk-energiforsyning/kraftforsyningen/

Table 3.1: Value of traditional power system assets for a 3-member household in Norway assuming electricity transport assets are shared equally among everybody.

Total value of assets per household	107.000 NOK/kW
Value of generation assets: **Needed hydropower capacity per household: 4 kW** **Cost per capacity for hydropower: 10 000 NOK**	40.000 NOK/kW
Value of transmission assets **Total value of national transmission assets: 59 000 MNOK** **Population in Norway: 5 200 000**	33.000 NOK
Value of distribution assets **Value of distribution assets for Skagerak Nett AS: 4 000 MNOK** **Customers in Skagerak Nett AS distribution area: 119 000**	34.000 NOK

In an age of increasing wealth inequality distributed energy resources offer the possibility for households to increase their wealth by a significant amount. A solar and battery installation, even with long payback times, still represent assets with a value in the order of 50.000 – 150.000 NOK. If the society manages to steer away some of the consumption towards investments at the household level, that is an achievement. If innovation renders these technologies more accessible to everyone, a future where the average person partly owns his energy assets could be possible. At a 2%-real growth per year, real incomes can double in 35 years. If, due to increases in energy efficiency, electricity consumption flattens out (grows slower than 2%) and technology prices continue to drop, investments in distributed energy resources will become more and more affordable.

3.6 Power market roles

To analyze the development of a ZEN, we need to better understand the roles of all ZEN stakeholders and their position in the market. Stakeholders are traditionally categorized as being on the *supply side* or the *demand side* of a market. In the development of a ZEN, however, this categorization is sometimes too simple, as several market participants tend to fall within both categories, especially when considering the allocation of energy.

Electricity markets consist of three segments: (1) the end-user segment (consumption of electricity), (2) the supply segment (production of electricity) and (3) the transport segment (transmission and distribution of electricity). Basically, consumers from the end-user segment buy electricity through retailers from the supply segment, and retailers buy electricity from producers in the wholesale market. In addition, consumers from the end-user segment pay distribution system operators (DSOs) and transmission system operators (TSOs) from the transport segment to cover the costs of electricity transport, and this payment is based on rules provided by regulators (see Figure 3.2).

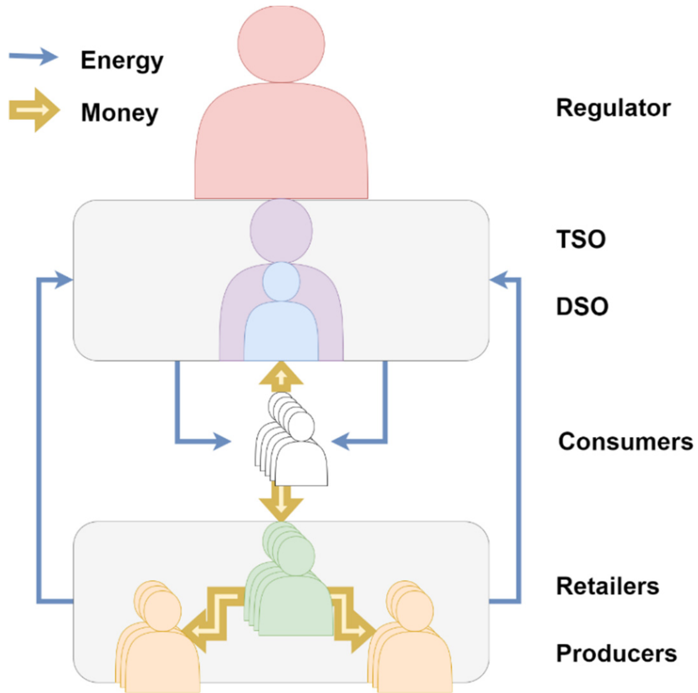


Figure 3.2: Illustration of roles in current electricity markets

Note that participants in the electricity market can fill several roles through vertical integration, e.g. retailers integrated with producers. Stakeholders in the transport segment of the market (DSOs and TSOs) are not allowed to integrate with the supply segment because the grid is a natural monopoly where producers ought to have access to compete on the same basis.

The different segments in electricity markets have varying interests. End-users want to consume affordable electricity when they need it. The supply segment wants to keep efficient operation of generators and maximize the value of the generated electricity, whereas the transport segment wants to ensure reliability and sufficient transport capacity while minimizing infrastructural investments. In a ZEN, traditional end-users could enter the production segment of the market with investments in neighbourhood assets (e.g. PV panels, combined heat and power supply, etc.) and thus want to both minimize electricity consumption costs and maximize profits from small-scale electricity supply.

The main stakeholders in the development of a ZEN are the building owners and the end-users on the demand side and the material- and energy suppliers on the supply side. A driver for stakeholders on the demand side is to link the demand for energy from end-users to choices in materials, design and technologies from building owners to save costs and emissions. There are two main categories of actions: (1) increase energy efficiency and/or energy savings and (2) supply energy with lower emission intensity. Both solutions are necessary in the transition towards a ZEN.

Increasing energy efficiency is a natural cost-saving driver from an end-user perspective, and it can be realized through responsive behaviour (non-investment measures) or upgrading the building envelope (investment measures) (Verbeeck and Hens, 2005). In Sweden, where most house owners consider saving household energy use important, most of them undertake non-investment measures rather than making building envelope investments (Nair and Garimella, 2010). Non-investment measures, e.g. reduce unnecessary use of energy, is not alone sufficient in reaching goals of ZEN. There are funding mechanisms for energy efficiency measures in Norway. However, larger investment measures can also result in larger rebound effects (Throndsen and Berker, 2012). Energy efficiency should be of high priority because it has a high potential for leading to long run emission reductions, although a rebound effect can offset or counteract these savings (Brännlund et al., 2007).

The difficulties of providing significant quantity from many small contributions, and thus also incentives for end-users, is a barrier to realize a ZEN. This barrier is related to (1) uncertainty in the aggregated resource potential in a ZEN (flexibility and generation) and (2) the question of how to efficiently operate and trade these resources to make most of their potential.

Another barrier of integrating end-users in energy markets include lacking regulatory frameworks, which reflects lacking knowledge of system consequences of the integration of distributed services and products in the long run. It is therefore important to investigate how to regulate ZEN business models to ensure a sustainable energy market in the future with a fair allocation of value and risk.

3.7 Energy market roles

3.7.1 Prosumer

The prosumer role is relevant both in electric and thermal markets. With new possibilities of small scale energy generation (see Section 2), consumers are starting to partly produce their own energy and thereby becoming "prosumers". In the ZEN context, these distributed generators are relevant as they are often related to very low emissions.

If prosumers are connected to a grid (electric or thermal), they mainly contribute to two changes seen from other market participants' view (Lindberg, 2017):

(1) Reduced demand of energy, and
(2) Bi-directional flow of energy.

Assuming there is not a full rebound effect, i.e. increase in energy use equal to the savings, the consequence of reduced demand will hold for consumers partly supplying and consuming self-generated energy. The second aspect will also hold for self-generating units that either produce too much energy for its owner or does not always match the owner's demand. These two aspects lead to new possibilities for consumers to be located both on the supply and the demand side of the energy market as active participants contributing to efficient use of resources.

Research has been done on the impact of Zero Emission Buildings (ZEBs) on the power system, where ZEBs are single buildings demanding little energy and producing some electricity. Research (Seljom et al., 2017) suggests that a large introduction of ZEBs in Norway and Scandinavia will lead to lower electricity prices and a higher export of electricity from this region, and this will affect the use of electricity nationally and internationally. Where and to which extent local energy production should be integrated in an interconnected energy system to achieve political goals of emission reductions remains uncertain.

In thermal markets, the prosumers are located both on the supply- and demand side of the district heating (DH) network, and they can both supply and consume thermal energy (Brand et al., 2014a). Thermal prosumers can be either existing residential and non-residential buildings or new nZEBs. Despite all benefits described in the literature about heat energy export of prosumers, this concept has also technical drawbacks that create new challenges. The distribution network places restrictions on heat trade. It places two different types of constraints: (1) pressure constraints and (2) temperature change constraints (Sipila et al., 2005). The presence of thermal prosumers could, for instance, induce higher or lower differential pressure among the customers reached by the flow from the thermal prosumer. The supply temperature and the velocity in the pipes might also be affected (Brand et al., 2014b). In addition, both thermal prosumers and renewable centralized systems need a tailored financial model to attract private small, medium and big investors (Paiho and Reda, 2016).

3.7.2 Flexible consumer

Through price signals from a grid operator, consumers can be given opportunities to respond to the system status and thereby become "flexible consumers". The idea is that flexible consumers can sell services to balance the system in a flexibility market. These services can be active responses by end-users or passive responses by units linked to an energy management system. Flexible consumers are relevant both for electric and thermal markets.

Several pilot projects in Norway have tested direct load control of consumer loads (Grande et al., 2008) (Sæle et al., 2013). In addition, agreements can be established in which flexible consumption can be disconnected from operating centers as a system service. The benefit for the customer in this case depends on the carrier's willingness to pay for the service and costs for the necessary technology. The customer's profitability has proven to be difficult to document, especially in test projects where equipment costs are far higher than expected for future mass produced commercial products.

In Norway, large consumers (industry, office buildings etc.) can sell electric flexibility to the system operator under contracts with certain retailers, e.g. LOS Energy. In (Jenssen et al., 2017), they emphasize that activating end-user flexibility is dependent on (1) offering a quantifiable flexibility service and (2) decreasing the minimum duration of the flexibility offer. The last point will require higher temporal and spatial resolution of the system status as well as efficient and reliable communication.

The "EcoGrid EU" project developed a marketplace application that sends out price signals that reflect the imbalance costs in the network. The price signals, with a 5 min time resolution, are stored in the cloud, where the involved technology providers can access the data. The developed applications optimize usage over time (based on price forecasts and 5-minute prices), and then send control signals to a portfolio of customers with flexible consumption.

Electricity price information is today available on the internet. Information about power market prices and net tariffs will be made available through the NVMS AMS requirements meter. Elspot prices for the next day are for example available at http://www.nordpoolspot.com/ approx. at 14 pm every day. That is sufficient to plan an optimal response to power prices by moving or avoiding consumption in the high price hours. Manual and/or automatic control can be realized by simple measures. Moreover, there are several management systems in the smart house category where the control system itself is mounted in the house (or cabin) and the owner can send control signals via a mobile app.

It is probable that thermal energy storage (TES) will play a pivotal role in future power systems, due to the increasing share of renewables that these systems must accommodate. One way of utilizing 'excess electricity' could be to drive electric heat pumps or refrigeration machines at low cost, storing heat or cold when there is no immediate demand for it, in either long- or short-term TES (Thomsen and Overbye, 2016).

3.7.3 Aggregator

With both prosumers and flexible consumers entering the energy market, a new role will be needed to aggregate their services and products to a quantifiable amount. This "aggregator" role (Jenssen et al., 2017) represents a group of prosumers and flexible consumers that links them with the system operator.

The role of the aggregator is to have good information about the system status and the available flexibility options on the demand side (Ottesen et al., 2016). The idea is to collect energy products and services from smaller agents and trade these internally and externally with the system operator. The aggregator's mission could be pursued by existing market actors, e.g. retailers.

The need for an aggregator role in a ZEN arises due to small contributions from single end-user prosumers or flexible consumers. The fragmented goods provided by responsive end-users could together provide an aggregated good to the system. The aggregator could thus contribute to shaving of peak loads and provide other services in electric and thermal systems. Aggregators can pool flexibility resources together and improve the short-term reliability of flexibility products when they are needed.

In Norway today, there is limited possibility for customers in smaller distribution grids to sell flexibility due to lack of metering infrastructure and unknown potential. With AMS installed in all connection points in Norway by 2019, new opportunities for successful integration of responsive end-users through aggregators arise.

3.8 Business models in ZEN

3.8.1 Definitions

The definition of a business model combines four elements: core logic, strategic choices, creating and capturing values and value network. Core logic means that a business model articulates and makes explicit key assumption about cause-and-effect relationship and consistency of strategic choices. All companies have to create value for their customers in a way that differentiates them from competitors, this is fundamental for any business. The design of a business model should ensure that all players concerned, from investors, owners, operators and utilities/suppliers to consumers, can benefit from direct profits as well as the greater sustainability gains (economic, environmental and social) (Fahl and Dobbins, 2017).

To realize the value of ZEN technologies, new business models and market design will be important to consider (Chesbrough, 2010). This is because business model innovation can induce a positive (or reduce a negative) environmental effect (Bocken et al., 2014). The description of a business model mainly answers three questions (Osterwalder and Pigneur, 2010):

1. What kind of good is provided (value proposition)?
2. How is the good provided (value creation and distribution)?
3. How is the value of the good allocated (value capture)?

Sustainable business model archetypes are developing today, and they vary in focusing on technical, social or organizational aspects (Bocken et al., 2014). Technical aspects relate to the good itself by valuing e.g. minimization or utilization of waste related to the good. Social aspects in business models relate indirectly to the good by adding value through intangible benefits, such as long lasting quality or shared access. Organizational aspects relate mostly to how the value of the good is allocated among stakeholders through cooperation and aggregation.

