Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ENERGY AND POWER: ESSENTIAL KEY PERFORMANCE INDICATORS FOR ZERO EMISSON NEIGHBOURHOODS

An analysis of 6 pilot areas

ZEN REPORT No. 36 – 2021

Synne Krekling Lien, Kamilla Heimar Andersen, Hanne Bottolfsen, Nicola Lolli, Igor Sartori, Åse Lekang Sørensen, John Clauss | SINTEF Community

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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 authors 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, Sør-Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, ÅF Engineering AS , Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Caverion, Nord-Trøndelag Elektrisitetsverk - Energi, Numascale, Smart Grid Services Cluster, Statkraft Varme, Energy Norway and Norsk Fjernvarme.

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 m^2 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.

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FME ZEN (page)

Norwegian Summary

I FME ZEN arbeides det med å utforme en definisjon av nullutslippsområder (Zero Emission Neighbourhoods) samt hvilke indikatorer som skal brukes for å måle oppnåelse av denne definisjonen i pilotområdene. De foreslåtte indikatorene kan deles inn i kategoriene klimagassutslipp, energi, effekt, mobilitet, stedskvaliteter, økonomi og innovasjon.

Formålet med denne rapporten har vært å teste ut de foreslåtte indikatorene for energi og effekt på 6 pilotområder. De utvalgte pilotene er; Ydalir, Oksenøya (Fornebu), Dolvik, Zero Village Bergen, Campus Evenstad og Mære landbruksskole. Dette er ulike pilotområder i ulike utviklingsstadier. To av disse pilotene har lokalvarmenett (Evenstad og Mære), mens de andre er koblet til fjernvarmenett. I denne rapporten beregnes indikatorene for pilotene slik de er planlagt (ZEN scenarioet) og for pilotene i to referansescenarior (business as usual).

Levert elektrisitet reduseres med 66% - 78% i pilotene i ZEN -scenariene sammenlignet med referansescenariene med direkte elektrisk oppvarming.

Rapporten viser at indikatorene får ulike resultater i ZEN-scenariene sammenlignet med i referansescenariene. Forskjellen netto energibehov er kun estimert til å bli mellom 8-32 % i ZEN scenarioene sammenlignet med referansescenarioene. Denne indikatoren har kun blitt beregnet for nye nabolag der bygningene allerede er forventet å bli relativt energieffektive i referansescenariet. Reduksjonen I levert elektrisitet er forventet å bli mye høyere. Netto levert elektrisitet er beregnet til å bli redusert med 28%-58% i ZEN scenarioet sammenlignet med referansescenarioet når man bruker fjernvarme til oppvarming. De viktigste årsakene til denne reduksjonen er økt energieffektivitet, samt lokal elektrisitetsproduksjon fra solceller. Hvis man sammenligner mot et referansescenario med direkte elektrisk oppvarming er reduksjonen i netto levert elektrisitet på hele 66 % - 78 %, ettersom det her også tas hensyn til reduksjon i elektrisitetsbruk ved overgang til ikke-elektrisk oppvarming. Testingen av indikatorene viser også at topplasten reduseres i stor grad I ZEN scenarioet som en konsekvens av mer energieffektive bygg og redusert netto levert elektrisitet, opptil 63 – 83 % sammenlignet med et referansescenario med elektrisk oppvarming. Topp eksport kan dog bli veldig stor – opptil 3 ganger (300 %) så stor som topplasten i pilotene der det er planlagt et stort PV-areal (ZVB og Oksenøya).