To understand the success of a business model in a ZEN, there are three important aspects to consider:

1. Allocation of value and risk;
2. Drivers and incentives; and
3. Barriers and conflicting interests.

Allocation providing sufficient incentives is a core challenge and barrier to successfully integrate ZEN technologies, and it arises because the value from investments in a ZEN is hard to aggregate (and disaggregate, i.e. distribute) to make an attractive good to involved stakeholders. For example, end-user investments in distributed energy generation and storage can provide cost savings for the electricity grid, i.e. value created in the end-user segment is realized in the transport segment. Designing the market to provide the correct incentives in the end-user segment to create such value will be a challenge and requires planning beyond traditional supply and demand. The complexity of roles in buying and selling energy can be dealt with by real-time metering infrastructure (AMS) and digital platforms. The complexity of roles related to building design and energy supply will require business models that integrate these two markets.

3.8.2 Energy trading in ZEN

Emerging local electricity markets challenge current power market structures and could be key to trigger more efficient use of electricity (Greinöcker, 2018). Current business models for local energy production have been focused on solar PV (Macé et al., 2018), but could be generalized for other local electricity generation. The ownership of the production facility determines the allocation of risk, and it is commonly owned by the consumer (residential/commercial) or by a third party through a leasing agreement (e.g. Solarcentury[12]). State-of-the-art business models for electricity trading in a ZEN can be split into three groups (Parag and Sovacool, 2016): peer-to-peer models (P2P), prosumer-to-grid models (P2G) and organized prosumer group models (OPG).

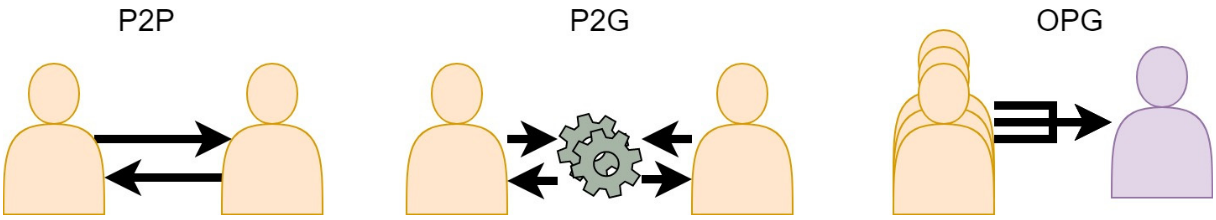


Figure 3.3 Illustration of three business model archetypes relevant in a ZEN. From the left: peer-to-peer (P2P), prosumer-to-grid (P2G) and organized prosumer groups (OPG).

The least structured group of new business models is the *peer-to-peer models (P2P)* (see Figure 3.3, left). These models are inspired by the sharing economy, and they can be very similar to platforms like Airbnb and Uber. Electricity is typically sold as a product in P2P models, but it can also be sold as a service. The idea is that consumers buy directly from independent prosumers through a decentralized market platform. P2P models are dependent on directly linking buyers and sellers together in an easy way. P2P models open for a more fragmented allocation of value and risk among prosumers as independent actors. The main driver is knowing where the electricity comes from, as well as better prices

[12] https://www.solarcentury.com/

due to direct payment. Barriers include lack of regulations and direction, which may lead to long term failure of P2P models. The design of rules and regulations is therefore very important. P2P trading without involving a third party is currently not legal in Norway, however, the new Norwegian retailer Otovo has launched a program ("Nabostrøm") where customers can subscribe to surplus power produced by your neighbours.

Another group is the *prosumer-to-grid models (P2G)* (see Figure 3.3, middle). In contrast to P2P models, P2G models are more structured and characterized by trading between prosumers and grid operators, e.g. within smaller microgrids. These microgrids can be connected to the main grid or operate in isolation. A third party is involved in the market operation. Offers and bids are continuously matched, and the main goal is to ensure efficient use of all generators and sinks within the system. If the prosumer is connected to the main grid, electricity can be traded both as a product and a service externally. The main idea of the P2G model is to use real-time information and communication to optimize operation of the system. Allocation of value and risk could be either concentrated or fragmented in P2G models depending on the ownership and operation of the microgrid and its components. Some P2G models involve third parties leasing on-site power production to customers, e.g. SolarCity. A driver of P2G models is the long-term efficiency gains that could lead to cost reductions. However, at the core of P2G models lies a lot of real-time data, IT infrastructure and complex control systems. One of the greatest barriers of P2G models is thus making this complexity easy and affordable to deal with for the market participants, and balancing consumer freedom with efficient system operation.

The third group of business models is somewhat a fusion of the previous two, and it is referred to as *organized prosumer group models (OPG)* (see Figure 3.3, right). Such models are characterized by communities pooling fragmented resources together and thereby harvesting benefits through cooperation and synergies. Trading in OPG models happens through an *aggregator* (see Section 3.7.3). With sufficiently many agents in an OPG model, the community could grow into a virtual power plant. The OPG models offer shared risk and value allocation for the community, which is also the natural driver for such models. The question of how to fill the aggregator role remains a barrier, as well as how to allocate value and risk in the community and how to operate the virtual power plant most cost-efficiently.

The three business model archetypes described above are to some extent in conflict with the current regulations. P2P is not allowed as energy is obliged to be transferred through a regulated actor. The current *plusskunde* agreement is a form of the P2G business model and hence legal (but not optimized), whereas the OPG implies the presence of an aggregator. OPG models have recently been enabled in Norway by NVE in shared apartment buildings (NVE, 2018a) with a requirement of individual metering of all involved customers.

Introduction of energy-service companies (ESCOs) is a relevant business model in energy markets. These companies could be a competitive alternative to traditional suppliers if they are not part of an affiliated group. Thus, even if there was no single market, the ESCOs would put competitive pressure on existing utilities. In this context, contracting companies oversee a generating plant's "planning, financing, construction, operation and maintenance and, in most cases, also fuel purchase" (Wissner, 2014). The business model is based on financing through long-term contracts with the customers (10-15 years).

3.9 Integration of markets in ZEN

3.9.1 Integrating markets for buildings and energy

A prerequisite to successfully plan, design and construct a ZEN is to improve the energy system. Within the ZEN centre and its predecessor, the ZEB centre, smart building solutions have been researched extensively (Hestnes and Eik-Nes, 2017). In addition to the reduction of heat-loss from the building and implementing sensors and control systems, the planning and design of different functions and buildings *in relation to each other* is crucial to optimize energy requirements. Utilizing synergies between buildings, vehicles and equipment in a neighbourhood can contribute to more efficient operation (Ruiz et al., 2014). From a market perspective, this means designing and operating buildings to better utilize energy products in the whole neighbourhood. This could mean that a building generating and consuming both heat and electricity has the potential to share and trade this with other buildings in the neighbourhood (Kayo et al., 2014). An example is a shared CHP plant for a neighbourhood (see Appendix B).

Some ZEN technologies that contribute to reduced emissions in neighbourhoods relate directly to the use of low-carbon and/or energy-efficient materials in buildings (Cabeza et al., 2013). The good provided through such investments are more related to cost and emission savings than to continuous value creation. There is often a threshold for investing in energy efficiency measures in existing buildings, because the value of such investments is mostly realized in the long run through operational cost reductions in existing business models. For new buildings, there might also be a threshold for choosing ZEN related solutions for buildings if initial investments in energy efficient options are large compared to alternatives.

Replacing conventional building components with façade-integrated (building integrated) energy production is becoming cost-efficient. An example of this is "solar roofs", where the actual material making up the roof has PV integrated (Ritzen et al., 2017). Energy producing building materials could also be used for walls. Such materials have an advantage in competition with conventional materials due to the continuous value creation from energy production. A case-study of Norway (Sandberg et al., 2017) found that on-site energy production for buildings can contribute to significantly larger reductions in external energy supply than frequent or advanced renovation alone. Note that the value of energy producing materials will depend on whether the energy is consumed by the building or exported. There is a challenge related to the lifetime of the energy producing component of the material being shorter than the lifetime of the building. This calls for close collaboration between building developers and energy providers to make the materials easy to integrate, maintain and replace through the building lifetime.

Current business models for energy tend to steer the direction of building design towards minimizing total energy use[13]. This is because end-users currently only pay for energy used. The value of timing energy supply can be captured from a centralized supplier's perspective in the wholesale market, but the value of timing energy consumption can only be captured indirectly in retail markets where billing is based on total energy consumed. One of the goals of a ZEN business model is therefore to stimulate

[13] Incentives are changing with introduction of power tariffs suggested by NVE in Noway HANSEN, H., JONASSEN, T., LØCHEN, K. & MOOK, V. 2017. Høringsdokument nr 5-2017 - Forslag til endring i forskrift om kontroll av nettvirksomhet. *In:* NVE (ed.)..

efficient utilization of local and clean resources *when* they are most available. This might be at the expense of minimized energy demand and can have consequences for smart building design.

3.9.2 Integrating energy markets for heat and electricity

A major part of energy demand in buildings is related to keeping a comfortable temperature (Hagos et al., 2014). The remaining demand can normally be met with electricity as the energy carrier (electric specific demand). The interaction between energy units providing thermal energy and energy units fuelled by electricity is very relevant for Norway since up to 70 % of electricity consumption is for heating purposes (Bøeng and Holstad, 2013). Thus, there is a great potential for increasing efficient use of electricity in Norway with smarter heating solutions, e.g. heat pumps, solar collectors, waste heat utilization through district heating networks, etc.

Supported by the European Commission within the 7th Framework Programme, the Intelligent Neighbourhood Energy Allocation & Supervision (IDEAS) project has focused on developing business models relevant for a ZEN (Crosbie et al., 2015). To integrate trading of all energy services in a neighbourhood (thermal and electric), they have proposed business models for a District Energy Provider (DEP) and Integrated Energy Contracts (IEC) (Crosbie et al., 2014). The idea is to have an inter-sectoral entity, an Energy Service Company (ESCO), be responsible to supply and distribute electricity and heat to a neighbourhood consisting of different buildings. Performing building renovation where it is most efficient to improve the energy performance of the neighbourhood will be possible with these integrated business models.

Residential buildings have a strong diversity in both electrical and thermal loads and there is no inherent coincidence between these loads. Each combination of house, occupants and climate will produce different patterns, and these will vary from day to day. This situation creates an opportunity to utilize the variations between residential buildings by trading in a network (Hensen and Lamberts, 2012).

Liberated heat trade can be carried out by the same principle in local DH network as electricity trade (Sipila et al., 2005). The interest of DH companies in buying excess heat from industry is clearly higher than in acquiring heat from small-scale production; on the other hand, customers want to sell heat if the required investments can be covered in a reasonably short period. To make heat trading possible, the DH needs to be opened to competition (Paiho and Reda, 2016). Third-party connection to DH is something that is currently being discussed (Nord et al., 2018). Presently, only one utility company supplies DH in each network, and the same company manages distribution and sales. With the third-party connection, one or more of these services can be subject to competition. Concern has been raised that third-party connection might lead to increased prices for the customers, since it adds costs related to the splitting of the present-day companies into producers and distributors. Furthermore, operation management and the balancing of supply and demand might become costlier when performed by more than one actor (Lindholm).

Both the industry, the municipality and the neighbourhood can benefit economically from local energy co-operations for both electricity- and heat networks. The obstacles are commonly organizational, how relation works between the parties and how the partners are organized. Openness and trust are crucial for a successful project. It is also necessary that the involved parties focus on the total benefits of the co-operation beyond their own, and that both parties benefit. The contract should be stable and long-term. It is crucial that the contract period is at least as long as the investment's payback period. It is also vital to involve experienced personnel and to educate the personnel responsible (Grönkvist and Sandberg, 2006).

4 Society and policy

4.4 About this chapter

The advance of a ZEN is not only dependent upon technical developments, but also how concepts and solutions are received and supported by the stakeholders. In this section, the primary focus is on institutional aspects and how society and its citizens, as well as the available choices of policy, may advance or hamper a development towards a ZEN. Policy actors and their toolbox are illustrated before ZEN is discussed in the Norwegian context: what policy choices are made, and what are the backgrounds for this? Towards the end of this chapter, citizen engagement is discussed, and exemplified by the use of Living labs.

4.5 Actors and the available toolbox

Regulations and standards for the building sector shape the energy performance of buildings, and different regulations apply within different countries to reach political goals (Annunziata et al., 2013). It is important that regulations stimulate measures that are thoroughly considered, such that the extent to which political goals are achieved is maximized, local opportunities are grasped and the potential negative responses, or rebound effects, are minimized.

In a policy process, there are normally hundreds of actors from interest groups, governmental agencies, legislatures at different levels of government, researchers, journalists, judges and more involved in one or more aspects of the process. Each of these participating actors (either individual or corporate) has potentially different values/interests, perceptions of the situation, and policy preferences (Sabatier, 2007). The relation between different "levels" of administration can be pictured as follows:

Table 4.1: Relation between different levels of administration and policymaking and their roles related to energy and climate

GENERAL ROLE IN ENERGY AND CLIMATE	EXAMPLES
INTERNATIONAL LEVEL (e.g. UN, EU)	
Setting global ambition and negotiating agreements. Developing regulation and recommendations.	Examples: UN sustainability goals and the Paris threaty. EU Roadmap. EU directives.
NATIONAL LEVEL	
Strategic national visions and sectoral plans for development and climate change, national policy through regulations and incentives.	National climate strategies (such as the Climate Act), plans of action, grid energy investments, social protection schemes. Translating and implementing EU regulation into national regulation.
REGIONAL and LOCAL LEVEL	
Geographically local impacts or responses requiring regional/local government, community or indigenous responses.	As planning authorities, the regional and local level of administration is responsible for incorporating national strategies and attend to regional interests. Municipalites are enforcing the planning and building act as efficient, clear and simplified as possible.