Studien viser at at når indikatorene estimeres gjennom bruk av simuleringer (for piloter i planleggingsfasen) vil resultatene i stor grad påvirkes av hvilken metode og simuleringsverktøy som er benyttet. Når en pilot er i driftsfasen, skal det benyttes faktiske måledata så langt dette er mulig. Det er flere utfordringer knyttet til å beregne indikatorene basert på måledata. Det er ofte tidkrevende å innhente og bearbeide måledata, det mangler vanligvis flere datapunkter, og det er gjerne få energimålere med lav tidsoppløsning tilgjengelig. Indikatorene ser ut til å spille en rolle for å kunne kvantifisere og forstå hovedtrekkene ved en kompleks virkelighet der ulike løsninger og teknologier kan ha påvirkning på ulike aspekter som kan stå i konflikt med hverandre. Arbeidet med denne rapporten har vist at kreves god kompetanse innen energibruksmålinger og energibruksberegninger for å beregne indikatorene for energi og effekt. For å gjøre beregningene mer tilgjengelig, er det et behov for et standardisert verktøy med et enkelt brukergrensesnitt basert på standardiserte metoder. Det er fortsatt et behov for videre arbeid med systemgrenser, definisjon av referansescenariet og å finne standardmetoder for beregningene. Resultatene fra denne rapporten vil bli brukt i videre arbeid med å etablere terskelverdier for indikatorene til bruk i evaluering av pilotene opp mot ZEN-definisjonen.

Involverte ZEN-partnere i denne studien har vært SINTEF, Elverum vekst, Elverum kommune, Bærum kommune, ByBo, Bergen kommune, Steinkjær kommune og Statsbygg.

Summary

The development of the definition, assessment criteria and key performance indicators of Zero Emission Neighbourhoods (ZEN), is an ongoing process that will last throughout the program period of FME ZEN. This work will enable an assessment of the performance of the ZEN pilot areas. Based on the draft for the ZEN definition, the KPIs for ZENs can be divided into the following categories: GHG Emissions, Energy, Power, Mobility, Spatial qualities, economy and innovation.

The scope of this report is to test the suggested KPIs for Energy and Power on six different pilot areas. The purpose is to evaluate the KPIs when used on different pilot areas in different development stages. The selected pilot areas (cases) are Ydalir, Oksenøya (Fornebu), Zero Village Bergen, Dolvik, Campus Evenstad and Mære landbruksskole. Two of these pilots (Evenstad and Mære) have local heating systems, while the others are connected to a district heating network. In the report, the KPIs are calculated for each of the pilots as they are planned (the ZEN scenario) and in 1-2 representative reference scenarios which represent the pilots in a business as usual case.

Delivered electricity is reduced by 66 % - 78 % in pilots in the ZEN scenarios compared to the reference scenarios with direct electric heating.

The testing of the KPIs for Energy and Power shows that the pilots get different results in the ZEN scenarios compared to the reference scenarios. The energy savings in net energy demand is only estimated to be between 8-32 %. This KPI has only been estimated for new areas, and the reduction in net energy demand is small in the ZEN scenario, due to the reference buildings already being rather efficient. The electricity savings is estimated to be significantly higher; the net delivered electricity is expected to be reduced between 28 – 58 % in the ZEN scenario (compared to the reference case with district heating) due to efficiency measures and local electricity production. When compared to a reference case with electric heating, the reduction becomes even larger, at 66 % – 78 %, due to efficiency, local electricity production and the transition from electric heating to non-electric heating (district heating and bio based local heating). The testing also show some potential for large reduction in the peak load (peak import), as a consequence of both more energy efficiency and reduced net delivered electricity, up to 63 – 83 % compared to the the reference case with electric heating. On the other hand, the peak export of electricity may become larger, up to 3 times (300%) of the peak import in the pilots where large areas of PV panels are planned (ZVB and Dolviken).

The case studies suggest that when the KPIs are estimated through the means of simulations (for pilots in the planning phase), the methodology and simulation programs used may have an effect on the results. When a pilot is in the operational phase, measurements should be used for KPI calculations as far as possible. Using measurements for the KPI calculations are linked to several challenges as obtaining measurement data is often time consuming, and there is usually missing data points and few, disorganized meters available. The KPIs seem to perform the main role of providing a way to quantify and grasp the main features of a complex reality where different solutions/technologies might have conflicting effects. The process of working with the KPI calculations show that a professional with competence in energy use measurements and calculations is needed to calculate the KPIs for the pilots, and that there is a need for a standardized tool with a simple interface and standardized methods to simplify this process. There is still a need for further work on system boundaries, definition of the reference scenario, and finding standard methodologies. The results of the study will be used in further work to establish threshold values for evaluating the pilots against the ZEN definition.

Involved ZEN-partners in this study have been SINTEF, Elverum vekst, Elverum kommune, Bærum kommune, ByBo, Bergen kommune, Steinkjær kommune and Statsbygg.

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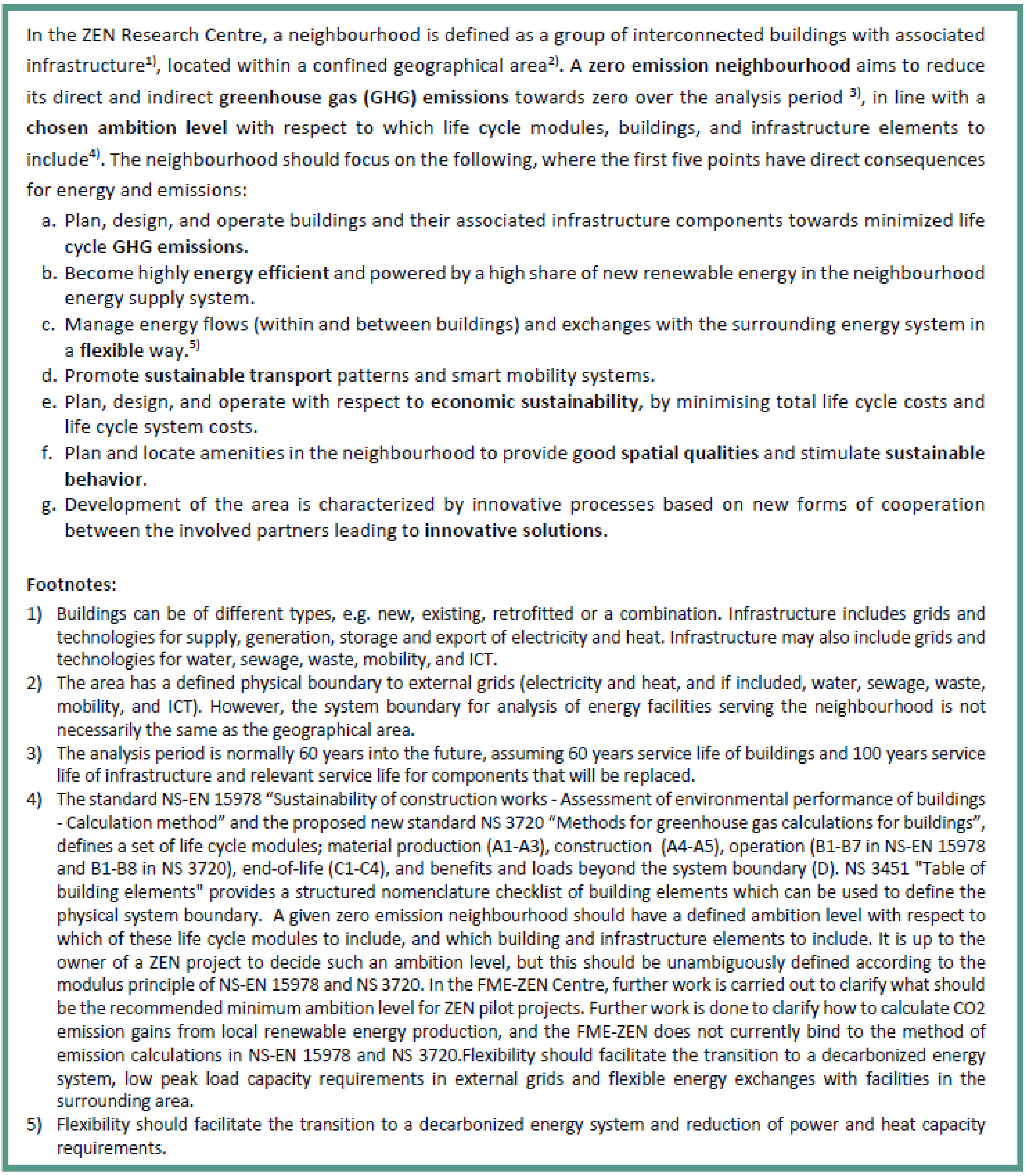
1. Introduction – Energy and Power in ZEN