According to IEA and the Norwegian Environment Agency, a combination of policy measures is needed to reach the climate targets.

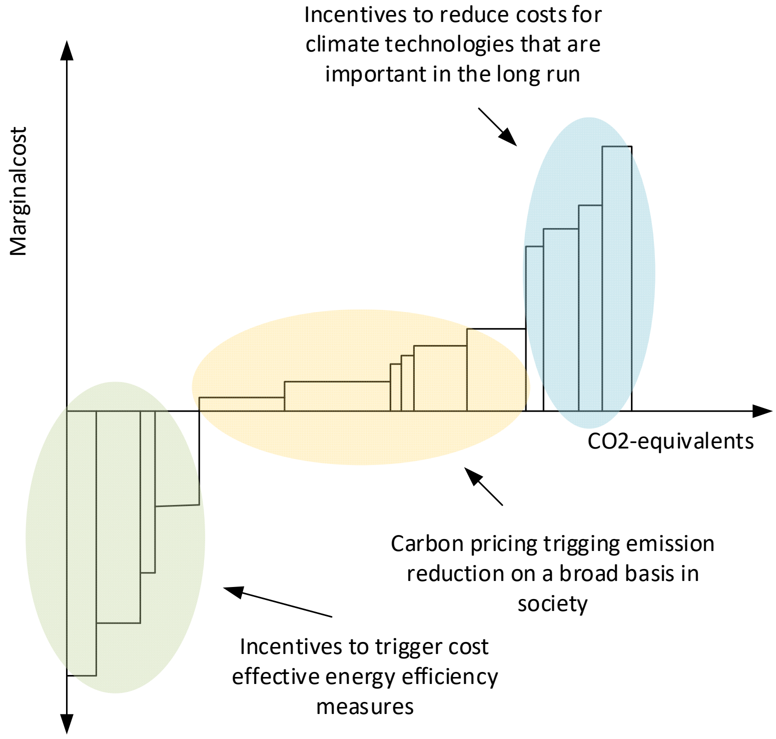


Figure 4.1 Combination of incentives in a cost-efficient policy-mix to induce climate friendly investments (Andresen and Gade, 2017)

The core of a cost efficient policy mix is a combination of policies adapted to the measures it aims to trigger. Some measures are not implemented even if they are cost efficient. This means that other barriers than economic ones are prevailing. In such cases, information, guidelines, and best practice examples may be enough to induce the desirable measures. At the other end of the scale, innovations in technologies and solutions are needed since the present ones are insufficient in reaching the climate targets. This demands research and financial support of relevant innovations. Finally, carbon pricing is arranged to induce an emission reduction on a broad basis in society (read more about the European emissions trading system (ETS) in sub-section 4.3.7).

4.6 ZEN in the Norwegian context

4.6.1 Background and developments relevant to ZEN

Over the last decade, energy requirements, particularly in new buildings, have become significantly more ambitious. This has been due to a joint effort of academia, industry and policy makers (Nykamp, 2017). The German passive house standard has affected the development of energy-efficient buildings in Norway with the introduction of a Norwegian passive house standard for both residential (2010) and non-residential buildings (2011). EU directives, like the EPBD and the RED, have contributed to a push on policy actors to implement energy efficiency measures in the building sector (ibid.). The building code is by 2017 declared to be at a "passive house level". The building code is now one of the drivers of energy efficiency measures in new buildings. With an ambitious building code, local energy production is increasingly relevant to achieve further savings and reduce the need for energy from external sources (Sandberg et al., 2017).

Historically, energy efficiency has not been high on the agenda in Norway. This is, according to a study by McCormick and Neij (McCormick and Neij, 2009), interpreted as a result of the abundant supply of hydropower. However, Norway has an energy efficiency target in existing buildings of 10TWh within 2030[14], but distribution of responsibility is lacking which can be expected to delay necessary actions. When it comes to distributed energy production, which is highly relevant both to nZEB, ZEB and ZEN, there is no target that has been agreed upon. This lack of information and direction makes it more difficult to design effective policy instruments, and for actors to give a coherent response.

In a report from SINTEF Energy (Knudsen and Dalen, 2014) an emerging societal interest for energy efficiency is identified. The report specifically elaborates the interaction between buildings and the energy system. Ownership and management of energy infrastructure is identified as important economic barriers. There are developments, such as regulation of third-party access to the district heating grid as well as the plus-customer (plusskunde) regulation, that are first steps towards a more interactive energy system. However, the costs and benefits in a Norwegian context are not clarified. The need of increased cooperation and coordination between different policy sectors, not least between the building and energy sectors, is underlined. Municipalities which are hosting innovative pilot projects and the innovative approach by the building industry are identified as important drivers that could have joint impact on the further development of a Norwegian policy framework. This, the report continues, could be an important addition to the impulse stemming from the EU legislation.

Energy-producing buildings are typical in a ZEN. In Norway, proponents and opponents of energy-producing buildings have different narratives of the (dis)advantages of on-site energy production. The narratives are used to influence policymakers and the public opinion. A distrust among central actors who are suspicious that actions of the others are motivated by business interests (Kvellheim, 2017) is demonstrated. It was found that energy-producing buildings need to solve a problem seen as significant by the current opponents, if the concept is to become mainstream. One example of a problem that energy-producing buildings could contribute to solve is the peak load challenge.

4.3.2 Discussion of drivers and barriers in ZEN

In a ZEN-workshop (2017) that focused on barriers and drivers towards a ZEN, experiences among the centre partners were shared and discussed. A quite complex mix of barriers and drivers were brought forward, and several of the drivers can be barriers as well, if lacking (such as key personnel). Partners of ZEN point to the limitation to energy production under the plus-customer arrangement (100kW), which is seen as a barrier to the development of the solar market. Strict regulation of trading is also seen as a limitation for producing more local energy than what is self-consumed.

Several of the drivers are related to ambitious targets, creating commitment to these targets through agreements and contracts and having the "right" companies and people for the job. Also, adding extra value to a project (in addition to energy and environment) is increasing the potential for success. A

[14] https://www.statsbudsjettet.no/Statsbudsjettet-2020/Dokumenter1/Fagdepartementenes-proposisjoner/Olje-og-energidepartementet-OED/Prop-1-S-/Del-3-Omtale-av-sarskilde-tema-/10-Mal-om-10-TWh-energisparing-i-bygg-innan-2030-/

municipality can also be affected by ownership interests. This can be exemplified by a perceived conflict between building passive-houses and the needs of the district heating company to obtain new customers. The reasoning behind a ZEN was also questioned. Are we actually able to explain, in a way that is easily understood, how a ZEN can contribute to a more sustainable society? If not, it is difficult to argue convincingly, and hence ZEN spread and developments might be delayed.

It was also discussed what the municipality could do to help ZEN developments. It is important to give developers realistic feedback on the potential of the development of an area through:

- Early dialogue with the developer about plans for development.
- Being predictable and consistent when giving permissions. No-one should be able to have their way simply by re-negotiating and being persistent.
- Create arenas where actors could meet, as well as creating possibilities for new knowledge/competencies.

In some cases, municipalities can also use exceptions from the Planning and Building Act to spur a preferred development.

4.3.3 Regulations relevant to ZEN

As ZEN is in an early phase, no formal requirements or definitions, other than from the ZEN research centre (see Section 1.3), have so far been developed. As ZEN builds on and expands the ZEB definition, it is relevant how ZEB is defined and implemented in Norwegian policy. By the time of the writing of this report, the EPBD is not fully implemented in Norwegian policy. However, it has influenced Norwegian building and climate policy for more than a decade, primarily as a notice of what is to come. Elements of the directive were taken up by the so-called Climate Act[15] which has given direction and influenced the developments of for example Norwegian passive-house standards and a stricter building code. When it comes to renovation/upgrading of existing buildings, however, energy requirements do rarely come into consideration, which is a persistent challenge. Research projects, such as SEOPP and the more recent OPPTRE[16], are developing solutions as a response to this.

Despite the lack of a coherent Norwegian definition of nZEB that gathers broad support, the aim is to develop the building code to be at a nZEB level in 2020 according to the Climate Act. In 2013, the Norwegian Building Authority engaged the consultancy Rambøll to develop a report that offered a coherent definition of nZEB. This report was extensively debated, but an agreement to a common definition was not reached. Other actors have made their own interpretation of what nZEB and ZEB would mean in a Norwegian context. Only the ZEB research centre had a life-cycle focus on emissions and introduced a CO_2 factor on electricity. Other approaches are largely limited to the phase of operation/use and take the position that energy requirements are met by Norwegian hydropower and therefore emission-free [17].

[15] The Climate Act refers to a broad political consensus on objectives and incentives in Norwegian climate policy, first decided in 2008, then revised in 2012.
[16] www.seopp.net and www.opptre.no
[17] https://www.energinorge.no/contentassets/fa5408b0d2d94d989a0f0e1e1acd195c/thema-notat-norsk-definisjon-av-nesten-nullenergibygg.pdf

Other examples of direct regulation in the Norwegian context is the Energy labelling system which stems from an early version of the EPBD. The requirements are that all non-residential buildings larger than 1000m^2 and all buildings for sale are obliged to have an energy certificate. So far, the energy labelling of buildings in Norway has not had the expected effect, which was to create demand for, and thereby also willingness to pay for buildings with a higher energy performance. The lack of coherence between energy efficiency investment and property prices is identified as a barrier to such investments (Tuominen et al., 2012). Other relevant directives from the EU, such as the Eco-design and Energy Labelling Directives, are introducing components requirement.

4.3.4 Economic incentives

The establishment of research centres on zero emission buildings and neighbourhoods (the ZEB and ZEN research centres) is financed by the Ministry of Petroleum and Energy. This is initiated to spur the development of technologies and solutions through research in close collaboration with business as well as public partners.

Through the administration of the Energy Fund, Enova is responsible for incentives addressing increased energy efficiency/-production, reduced emissions and reduction in peak load. Enova has support schemes that offer support to private and professionals and is organized as a public enterprise under the Ministry of Climate and Environment.

Examples of support schemes relevant to a ZEN are:

1) The concept assessment program
2) Introduction of new technologies in buildings and neighbourhoods

1) **The concept assessment program** offers support to map the potentials within an area to reduce energy requirements, emissions and peak loads. An example of such support is the support to Ydalir, one of the pilot projects within the ZEN centre. Ydalir received support to undertake a concept study. The program offers a maximum support of 1MNOK, but no more than 50% of the project costs are eligible.

2) The support scheme **Introduction of new technology in buildings and neighbourhoods** offers support per m^2 according to improvements compared to the building code. Innovative solutions in buildings and neighbourhoods as well as solutions that are reducing emissions, can be supported. Maximum support is 60% of total eligible extra costs. The ZEB project Heimdal high school (building owner: Trøndelag county) received 21,5MNOK from Enova for the implementation of a number of innovative solutions such as the energy system, which consists of 1) very low energy requirements and 2) supply of energy from several renewable energy sources in an effective energy system with low GHG emissions. In addition, several innovative products were applied, such as sun screening through electrochromic glazing, and an electricity storage solution[18].

4.3.5 Incentives for small-scale energy production

The energy market in Norway is designed for centralized energy supply. This has been a cost-efficient and highly reliable way of supplying energy, which in Norway is dominated by hydropower.

[18] https://www.enova.no/

As photovoltaic panels have diffused in the Norwegian market, the Norwegian Water Resources and Energy Directorate (NVE) (NVE, 2018b) has adapted the legislation to include a Plus-customer (*plusskunde*) arrangement. This is meant for customers that are having an energy surplus at stand-alone hours to supply power back to the grid. The Plus-customer arrangement limits the sale of power within this arrangement to 100kW, which is generous for households but a limitation to larger entities. Surplus energy can be sold solely to the preferred electricity producer, which limits the possibilities to trade within a neighbourhood. Signing a *plusskunde* agreement with their DSO gives the prosumer several benefits, including revenue from surplus generation, exemption from paying taxes for their self-consumed electricity and reduced tariff for the net energy exported to the grid.

Table 4.2 Overview of the Norwegian business model for prosumers

Plusskundeordningen in Norway	
Number of customers (2018)	1000+[1]
Support mechanisms	Financial support through Enova[2] Green certificates[2]
Revenue from surplus (max. 100 kW export)	Selling back to retailer, usually hourly spot price[2]
Third-party ownership	Allowed[2]

[1]Number of *plusskunder* in Norway as of February 2018. Based on data from Norwegian grid companies. Source: SINTEF ProAktiv.
[2]National Survey Report of PV Power Applications in Norway 2016. URL: http://iea-pvps.org/

A *plusskunde* will only be billed according to a marginal loss rate, which depends on the impact that the exported electricity has on local grid losses. This rate is in most cases negative, meaning that the *plusskunde* is compensated per net kWh exported in addition to revenues from selling the electricity. However, most value is realized for a *plusskunde* if electricity is self-consumed through saved costs of electricity import. This is because there are greater cost savings through decreased import than profit from surplus export. A *plusskunde* is required to have a smart meter installed. A *plusskunde* cannot install electricity production that requires concession from the Norwegian regulator to be built.

The current regulation does not allow trading behind the connection point, but the customer can sell exported energy back to the retailer (normally at spot price). It is also possible for housing cooperatives to become *plusskunde* where production is measured for the whole housing cooperative[19]. The saved costs and export revenue from production is allocated among all the end-users. Consumption measurements must still be done for single customers, and the allocated *plusskunde* benefits are subtracted from each end-user bill. There have been technical barriers related to this due to a lack of metering infrastructure for individual customers.

The estimated number of *plusskunde* prosumers in Norway was around 1000 in February 2018. The majority of these have rooftop PV systems, and there are a few prosumers with small wind turbines (2018b).

The most significant financial incentive for plus-customers is the investment support by Enova. Enova offers a fixed 10.000NOK of support for residential installations plus 1250NOK/kW of installed

[19] Nytt fra NVE. URL: https://www.nve.no/nytt-fra-nve/nyheter-reguleringsmyndigheten-for-energi/mulig-a-bli-plusskunde-i-boligselskap/

capacity up to 15kW, whereby the support cannot exceed 35% of the cost. A 3-kW installation corresponds to 13.750NOK and a maximum of 28.750NOK for a 15kW installation (Enova). Returns on investment in solar PV are lower than standard stock market investments, but PV provides additional financial security by being a source of electricity at a fixed price. Enova has signalled that the support for solar PV will be reduced in spring 2020 due to the market situation. This means that the technology is almost cost-efficient without economic support. In addition to Enova, there are some local support schemes for renewable small-scale energy production. An example is the municipality of Oslo which offers up to 40% of the costs as refunds. It cannot be received financial support for the same measure from more than one source.

Plus-customers are also entitled to el-certificates. However, there is a fee that has to be paid to become part of the system of el-certificates, which at present amounts to 15 000 NOK for a small-scale producer. Depending on el-certificate price and kWh produced, el-certificates are unlikely to be any kind of incentive for the plus-customers as the pay-back time can be as much as 50 years.

It is suggested to change the tariff system to reduce the peak load through a price incentive.
A hearing to a consultation paper on changes to the tariff system was closed by the 1st of March 2018 (Hansen et al., 2017). NVE received a lot of comments to their consultation paper and is about to release a revised version, expected at the beginning of 2020.

4.3.6 Regulations on electricity storage

In many cases, storage systems either have no access to the market or are put at a disadvantage when they do have access (for example for balancing and wholesale). In practice, access to these markets would be required to generate enough turnover from energy storage. Product definitions also need to be modified to provide storage with equal opportunities. At a European level, there are currently no specific initiatives to ease broader market access for energy storage, although they do exist in several countries at the national level. For instance, at the German grid operator TenneT, a pilot is about to start allowing small-scale storage to supply primary reserve. Access to the wholesale market is possible for larger systems but not for individual consumers.

There is no established definition of energy storage in electricity markets yet. Consequently, energy storage is seen as both ‘generator’ and ‘user’. This means that energy tax is paid both when charging and discharging. The Winter Package indicates that energy storage should become a separate entity with a modified definition, which can include characteristics and services of generators as well as users and electricity grids. The turnover of such systems could then be market based, depending on the services provided by the system.

Along the value chain, batteries can provide value to market segments. Table 4.3 provides an overview of ownership alternatives and uses of battery systems. To improve the economics, some suggest shared ownership. The problem with shared ownership is that it is difficult to establish operational rules and distribute the added value. We are currently missing both related business models as well as legal means to achieve this. Distribution system operators cannot operate batteries on the spot market because operating a battery for any service will at the distribution level have effects on the spot market (Fladen, 2018). NVE, the regulating body in Norway, has given some DSO a temporary exception to this rule to unbundling, so that they can develop the services they need.

Table 4.3: The ownership of batteries from different ownership perspectives

Ownership	Main user	Typical battery service and value
End user	Prosumer	Maximize self-consumption & reduce peak
	Normal customer	Peak load reduction & price arbitrage
Neighbourhood or industrial site	Neighbourhood	Maximize self-consumption
	Industry or business	Peak load reduction, grid reinforcement deferral
Aggregator	Aggregator	Price arbitrage & stand-by capacity
	Flexibility operator or DSO	Maximize self-consumption & stand-by capacity. P2P trading
System operator or mixed ownership	DSO or TSO	Congestion management Voltage/reactive power regulation
	End user or neighbourhood	Maximize self-consumption Price arbitrage

It is not yet entirely clear which parties will be allowed to own energy storage systems. A positive move towards encouraging storage would be if the transport segment (Distributed System Operators -DSO and Transmission System Operator- TSO) were permitted to be owners as an alternative to grid upgrade, as battery technology is moving electricity in time (instead of moving it in space). However, due to their status as state monopolies in lots of countries because of unbundling, this could upset the market. The Winter Package (2016) states that ownership by DSO and TSO could be possible in very limited cases, provided this was only for their own services in their own market and if there were no other service providers in the market. However, it appears that the preferred option would be to leave the decision to the market where possible. ACM in the Netherlands has indicated that they agree with this, although they do encourage purchase of services to launch the flexibility market.

4.3.7 EU-ETS

An important measure to reach the Norwegian climate targets of 40% reduction of climate gases within 2030, is the EU Emissions Trading System (EU ETS) (Ellerman et al., 2016). About 50% of Norwegian climate gases are included in this market-based system (Directorate;, 2017). It is a classical cap and trade market where emitting sectors are obliged to possess allowances for their emissions. The total emissions are limited by a declining cap. Allowances are allocated free of charge or traded among the participating sectors, and the total emissions by a sector must be covered by acquired allowances every year. Heavy fines are charged if annual emissions exceed the possessed allowances. The EU ETS puts an upper bound on emissions from the electricity sector and other carbon intense sectors, and it has (combined with national incentives and EU-regulation) spurred the electrification of the transport sector in Norway.

It may be argued that more efficient energy consumption does not lead to emission reductions since the total emissions are regulated through the EU ETS on the supply side of the electricity market. This is, however, dependent on the flexibility of the emission trading system; if higher energy efficiency (pushing down the emission allowance price) can trigger a reduction in the total emission cap of the EU ETS (raising the emission allowance price), energy efficiency could indirectly participate in lowering emissions and speeding up the decarbonization of Europe. There has been a lack of credibility regarding the reduction of the emission cap in the EU ETS (Fuss et al., 2018) which calls for further research to support political commitment on the emission cap development in the long-term.

4.3.8 Soft instruments

The development of voluntary standards, agreements or environmental labels has so far not included ZEN. However, the environmental label BREEAM NOR does include some related elements, such as energy efficiency measures, transport, waste reduction and so on. As a result of the research centres ZEB and ZEN, interdisciplinary Master courses and continuing professional education has been established. Also Enova has some soft instruments, such as a helpline and courses and conferences mainly for professionals.

4.4 Living labs and citizen participation

The physical environment is human centred, it supports the needs of the people who live, work, visit, relax and socialize in it. Achieving a well-functioning neighbourhood therefore requires user engagement. A neighbourhood design and development process that does not involve citizens risks slowing down the transition to a low carbon society, causing disaffection because users do not understand the changes being made or associate themselves with the aims being set.

The ZEN research centre has chosen living labs as a framework to work with user engagement and citizen participation. The decision is based on the living lab concept being well established within European research. The European Network of living labs (ENoLL) was launched in 2006, and its declared aim is "to support co-creative, human-centric and user-driven research, development and innovation in order to better cater for people's needs" (Eskelinen et al., 2015). A strong focus on innovation in addition to user needs, through co-creative processes is implied by ENoLL's aim (Ruijsink and Smith, 2016). In 2011 EU stated that a criterion for success in Smart Cities was people involvement, an involvement that would provoke participatory reform (Veeckman and van der Graaf, 2015). Living labs were regarded as one solution to achieving participation, and interest in using living lab formats increased. In 2016 at least 400 different living labs had at some point been registered as members of ENoLL (Burbridge, 2017).

Within ENoLL there is no clearly defined format or methodology that should be included in a living lab, or theme that it should concentrate on, but there are two main types of living labs. These provide a background to understand how living labs often are applied. Both types depend on the involvement of end users (Raven et al., 2016b, Schliwa and McCormick, 2016):

1. Innovation and technology driven, new market creation and product, service and systems development: Associated with the original concept developed by Mitchell at MIT in the 1990's (Eriksson et al., 2005, CLG, 2008).

2. Citizen-centred urban living lab: whose aim is to inspire citizens to move towards sustainable urban transitions that arose with EU initiatives around 2006.

Innovation or technology driven living labs are often understood as offering an open innovation research form where technologies, systems, services and products may be co-designed with user groups and evaluated under real-world circumstances (Parker and Murray, 2011). This kind of living lab was the inspiration for ZEB Living Lab, which is one of the nine pilot buildings developed by the ZEB research Centre. An innovation or technology living lab focuses on a single product or process, or in the case of the ZEB Living Lab a single building. The neighbourhood transitions proposed by the ZEN Centre require a broader concept that can include a larger social and physical context and more than one process at once. Citizen centred living labs have a broader social and locational concept. Innovation may also motivate living labs that support urban transitions, but the focus is on the social rather than technical context.

The introduction of citizen centered living labs within urban contexts coincided with three main trends within governance; the (de)carbonization of urban governance, experimental governance and the transition to a low-carbon economy (Evans and Karvonen, 2014). User participation in the format of a living lab is included in a democratic process that aims to guide the way towards policy change on a local government level. Urban living labs can have a broader focus than governance. (Veeckman and van der Graaf, 2015) propose that they may be used to involve citizens in city development, making urban areas better suited to their needs. The ZEN research centre has chosen the citizen-centred urban living lab as the conceptual inspiration for its living labs. The ZEN version of an urban living lab will be known simply as a ZEN living lab.

Living labs lack a clearly defined methodology. This allows flexibility to choose methods relevant for the social and physical context, but they do have a set of characteristics established around the living labs and urban experiments that have taken place since the 1990's:

1. The first is the aforementioned social and citizen-centred focus.

(Evans and Karvonen, 2014) suggest three additional characteristics:

2. Geographically and institutionally bounded space.
3. An experiment is conducted.
4. They display iterative learning.

The four characteristics form a broad framework to work with that allows the inclusion of themes such as energy management, neighbourhood liaison during municipal planning processes and the construction of a zero emission building, but because their use is so diverse it can be a challenge to understand what the laboratories actually achieve. Will they make a meaningful difference for those affected by neighbourhood transitions, or is including a living lab a token act that never empowers or engages citizens within the process taking place around them? The motivations of citizens are important when developing and evaluating participatory processes because choosing to engage in an urban experiment or laboratory is based on rational choice (Parker and Murray, 2011). For the ZEN research Centre and partners their motivations are clear, a zero emission neighbourhood, based on the definition developed by the Centre, is to be established, and living labs should support this activity. For citizens in pilot neighbourhoods, however, it can be unclear what is in it for them and thereby they can function as a barrier to the development of a zero emission neighbourhood.

Not all processes where citizen participation is involved aim for a redistribution of power, but it is not useful to assume that experiments or living labs are user centred and beneficial to a broad stakeholder group. They can be top-down and carry a political agenda (Raven et al., 2016a). Working towards a broad user engagement, involving the majority of user groups on the end-user level is perhaps the ideal, but a "meet in the middle philosophy" is also a possibility, where the voice of the citizen (bottom-up) meets governments and companies (top-down) (Veeckman and van der Graaf, 2015). Any living lab should avoid the "tokenism", which is the classic challenge associated with any user engagement process. Tokenism implies that citizens have been offered a voice, but lack the power to ensure that they will be heeded (Arnstein, 1969). In the UK, the "duty to involve" has been on the agenda of local authorities since 2008 and the introduction of the Government white paper "Communities in control"

(CLG, 2008). Even this anchoring within local government has often not managed to go beyond "tokenism and short-termism" in participation in planning (Parker and Murray, 2011). Knowing that there is a need to engage does not necessarily mean the instigation of effective participatory processes.

It is important to establish awareness about who is involved and why during the early stages of the living lab, thereby offering room for adjusting who is included and establishing relevant activities or experiments. Users are not always easily defined, or placed into categories, and there may exist a variety of conflicting issues and motives that can challenge a living lab. However, establishing whom the different user groups are, their background and role, can provide a basis to understand the motivation for participating in a living lab. Veeckman and van der Graaf (2015) propose that the participatory process should rely on the commitment and capacities of people to make sensible decisions through reasoned deliberation. Three basic parameters support citizen participation; ability (not everyone is able, and guidance and support are necessary), motivation and satisfaction (Veeckman and van der Graaf, 2015). Rydin (2013) suggests that the challenges of communicating between user groups can cause new knowledge sets to be black boxed. This black boxing can ease the transition into using, for example the new energy systems, by avoiding conflict where new knowledge is disputed, but it can also serve to gloss over problems rather than offering access to relevant expertise and information (Rydin, 2013).

According to (Hvitsand and Richards, 2017) there has so far been no systematic use of "urban living labs" (referred to here as citizen centred labs) in Norway, although some towns are using elements from living lab methodology in activities aimed at promoting user involvement (Hvitsand and Richards, 2017). Urban living labs are understood as a relatively new concept in Norway, and there is limited experience about their long-term effect. Representatives from living labs emphasize that it takes time to "build relationships, create trust and create a common platform for the work" (Hvitsand and Richards, 2017). This could be a barrier because it takes time to establish a living lab and therefore time to gather feedback about their impact. Time is a limited resource within municipalities, citizens and researchers. The ZEN Centre's use of living labs stands as a long-term commitment to user engagement within its pilot neighbourhoods, through the Centre's 8-year research period. The living labs should help to secure partner and stakeholder involvement in pilot projects, as well as securing understanding and acceptance of ZEN aims and ambitions within pilot projects. The intention is to develop citizen centred site-specific processes that a broad group of users have been involved in the development of. The pilot neighbourhoods all have different qualities and are involved in different processes, and this requires a variety of actions and experiments that highlight the challenges and aims that the neighbourhoods are dealing with. Two neighbourhoods have been chosen as the focus for the living lab activities, Campus Evenstad and The Knowledge Axis in Trondheim. There should be a high degree of knowledge transference between the neighbourhoods where living lab activities are centred and the other pilot neighbourhoods.

5. Discussion and conclusions

5.1 About the report and this chapter

This report has elaborated upon zero emission neighbourhoods, identifying primary drivers and barriers to its further development. The three core parts of the report are illuminating the technical, market based and institutional aspects of the development:

- Chapter two identifies the currently most relevant technology options for designing energy systems in a ZEN. Technology cost reductions (especially PV and li-ion batteries), as well as their potential to contribute to the decarbonization of the energy sector, is making a ZEN technologically and economically feasible.
- Chapter three identifies the challenges and opportunities of integrating ZEN energy resources in current markets. The integration of ZEN assets, such as local production of energy, will challenge current market structures and require higher integration of markets related to building design, thermal energy and electricity. Furthermore, challenges and opportunities related to value distribution and capture within different business models are elaborated upon.
- Chapter four elaborates the institutional aspects of a ZEN and how current policies and regulations affect the development. This includes the importance of citizen participation and the use of living labs as a tool to highlight issues related to ZEN developments.

In the following, we will discuss barriers and drivers identified in the report and relate these to the stakeholders depicted in Figure 1.1 in Chapter 1. Towards the end of this chapter, based on the discussion of drivers and barriers, we propose some recommendations to the relevant stakeholders.

5.2 Drivers and barriers towards the development of ZEN

Throughout this report, issues important to the further development of a ZEN have been elaborated upon. These issues have been organised along technical, market related and institutional aspects of relevance. In the current chapter, we link these aspects to relevant stakeholders in a ZEN.

It is important to bear in mind that the depiction of stakeholders is undertaken primarily with the aim of discussing drivers and barriers. There are several other ways of illustrating stakeholders as well. Stakeholders of ZEN are largely interdependent for a ZEN to further develop and spread in the market. Challenges and possibilities are diverse and complex, and hence no single stakeholder group would be likely to drive this development alone.

The drivers and barriers identified are related to the stakeholders considered most relevant and presented in Table 5.1 and Table 5.2 respectively. The drivers and barriers have been sorted according to the use of colours in Figure 1.1, where grey represents *Society and policy*, **orange** represents *Infrastructure and supply*, and **red** represents *Owners and developers*. A driver could in some instances also be a barrier, if lacking. Drivers and barriers have not been valued in terms of *impact*. The significance of drivers and barriers is therefore likely to be better understood if analysed qualitatively and cannot be compared solely by numbers.

Table 5.1 A list of ZEN drivers and their relation to three stakeholder groups: Society and policy (S), Infrastructure and supply (I) and Owners and developers (O).

S	I	O	DRIVERS
		1	Attractive area as part of a larger project
		2	Extra value (in addition to energy and climate)
		3	Ambitious building- and area developers
	1	4	An innovative approach by the industry
	2	5	ZEN relevant technology development and cost reductions (e.g. solar PV)
1	3	6	Key personell
2	4	7	Efficient investments in integrated energy networks through smart metering
3		8	Building and construction agreements and contracts
4		9	Cooperation between municipality and building developer
5		10	Living labs can provide insight into how technology is used and understood
6		11	Budget incorporating ZEN measures
7		12	Municipalities and other building owners that build pilot projects
8		13	Engaged, involved and motivated citizens and communities
9		14	A broad framework which allows the inclusion of numerous different processes
10	5		Reduced need for grid investment (e.g. exploiting energy and flexibility mechanisms within the neighbourhood)
11	6		AMS/Elhub provides larger potential for new business models and demand response schemes
12	7		Higher export of renewable energy from Norway
13			Ambitious targets and standards on a national level
14			EU regulation and policy targets
15			External funding
16			Best practice cases (ZEN pilots)
17			Allocation of welfare through distributed energy resources

Among the drivers identified, the largest number is related to the stakeholder group *Society and policy* (17 drivers identified). These drivers are related to issues such as regulation, funding, citizen involvement and the importance of ambitious targets also on a national level. The stakeholder group *Owners and developers* is the second largest group (14). These are focused on added value to the ZEN development, such as an attractive area and other qualities in addition to energy and climate. It also points to the importance of ambitious buildings and area developers.

Seven drivers address stakeholders from the I group, respectively also addressing the S group (5) and the O group (4). Innovative approaches by developers and suppliers create a good foundation for green neighbourhood development. New opportunities to contribute to decarbonization through technology development (e.g. solar) and enabling infrastructure for smart solutions (e.g. AMS) are key drivers for both suppliers and building developers to implement ZEN solutions. Local energy supply and increased energy efficiency in a ZEN could also increase Norway's possibility of exporting clean hydropower to other European countries and can be a driver for both energy suppliers and neighbourhood developers.

Nine drivers address actors from both the S group and the O group. These are related to a variety of drivers, naturally focused on drivers such as agreements and cooperation. Also, the importance of public actors leading the way by realizing pilot projects, is pointed out. Furthermore, the importance of involving citizens in such a way that they can take fully informed decisions and eventually support the project, is included.

Two drivers are present in all stakeholders' groups, namely the presence of key personnel and the vision of developing an integrated and more efficient energy network through smart technology. Even though there is a lot of push towards smart technology integration, there is still a lack of knowledge about the total costs and benefits. Key personnel could be an enthusiast and/or a particularly skilled and often convincing person that manages to persuade and convince people around him/her about the advantages of the ZEN project.

Table 5.2 A list of ZEN barriers and their relation to three stakeholder groups: Society and policy (S), Infrastructure and supply (I) and Owners and developers (O).

S	I	O	BARRIERS
		1	Power and position of the building developer
		2	Business perspective of the building developer
		3	Lack of ambitious building and area developers
		4	Budget not incorporating ZEN measures
1		5	The need to develop a ZEN is poorly understood.
2		6	Capacity and competence at the local level and at the building developer
3		7	Unclear if the processes are always meaningful for the users they are intended for
4		8	Only tokenism or short termism is achieved
5		9	Lacking incentives to capture the value of demand side energy flexibility
6		10	Improved energy efficiency does not increase the value of the property
7	1	11	Lack of key personnel
8	2	12	Techno-economic complexity of implementing smart technologies
9	3	13	Lack of integration between stakeholder groups and markets
10	4		Distrust among central actors
11	5		Regulation of ownership, management and trading in energy systems
12	6		Ownership and management of energy infrastructure (restrictions on third party access)
13			Lack of regulatory incentives 1) cannot demand better than the law 2) cannot impose requirements for existing buildings
14			Few demonstration projects related to the ZEN concept
15			Restrictions on access to energy infrastructure (e.g. <100kW local power export)
16			Lack of ambitious targets and standards on a national level
17			Too much focus on technology innovation leading to user alienation
18			Lacking/conflicting user interest and potential technology misuses/sabotages (myths and opposition)
19			Citizen engagement takes time to establish and it is not easy to evaluate
20			Limited information about its actual impact on citizen engagement

The same exercise is undertaken for the barriers and listed in Table 5.2. By far, the stakeholder group *Society and policy* contains the most barriers (20). These are diverse barriers and include lack of understanding of the necessity of a ZEN and doubts whether the effects are short-sighted and really benefiting the ones *intended.* Furthermore, the lack of national targets as well as lack of incentives to impose the targets are identified barriers. Citizen engagement, or lack thereof, can also be a barrier, as well as failing to focus on citizens when developing ZEN technology and innovations. Concrete issues of the present regulations are included, such as the 100kW threshold for power export and the lacking knowledge of system consequences and benefits of allowing trade in microgrids.

Barriers primarily related to *Owners and developers* are second in number (13) and contain barriers such as lack of ambition and business perspective of the area and building developers. This stakeholder group may also not understand why the high ambitions of ZEN are necessary. In addition, there are yet limited incentives to provide energy flexibility services in neighbourhoods, and improved energy efficiency does not necessary improve the value of a property.

Equivalent to drivers, key personnel, or lack thereof, is a barrier which relates to all stakeholder groups. The lack of integration between markets, as well as complexity regarding implementation and operation of a ZEN, is another barrier concerning all stakeholder groups. There is also an underlying distrust among some of the key stakeholders in a ZEN, which seems to be caused by a suspicion that the others are motivated by business interests solely, and not necessarily carry any motivation for any greater good (reducing emissions, in this case).

5.3 Recommendations

The starting point for our research on pathways, policies and regulation in the FME ZEN research centre is to model the properties that make a ZEN attractive both from a climate mitigation perspective and from a long-term cost and welfare perspective (such as energy efficiency, avoiding lock-in effects and ensuring flexibility by the balancing of energy supply and demand). Our hypothesis is that ZENs will play an important role in the transition from both perspectives. If this is confirmed by model studies, we need to understand what the best mechanisms will be to support the transition in terms of regulation and policy instruments, recognizing both the climate impacts and the benefits to the system.

Based on the identified drivers and barriers in this report and our hypothesis on the role of ZENs, we have the following recommendations for the three stakeholder groups:

Owners and developers:

- ✓ Set ambitious objectives and develop innovative and sustainable business models
- ✓ Create a demand (and supply) for ZEN solutions through ambitious goals and long-term value creation
- ✓ Engage users in co-creating attractive neighbourhoods
- ✓ Support innovative approaches and acquire competence on smart technology

Supply and infrastructure:

- ✓ Challenge the current market with innovative business models and efficient solutions
- ✓ Grasp opportunities provided by technology development and digitalization
- ✓ Create new business partnerships across disciplines and traditional markets (energy and building industry)

Society and policy:

- ✓ Engage and be engaged as citizens in the development of sustainable solutions
- ✓ Frequently evaluate regulations limiting a ZEN based on updated research and development
- ✓ Support research to develop more knowledge on the impact of a ZEN

- ✓ Developing several best practice projects is essential for learning and further development

There are still few ZEN projects that have been realized, and major leaps in future development are expected. We hope that this report will contribute to further progress for future ZEN developments.

Appendix A - Case examples

This section presents some examples of projects relevant for the development towards a zero emission neighbourhood as described in this report.

A.1 Campus Evenstad

Campus Evenstad is one of the Norwegian pilots in FME ZEN. It is a rural university campus in Stor-Elvdal municipality consisting of about 20 buildings, including offices, a cantina, lecture rooms and student housing. Most parts of the neighbourhood is owned and operated by Statsbygg, a publicly financed builder in Norway with a clear vision towards developing and delivering low-carbon buildings by 2030. By early 2017, the construction of a new administration building made Campus Evenstad one step closer to becoming a ZEN (Selvig et al., 2017).

The new administration building fulfils the requirements to a ZEB-COM building (Fufa et al., 2016b). This means that emissions related to the energy used for **c**onstruction and **o**peration of the building, as well as energy used for production of building materials, is compensated for over the lifetime of the building through local renewable energy production. The ZEB-COM building on Campus Evenstad consist of mostly tree-based materials related to low emissions and has a floor area of 1 141 m^2. The floor area has been minimized to reduce emissions related to construction, materials and operation of the building. The responsible stakeholders for the project highlight the need for Environmental Product Declarations (EPD) on materials to pursue emission related goals. The local production plant is a combined heat- and power plant (CHP) fuelled with biomass. The CHP plant produces more heat and electricity than is needed for the building to classify as a ZEB-COM, and this is used by nearby buildings. This calls for increasing the system boundary to a neighbourhood level.

Figure A.1: Campus Evenstad, Norway. Photo by Statsbygg

The energy consumed in the neighbourhood is partly provided by local renewable energy sources. Electricity demand is partly met by on-site solar cells and a combined heat- and power plant (CHP), and the remaining demand is served by the electricity grid. There is an electric vehicle (EV) charger on Campus Evenstad, and a stationary electric battery will be installed by spring 2018. It has been decided to make the EV charging station bi-directional, meaning connected EVs can provide electricity back to the grid (vehicle-to-grid, V2G). Heat demand is almost completely met by the CHP, a bio boiler and solar collectors, and the rest is delivered with electric units including an electric boiler and electric heaters. With the energy management system, the extent to which Campus Evenstad could utilize its local energy resources can be maximized.

With energy efficient buildings and local low-carbon energy generation, Campus Evenstad is realizing goals related to a ZEN. Being in Norway, however, the goal of having buildings related to zero emissions in operation is potentially realized if electricity from the grid is related to a low emission factor. With renewable hydro power dominating the production of electricity fed into the grid in Norway, this could arguably be the case. Prioritizing energy efficiency and energy saving is therefore especially important in the Norwegian context. Nevertheless, local production of energy does potentially decrease the need for grid infrastructure, adds renewable energy to a largely interconnected power system and increases the awareness around energy consumption. At Campus Evenstad, electrification of transport and waste handling are very relevant parts to include in the neighbourhood, since these elements raise a clear potential for emission reductions in a Norwegian neighbourhood.

A.2 Project GrowSmarter

A.2.1 About the project

In three lighthouse cities, Barcelona, Köln and Stockholm, the GrowSmarter project set out to respond to modern cities' needs and reduce the environmental footprint . The solutions introduced are categorized into three main categories: Low Energy Districts, Integrated Infrastructures and Sustainable Urban Mobility, which are further subdivided as shown in Figure A.2:. The measures are linked to both new technology implementation and user behavior. The targets of the project is to promote the three pillars of sustainability (social, economic and environmental) through e.g. job creation, reduced energy use and emissions, increased cost efficiency and improved quality of life. The project is funded through the EU's horizon 2020 research and innovation programme.

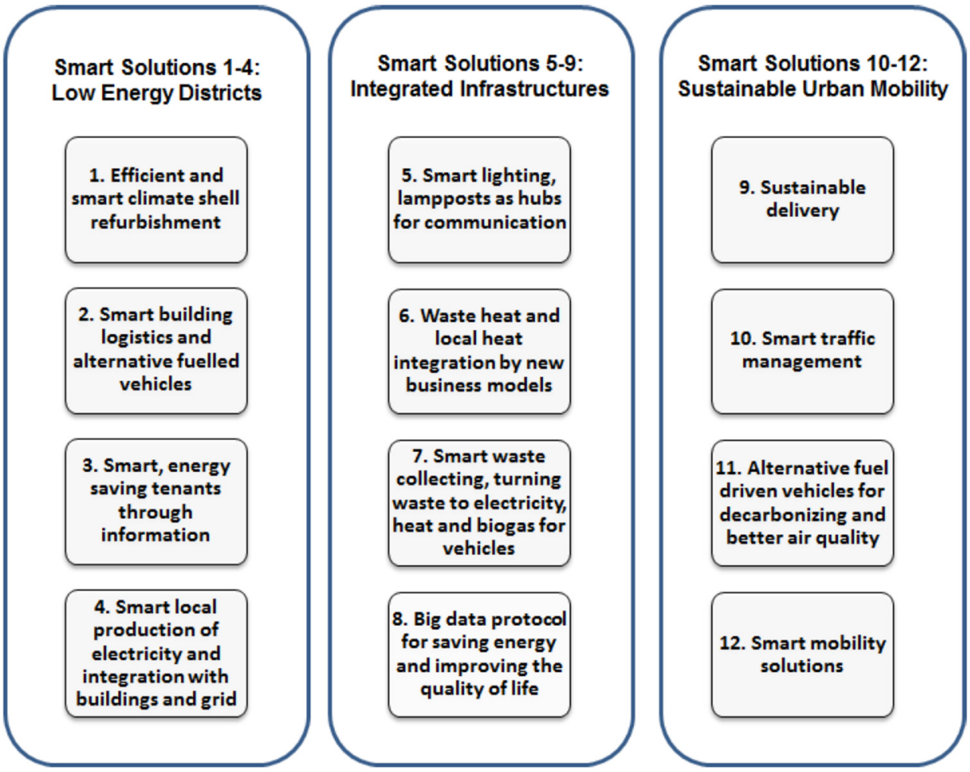


Figure A.2: Overview of the 12 smart solutions in the EU project GrowSmarter

A.2.2 Low Energy Districts

The first action area has a goal of reducing environmental impact through making sure energy use in buildings is optimized and minimized. Aside from the improvements to the building envelope, the project introduces a logistics center to reduce the impact of building materials being delivered to and transported from the refurbishment sites. Smart home systems are integrated with smart meter data and dynamic electricity pricing. The technology is also used to form virtual power plants making use of locally produced solar energy and local flexibility potential. In addition, real-time data on energy consumption is available for tenants through user friendly platforms with the goal of incentivizing energy saving behavior.

A.2.3 Integrated Infrastructure

The main goal of these solutions is to integrate active and passive infrastructure for energy-, communication-, transport- and other networks to optimize investments and operation related to them. Some of the proposed ideas include integrating lamp posts with electric vehicle charging stations, traffic and environmental sensors as well as using smart meter data to visualize energy parameters related to individual devices. There is also a focus on utilizing waste products by creating efficient waste collection and allow feed-in of waste heat into open district heating grids.

A.2.4 Sustainable Urban Mobility

Solutions in this action area seeks to deal with challenges linked to mobility. By collecting traffic data, there are solutions related to smarter delivery services and general traffic management to avoid congestions. There is also focus on the use of electric vehicles by optimizing the roll-out and operation of charging infrastructure and deliver electricity from the vehicle back to the gird. New platforms for flexible public transport and car sharing is also part of this action area.

Appendix B – ZEN relevant technologies and developments

B.1 Prosumer business models for electricity trading

B.1.1 Vandebron

Vandebron, meaning "from the source", is a Dutch energy company established in 2014. They offer a virtual platform where renewable and locally generated energy can be bought from independent prosumers, typically farmers with surplus investment in green and local generation capacity.

In addition to paying for the energy volume, customers pay a monthly fixed subscription fee to the company. Suppliers selling their energy also pay a subscription fee. All suppliers and customers are connected to the grid, and the role of Vandebron is to make sure that the energy fed into the grid by the independent supplier is equal to the energy consumed by the supplier's subscribers.

Most suppliers are supported by the Dutch sustainable energy production subsidy scheme (SDE+), which provides a subsidy to produce renewable energy. Vandebron has proven successful with more than 100,000 customers and more than 100 prosumers selling energy in 2017.

Companies like Vandebron are present in other countries as well, including Piclo in the UK. The Norwegian company Otovo has also tried a similar business model in Norway, but there are barriers related to the regulatory framework (see Section 5).

B.1.2 Brooklyn Microgrid (BMG)
Mainly motivated by ensuring reliability of supply, the Brooklyn microgrid (Mengelkamp et al., 2018) is a pilot project since 2016 in New York, USA. The microgrid is privately owned by the company LO3 Energy, and it is a physical microgrid connected to the main grid. The pilot project has so far proven that a simplified version of a P2G model works in practice.

Trading in the BMG is blockchain-based, and the transactions are made in real-time in a virtual market. With data from smart meters and customer settings, the trading is automatic. The physical operation of the BMG is still done by the system operator, Con Edison, due to lack of legal framework for independent operation of a microgrid.

B.1.3 Power Matching City
Since 2009, a pilot project referred to as the Power Matching City (Kamphuis et al., 2013) has been running in the town of Hoogkerk in the Netherlands. A neighbourhood of 42 households are part of a virtual platform, PowerMatcher, where the community's resources are put to best use.

The PowerMatcher platform provides communication to users and units of the community system. Some settings are made by users about their preferences, and the platform either controls units directly or sends signals to affect the consumption pattern. The pilot project has demonstrated a big potential for flexibility within the community. The scaled-up flexibility could be of great value to the grid, but there is still a question of how to sell this flexibility product in the energy market.

B.2 Prosumer business models for district heating trading

B.2.1 District heating trading in Norway
The cost-plus pricing method is often used in regulated DH markets which is the case in Norway. Cost-plus pricing offers several advantages to sellers, buyers and regulators, such as ease of administration. However, a regulated market does not allow DH companies to compete with other heating solutions by adjusting DH prices, while the subsidization of DH systems is often needed to make DH a competitive option compared to its alternatives, e.g. oil boilers, gas boilers and electricity-driven heat pumps (Li et al., 2015). Existing pricing methods, such as the cost-plus pricing method and the conventional marginal cost pricing method, cannot simultaneously provide both high efficiency and sufficient returns (Zhang et al., 2013). New pricing is required and could assist in further energy saving and CO_2 emission reduction, which is essential to promote sustainability of energy systems (Sun et al., 2016).

DH companies in Norway does not yet provide incentives for thermal peak load shaving. The only known fact is the incentive for reduction of the return temperature and tariff scheme to praise this user behaviour exists. This is usually implemented for commercial and public buildings. Currently, a study is initiated at a DH company in Norway to evaluate potentials for thermal storage in buildings. This means to preheat the buildings when possible by storing heat in the building construction and air to avoid peak heat load. Based on some preliminary analysis and experiences from Sweden, existing buildings with either heavy constructions or buildings with a strong dependency between outdoor temperature and heat demand may be relevant for this heat storage in buildings. The consequences of this measure may be hard to evaluate now for the application in nZEB due to different constructions and different behaviour in terms of energy use.

B.2.2 Fortum

Fortum is a DH company that operated in Stockholm Sweden has launched the "Open District Heating and Cooling (DHC)" business model in 2012. Open DHC provides an example of an ongoing project that is very similar to the thermal prosumer concept presented in this report. The objectives were utilization of the most efficient energy sources available and enhancing the profitability of the DHC system by minimizing costs related to heat supply. This is achieved by opening the network to a wide range of energy sources.

For example, the business model makes use of the large excess heat produced by the city's large data centers and feeds it into the DH network. Three types of rates are offered for the surplus heat depending on the type of line through which heat is being delivered: open spot market price for heating (through feed lines), open returned heating price (through return lines), and open residual heating price (through district cooling return lines during winter). Customers are hereby encouraged to recover their excess heat and become suppliers, which in turn taps into an otherwise unexploited resource using local waste heat. This system does not only offer a market price for surplus heat from consumers, but also ensures sustainability by reducing their heat demand through improved demand-side management or thermal storage.

Fortum has also launched several Open DHC pilots in Finland, which have the potential to be reproduced in other networks across the globe (R.B. Stockholm).

B.2.3 Hamburg Energie

Another example of a business model related to thermal energy is the feed-in model by Hamburg Energie in Germany . The Hamburg Energie announced that it will buy the surplus heat from its customers at a price of 0.045 EUR/kWh, when the heat is produced by solar, bio-energy or HPs. There is no minimum capacity, but as the customer will have to pay the heat exchanger system for the feed-in, the solution remains out of the question for small solar systems of single homes. The minimum temperature is 75°C on frost-free days and higher when frosty.

Customers with surplus heat can feed it into the grid. However, customers will only be allowed to supply at least 90% of the grid heat with its own facilities during the first construction phase. The model is targeting the housing enterprises. The model allows customers to design bigger solar plants to cover more than their own heat need, since there is no risk to produce too much heat as it can fed-in in the grid.

B.2.4 Sitra

Mainly related to district heating (DH) networks, several business models to trade thermal energy are emerging. A two-way heat trading concept developed by Sitra[20] in Skanssi, city of Turku, Finland encourages bidirectional DH with several categories of prosumers. In relation to this, several types of business models have been suggested (2016a).

The fixed price model is aimed to have fixed prices over a longer period. This is the easiest way to start bidirectional trading in the heating network. The target group for the model may be small producers, who have no previous experience in heat trade, but also individual larger producers. The model is best

[20] https://www.sitra.fi/en/projects/two-way-district-heating/

suited to a limited number of producers on a case-by-case basis due to customization and customer-specific agreements. The model assumes that the number of customers would be reasonably small for the most part DH networks in initial stages, which is the case in Finland.

The marginal-cost pricing method is commonly utilized in deregulated markets. The marginal cost model primarily aims to obtain DH customers as heat producers to generate heat when it is beneficial for both producers and DH companies. Customer can decide on their own willingness to generate heat for DH company based on the cost-varying purchase price. Compared to the fixed price model, this model can consider closely cost variation even at day or hour level. The model is particularly suitable for DH companies with the ability to integrate more and more customers with their own capacities to fill the heating demand. The producers have bilateral agreement with DH company. For example, the quantities of available capacity, possible priority purchases and the general principles of purchase are agreed. The heat purchase price is defined by the DH company for instance at hourly, daily or weekly levels, and the price is published in advance to initiate production decisions. The price is based on the marginal cost, if necessary, on the power path, including the maximum amount of the purchase at that price. This model requires hourly consumption and production measurement with updated billing system. In addition, there is a need to manage tenders and agreed sales. The system should be developed as well as the staff who will handle the arrangement in practice. The marginal cost model was not seen as encouraging new investments in heat production. In this sense, the model was found to fit well in places where it is possible to enter the network without significant additional investments.

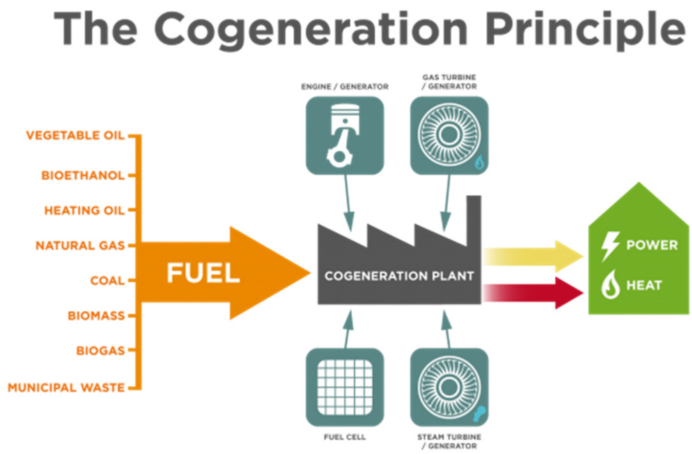
In the capacity model the prosumers must provide predefined level of heating energy to the DH grid. The model is appropriate for DH companies with scarce capacity who want to provide customers with the opportunity to invest in distributed heat production. For example, the target audience may be large industrial plants that can anticipate their available capacity or those who are planning a new investment in heat generation and want a more stable income stream for their investment. The model can be used to apply public pricing levels to certain types of production and profiles, and the prices can be negotiated if the customer are significantly different from the defined profiles. The contract is typically time-limited, and the length of the contract period is agreed upon by the parties. Typically, the contract is longer the more significant investments in the arrangement implementation. The customer is responsible for the delivery obligation up to the amount of agreed capacity and, if necessary, to generate heat according to the agreement of the DH company on application. The DH company, on the other hand, is not required to buy energy. It is also possible to include a sanction facility for the model to encourage the producer to maintain the agreed delivery responsibility. Despite the difficulties of providing a certain capacity for a sufficient length of time, it was pointed out that the contracts should be long enough to make the investment repayment guaranteed.

The DH network can in theory act as an open platform, through which producers and customers meet. The "Network as Open Platform" model is in line the principles applicable to the electricity market. The model has a chance attracting different producers with different types of pricing models. Producers may, after joining the network, sell heat through bilateral agreements for heat users. Heat distribution is the responsibility of a DH network company, which charges the distribution price of the transferred heat. The model can be used to create theoretically open and versatile competition, but the implementation also requires high costs. Despite several benefits, this model still has some issues to solve. Particularly, ensuring sufficient quantity of heat in the network, technical issues with pumping under various driving situations and imbalance between buyer and seller of heat due to transport losses. Under such conditions, the model requires someone to take care of the network balance and balance management. Further, there may be a need to differentiate heat transfer and production and sales activities, whereby customers can buy heat from the heat producers they choose connected to the network.

B.3 Co-generation of heat and power

B.3.1 High efficient cogeneration of heat and power (CHP)

While CHP is used for DH primarily in the North and East European countries, in other countries CHP applications have been primarily restricted to industry and commercial buildings. Small-scale CHP systems have only recently begun experiencing some growth due to the large potential market in the residential and commercial sectors. Currently, CHP systems are in the early stage of commercialization. The applications are used both in residential and commercial sector. CHP system are capable to operate with both low and high temperature SH and DHW systems. Since a micro-CHP produces relatively high temperature heat, it can easily be implemented in the heating systems of existing buildings.



Figur B.3.1: Illustration of co-generation of heat and power. Source: The Association for Decentralised Energy (ADE)

Stirling engines (SE) and internal combustion engines (ICE) are heat engines. The heat realized by the combustion is then converted to mechanical energy in thermodynamic cycle. The well-known Otto and Diesel cycles are employed in ICE, whereas SE are external combustion devises operating with closed cycles. Both ICE and SE devices can be fuelled from variety of sources, such as gasoline, petro diesel, natural gas, LNG, bioethanol and biodiesel. Wood chips, industrial wood residues, demolition wood and energy crops is another possibility for SE. The engine principle is very flexible with respect to fuels which make the engine interesting also in relation to the use of renewable energy sources (STYRELSEN, 2012b).

It is expected that micro CHP systems will show considerable development in the residential sector by 2030 and the annual sales of 3 million units per year is expected 0.8 million units is expected to be installed in 2030 (Europe., 2014). Among micro and mini CHP technologies, the products available on the market are mostly based on conventional gas engines. The gas engine technology has been used for many years. During the years, the efficiency has been steadily improved, and the emissions have been reduced.

The mechanical efficiency of a gas engine is around 20% as annual average for micro CHP units and 28-36% for mini CHP units, while the thermal efficiency can be reached up to 90-96% depending of capacity of the unit. The heating capacities are ranging from 3-300 kW, while electrical from 1-180 kW. At the same time, the mechanical efficiency of a SE is approximately 25%. However, for most small applications, it is lower, in the range of 12% as annual average efficiency. If the heat recovery is employed, the total efficiency is up to 90%. The capacities range from 7-15 kW for heat generation and 1-7 kW for power.

CHP technology is mature and proven with few technical components, has reasonable efficiencies and commercial availability. In addition, it is flexible with respect to fuels. Despite several advantages that micro CHP can show, the disadvantages are also present. Some level of noise occurs under operation, although units are delivered in a noise insulated cabinet, a relative high level of emissions and relative high maintenance and service costs.

B.3.2 Solid Oxide Fuel Cells (SOFC) and Proton Exchange Membrane Fuel Cell (PEMFC)

The solid oxide fuel cell (SOFC) and Proton Exchange Membrane Fuel Cell (PEMFC) are electrochemical cells that convert hydrogen and oxygen into electricity, heat and water (see Figure 2.9). When the heat is recuperated, the fuel cell work in a CHP mode, otherwise it is a power generator only (STYRELSEN, 2012b).

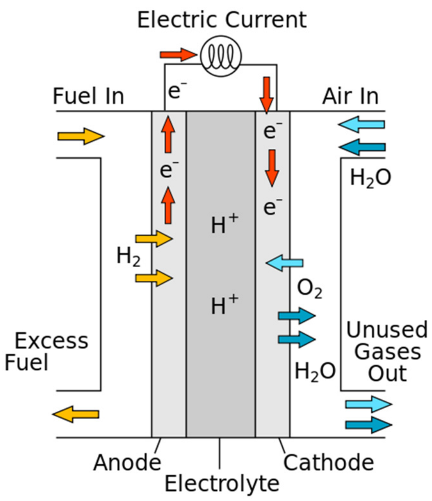


Figure B.3.2: Illustration of a fuel cell powered by hydrogen. Source: Wikipedia

The SOFC is a high-temperature fuel cell (600-1000°C). Electricity efficiency of a single cycle SOFC-plant in the range 1-200 kW can be approximately 60%, when fuelled with natural gas. The systems may achieve overall efficiencies up to 88%, if low temperature heat can be utilized. The typical capacities can range from 10 kW to multi megawatt of electricity and heat with good part load capabilities between 100-20% load.

Natural gas, methane, methanol, hydrogen and similar fuels can be used. The fuel cell micro CHP system should be equipped with a heat storage so that the capacity of the unit can be limited, and the fuel cell can optimize its production taking not only the heat demand but also the electricity demand/prices into consideration (STYRELSEN, 2012b).

Technologically the PEMFC can be divided in low temperature (LT), medium temperature (MT), high temperature (HT) PEMFC. The operation region of LT units ranges from subzero up to 80ºC and are sensitive to impurities of carbon monoxide in the fuel gas. MT units can operate from subzero to around 120ºC and are less sensitive to fuel impurities than. HT units operate from 120ºC up till 200ºC and can work with even several percentages of carbon monoxide in the fuel gas. This type of fuel cell employs hydrogen as a fuel input with capacities from 1 to 200 kW. These fuel cells have a very short start-up time and in general enables fast regulation of load due to the relatively low operating temperature.

A disadvantage of SOFC is the long start up time needed to heat up the fuel cell from cold-state (4-6 hours). Another disadvantage is relatively low operating temperatures. However, these temperatures suit well for nZEB due to low temperature approach in heating. Due to higher efficiencies, absence of open flame as well as other features, fuel cells are less polluting per kWh electricity than conventional and other competing CHP technologies.

B.3.3 Trends and development

Numerous companies are actively developing fuel cells, internal combustion engines and Stirling cycle engine, and actively introducing these to the market. These technologies are technically immature, and their potential benefits remain unproven. However, promising indicators of their performance have led to financial incentives and favourable tariff structures in many countries to encourage their adoption.

The fuel cell technology has proven higher electrical efficiency than competing power generating technologies. However, the fuel cell technology still must mature with regards to issues such as life time and cost reduction. It is expected that fuel cell technology matures to reach a commercial level within this decade. Among other conclusions it states that fuel cell systems have potential interest for society based on environmental-, economical-, energy-, and system considerations.

B.4 Heat pump systems and flexible end-user technologies

B.4.1 Heat pump (HP) systems

For on-site or large-scale heat generation, heat pumps (HP) may be a suitable solution. HPs use electricity as fuel to move heat from one place to another, and can exchange heat between different mediums, e.g. from water to air. HP works best when the temperature of the released heat is low, therefore, low temperature heating systems are of interest for the HP application. The heat source is renewable energy such as accumulated solar heat in top layers of the ground, in lakes, streams or seawater. Also waste heat from industrial process can be utilized as heat source, as well as heat in waste water (STYRELSEN, 2012b).

Over 25% of the EU population lives in areas suitable for geothermal heating. Ground source heat pumps (GSHP) are receiving interest worldwide and the number of installed units increases each year. Over 80% of installed units belongs to domestic installations (Rawlings et al., 2004). GSHP represent technology that transform geothermal heat into useful space or water heat with the support of electricity. GSHP can be open- or closed-loop, and used for heating and cooling in single-family houses, and industrial and public buildings. The most common type of GSHP is the vapour compression heat pump (HP) with coefficient of performance of about 4. The heat source may be a horizontal collector in the soil or a vertical collector in the ground. Normally, the GSHP is designed to cover 80-95% of heating load with output of thermal energy at 50-60°C. There is a range of capacities available, ranging from

1.5 kW up to several hundred kW covering the needs for both SH and DHW in both nZEB and large buildings.

The advantage of a HP system is that it incorporates waste or free energy and transforms it to a higher temperature, which is useful for the specific application. GSHP has high security since there is no visible external components that could be damaged or vandalized. Low noise under the operation is also a benefit. The HP systems have long life expectancy, which is typically 20-25 years and up to 50 years for the ground coil. In addition, it has high reliability due to few moving parts and no exposure to outdoor conditions.

The disadvantage is the energy needed for the transformation and the cost of the necessary equipment (Garcia et al., 2012). Another drawback is that the ground heat source involves digging in the ground or other arrangements to retrieve the necessary heat (STYRELSEN, 2012a). Other disadvantages are relatively high investment cost and limitations due to refrigerant use. Further, a disadvantage is new control and operation strategies required for efficient HP operation and integration with other system. Proper control and possibility to be integrated with other system is crucial for a successful implementation of HPs. However, this is still a problem for most of the HPs available on the market (Frederiksen and Werner, 2013).

B.4.2 Flexible end-user technologies

Different technologies can be used to control the consumption of water heaters, including switching controlled by relays that can either be used for central control in conjunction with a smart meter or with local control.

Thermostatically controlled heat and cooling loads are suitable for moving consumption from high load to low load. The response in kWh / h will depend on the consumption pattern and the coincidence factor. Systematic testing of approx. 1200 water heaters in the project "Consumer Flexibility in Effective Use of ICT" (2004) demonstrated that the disconnection of water heaters resulted in an average response per household of respectively 330 W in hour 8, 600 W in hour 9, 300 W in hour 10 and 50 W in hour 11. Though, this response can result in a significant rebound effect that needs to be considered.

Mass transmission of broadcast signals has been used in other countries. New Zealand (2017a) has, for example, used so-called ripple signal for switching on and off water heaters to relieve the network in strained situations since the 1950s and 1960s. Such systems are still in use. The ripple signal is sent over the electricity grid and disconnects all controllable units. The average disconnection time is less than 3 hours, which in most cases does not cause customer inconveniences in the form of cold water. Newer "broadcast" systems now use PLC or radio and IP-based communication channels.

Panel ovens can also be used for shifting consumption from high-load to low-load hours. They are not necessarily as effective as water heaters or heat pumps for water heating, since water has much higher thermal capacity than air. The shifting periods when a panel oven can be turned off before the comfort of the customer is reduced, are therefore limited.

Managing the lighting in a home can provide some flexibility, but with far less potential than flexibility from thermal storage (especially considering the growth of efficient LED lighting). The customer's requirements here may have great impact on potential, since the control of lighting will be immediately noticed by the user. An alternative could be automatic control of light outdoors, where the control depends on the amount of daylight.

B.4.3 Trends and development

Both the decarbonization of electricity production through the integration of variable renewable resources and the growing load variations represent a potential strain on the electricity grid. Variable renewable resources introduce new production peaks at times of low demand, whereas new load components, such as electric vehicle charging stations and instant electric water heaters, can introduce new consumption peaks. This challenge can be addressed by replacing existing lines, transformers, protection mechanisms and other infrastructure with higher capacity components or by rendering the grid smarter, meaning more responsive to the changing conditions. This can be achieved mainly by rendering demand flexible and/or integrating more storage capacity into the grid.

While electric appliances are becoming more energy-efficient, household electricity consumption is expected to increase on an EU level (2016c). This is due to (1) a growing number of electric devices in use and in the EU and (2) the shift toward electrification of appliances such as stoves and water heaters and heating. If powered by renewable electricity, it is still possible to reduce greenhouse gas emissions.

Heat pumps can be a particularly efficient technology compared to gas or oil fueled heaters (Stene et al., 2018). Even in Norway where heating is already mainly electric, heat pumps can reduce energy consumption. The savings from installing a heat pump, however, tend to be lower than the potential due to the rebound effect (Winther and Wilhite, 2015), where the initial reduction in electricity consumption due to the higher efficiency of the heat pumps is partly offset by an increase in thermostat temperatures as heating becomes more affordable. Induction ovens are becoming popular and contributes to energy efficiency, but due to their fast switching consumption can represent a problem for the electricity grid (Coenen et al., 2014). Instantaneous electric water heaters are a technology that increases the efficiency of hot water preparation since it requires no hot water storage and consequently eliminates thermal losses. However, these devices are even less desirable from the grid perspective due to their power-hungry properties which calls for some flexible and responsive control if implemented.

Many expect electric vehicle charging to pose problems to the grid operators. A ZEN study found that most electric vehicle owners tend to charge their vehicles at night when load is low allowing for very high penetration rates (Sørensen et al., 2018). Other studies (Lillebo, 2018) show that relatively high market shares of EVs in Norway (60% and upwards) should not pose difficulties for the grid. Fast chargers at the distribution level can, however, represent problems like voltage instability (Putrus et al., 2009) and should be strategically placed in the distribution network (Deb et al., 2018). Depending on the timing of charging, some smart management and coordination of EV charging might also be required (Clement-Nyns et al., 2010). On the other hand, the additional mobile storage capacity provided by a high market share of EVs could provide a flexibility service, and potentially reduce peak load in Norway by 10-50% with the current development towards 2030 (Henden et al., 2017).

Norway could serve as a green battery for Europe (Gullberg, 2013). Since there are limited plans of new hydro capacity developments over the next years, solar power could provide extra electricity and increase clean Norwegian exports. Solar energy at the distribution level can pose problems for the grid (Von Appen et al., 2013) requiring reinforcements, voltage control or flexibility. Norway has abundant flexible resources in its hydro power, but these cannot solve the problems at the distribution level.

Flexible resources at the neighbourhood level can reduce the need for grid investments that are due in Norway in the next years.

B.5 Thermal energy

B.5.1 Solar thermal heat

Solar energy is widely available in all EU countries and urban locations. This is one of the strategic renewable recourses that is used for heat generation in district heating (DH) systems centralized and decentralized. In recent years, the dominating market has shifted from individual systems to large-scale systems for DH due to economy of scale benefits. However, with the increasing demand for energy efficiency of new buildings, individual solar heating plants are becoming more and more common (STYRELSEN, 2012a).

Solar heating systems can be applied for space heating (SH) and domestic hot water (DHW) preparation. Many different design options for solar collector connections to DH exist. Collectors can be various types depending on operation conditions and type of system operation. For example: unglazed water collectors, evacuated tube collectors, flat plate collectors, glazed and unglazed air collectors and concentrating collectors. The performance is very dependent on especially the size of the solar collectors in relation to the energy consumption (Garcia et al., 2012).

The global solar thermal capacity has been increased considerably during recent years. In Norway the total thermal capacity from water solar collectors was 30 MWth in 2014. Most of the energy that is generated by solar collectors these days refers to heat generation. The international solar thermal industry is one of the fastest growing sectors, with 20-30% annual growth rates (Mauthner et al., 2013).

When properly designed, solar collectors can work at the outdoor temperature well below freezing and they are also protected from overheating on hot, sunny days. The output is thermal energy at medium temperature, typically 20-80°C, depending on operation conditions and collector type. Higher temperatures are possible with special double-glazed solar collectors for district or industrial heating. The thermal heat rate is largely determined by the solar irradiance and the actual operating temperature.

The solar collectors as heating energy source have both advantages and disadvantages. An advantage is that it does not produce pollutions. Further, the solar collector can be integrated in the urban environment and may substitute a part of the building envelope. However, the installation is relatively expensive, except for large systems. A disadvantage is mismatch between heating demand and solar availability in the areas with low solar availability. In addition, it requires sufficient area on the roof with appropriate orientation. Nevertheless, with improved architectural design and improved building envelope, this is less of an issue.

B.5.2 Waste heat utilization

Utilization of waste heat is a promising solution for a ZEN when local resources of waste heat exits. Waste heat can be provided from different sources such as industry, IT centers, and buildings with high cooling demand. IT centers have high cooling demand. By cooling IT centers, waste heat from the condenser may be utilized for local heating. District heating ring at Gløshaugen in Trondheim is utilizing waste heat from the IT center at the campus. Buildings such as hospitals and sport centers may have a high need for cooling year around. By cooling these buildings, waste heat may be provided for heating the other local buildings.

Recycling heat from industrial processes represents one of the main strategic opportunites for providing heat, in line with the basic idea of using heat that would otherwise be wasted (see Figure 2.8). In Sweden, recycling of industrial waste heat makes up around 6% of the total energy supply to district heating networks in the year around 2010. For Danish district heating systems, the proportion is about 2%~3%. In one Swedish district heating system in the city of Gothenburg, two oil refineries supply 1112 GWh waste heat to the district heating system, which is approximately 27% of heating demand in 2010 (Frederiksen and Werner, 2013).

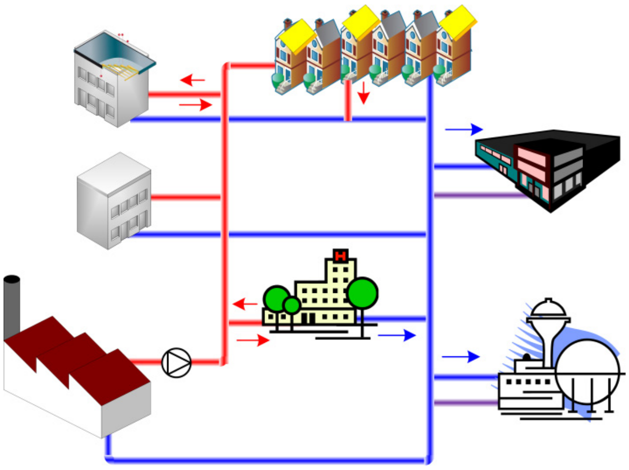


Figure B.5.2: Illustration of waste heat utilization and future district heating system. Source: (Nord et al., 2017)

Utilization of industrial waste heat may be challenging due to distance. The recommended radius for industrial waste-based district heating is 5~10 km for a small-scale town and 20~30 km for a large-or-medium-scale city, due to the investment of transmission network and heat loss during the transmission. However, such a radius might vary with different economic conditions (Fang et al., 2013).

Finally, the temperature difference between the supply and return water temperature should be increased to reduce the energy use of transmission pumps. As the advantages of low temperature district heating, the key solution is to start reducing the return temperature.

B.5.3 Thermal energy storage

Thermal energy storage (TES) solutions can be based on sensible, latent or thermochemical energy storage (Tatsidjodoung et al., 2013) and may be implemented in buildings through passive and active applications (Navarro et al., 2016a, Navarro et al., 2016b). Passive applications allow reducing energy demand in buildings by means of a higher thermal inertia, decreasing indoor peak-temperature, and improving thermal comfort. Active applications allow reduction of the peak load thanks to the supply of stored energy, improve the efficiency of systems by adjusting the operation range and increase renewable energy contribution by overcoming the time mismatch between demand and supply (Lizana et al., 2017).

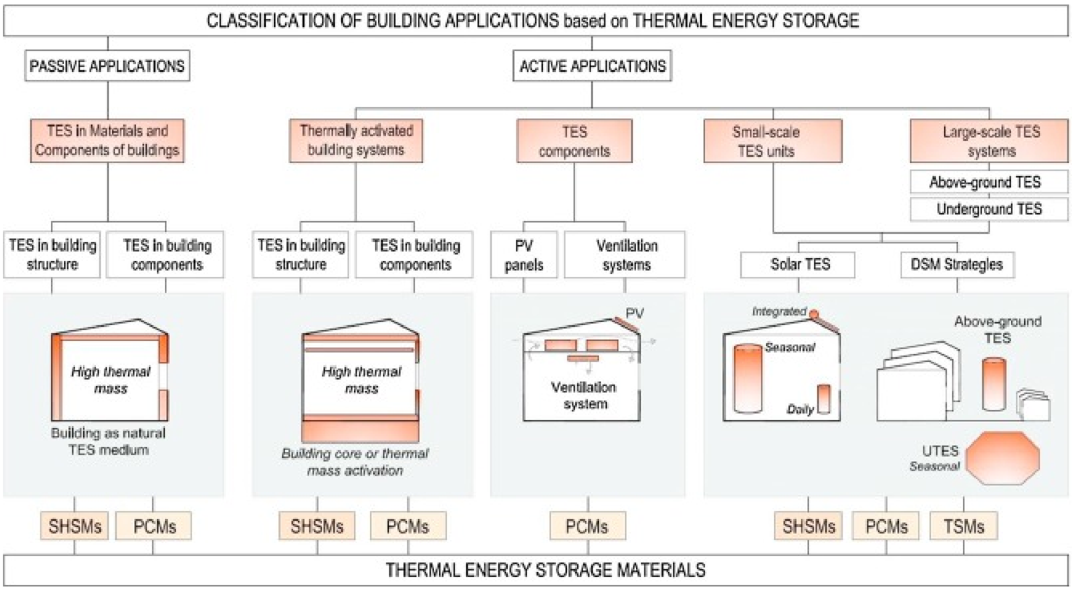


Figure B.5.3: Illustration of passive and active applications of thermal energy storage. Source: (Lizana et al., 2017)

Investigation of the effect of thermal mass in a building must consider the unique properties of the building envelope. High thermal mass is often presented as a desirable feature of buildings and structures. Indeed, in many cases discussion of thermal mass takes precedence over discussion of insulation performance. Unfortunately, the effects of thermal mass are very poorly quantified due to complexity of modelling compared to thermal resistance. In addition, they depend on wider range of factors such as average temperatures, occupancy patterns, external temperature profiles, and details of the wall construction (Reilly and Kinnane, 2017). However, studies show that energy saving effect could be achieved while employing thermal mass as a short-term energy storage. Further, it should be noted that buildings that are highly insulated, like nZEB, behave in a significantly different manner with respect to heat transfer and storage than buildings that are of light construction. Simulations show that the use of thermal mass could contribute to energy savings of 10–15% when different types of thermal mass were mixed into the building envelope (Siddiqui et al., 2017).

A new project was launched recently named RockStore (2017) by ENERGIX research program, with focus on ZEN areas. The main aim is to investigate the potential of Borehole Thermal Energy Storage (BTES) for efficient use of energy recourses and balancing energy production and demand in the DH system. The main barrier in this project was found lack of performance monitoring data. The detailed long-term measurements are crucial for understanding the operation of the system as they will verify the real energy demands of building. Large deviation was reported between building's heat and cooling demand based on monitoring and simulations (Stene and Alonso, 2016). Improved operation of DH system by reducing capacities of peak load installations, smooth system operation due to storage capacity, direct impact on operation cost and therefore strengthening market positions of energy providers involved are expected impacts of RockStore.

B.5.4 Trends and developments

The development in the heating market implies that the heating energy distributed to the buildings could be generated in two ways: centralized and decentralized. Since ZEN is a new concept in the framework of the heating market, it is not yet very clear how the heat demand will be satisfied. The ZEN concept implies that buildings within the area should meet their thermal requirements in self-generation of heating for space heating (SH) and domestic hot water (DHW). However, the possibility for self-generation of heat may induce mismatch in used and generated heat based on implemented technologies (e.g. solar heaters). This means that ZEN areas will still be require flexible solutions, e.g. district heating (DH) network, to balance demand and supply. Under a mismatch between supply and demand, the high temperature heat supplied from local DH grids could be the solution to cover unexpected heat demand. The temperature cascading is one of the ways for gradual reduction of high temperature levels in DH to low temperature applications (Imran et al., 2017, Köfinger et al., 2017). It is worth noticing that reducing the heating demand in a DH network goes against the effectiveness of the DH production (Sartori et al., 2009).

Conventional heat load profiles that are used by DH companies these days will change. As the number of very efficient and passive buildings will increase, very miscellaneous loads of the DH demand side will appear. This is mainly due to the fact that passive buildings have significantly lower energy demand, typically 25–50% less than conventional buildings (Ekström et al., Paiho and Reda, 2016). Simultaneously, the share of currently existing buildings in the building stock is expected to remain high for many years (Lund et al., 2014). This implies that existing areas will develop itself in a mixed building stock with variety of building types (Lund et al., 2014).

New developments within residential areas create peak loads in the hours with high cost for DH production. This motivates DH companies to focus mainly on methods for moving peak loads and reduction of high cost for heat generation. The technological challenge therefore depends on the market conditions. Lower future temperature demands in new buildings, low temperature requirements from RES and higher efficiencies at low temperatures in almost all energy conversion plants call for a new DH generation, especially for new buildings (Werner, 2017). Hence, the current trend in the development of DH is in the process of moving from hierarchical and fossil fuel dominated large scale structure toward future decentralized, multiple renewable and waste heat sources dominated by small structure (Li and Wang, 2014).

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