The goal of the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN) is to enable the transition to a low carbon society by developing sustainable neighbourhoods with zero greenhouse gas emissions (GHG). The development of the definition of a Zero Emission Neighbourhood (ZEN) is an ongoing process that will last throughout the program period of FME ZEN. The following ZEN-definition was formulated for the first version of the ZEN definition report[1].



In the ZEN Research Centre, a neighbourhood is defined as a group of interconnected buildings with associated infrastructure[1)], located within a confined geographical area[2)]. A **zero emission neighbourhood** aims to reduce its direct and indirect **greenhouse gas (GHG) emissions** towards zero over the analysis period [3)], in line with a **chosen ambition level** with respect to which life cycle modules, buildings, and infrastructure elements to include[4)]. The neighbourhood should focus on the following, where the first five points have direct consequences for energy and emissions:

a. Plan, design, and operate buildings and their associated infrastructure components towards minimized 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 **flexible** way.[5)]
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 and life cycle system costs.
f. Plan and locate amenities in the neighbourhood to provide good **spatial qualities** and stimulate **sustainable behavior.**
g. Development of the area is characterized by innovative processes based on new forms of cooperation between the involved partners leading to **innovative solutions.**

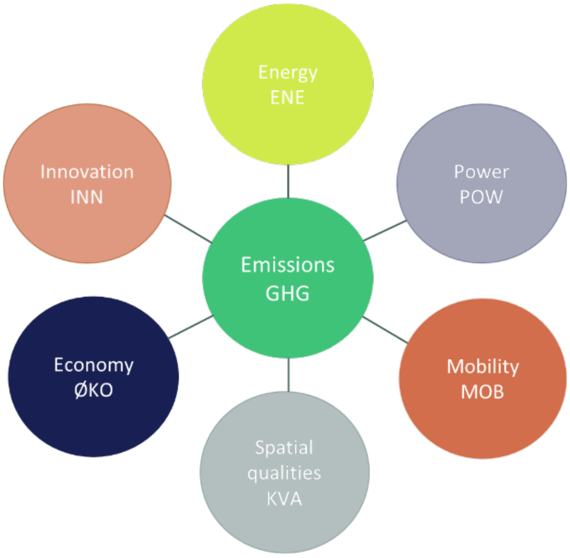
Footnotes:

1) Buildings can be of different types, e.g. new, existing, retrofitted or a combination. Infrastructure includes grids and technologies for supply, generation, storage and export of electricity and heat. Infrastructure may also include grids and technologies for water, sewage, waste, mobility, and ICT.
2) The area has a defined physical boundary to external grids (electricity and heat, and if included, water, sewage, waste, mobility, and ICT). However, the system boundary for analysis of energy facilities serving the neighbourhood is not necessarily the same as the geographical area.
3) The analysis period is normally 60 years into the future, assuming 60 years service life of buildings and 100 years service life of infrastructure and relevant service life for components that will be replaced.
4) The standard NS-EN 15978 "Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method" and the proposed new standard NS 3720 "Methods for greenhouse gas calculations for buildings", defines a set of life cycle modules; material production (A1-A3), construction (A4-A5), operation (B1-B7 in NS-EN 15978 and B1-B8 in NS 3720), end-of-life (C1-C4), and benefits and loads beyond the system boundary (D). NS 3451 "Table of building elements" provides a structured nomenclature checklist of building elements which can be used to define the physical system boundary. A given zero emission neighbourhood should have a defined ambition level with respect to which of these life cycle modules to include, and which building and infrastructure elements to include. It is up to the owner of a ZEN project to decide such an ambition level, but this should be unambiguously defined according to the modulus principle of NS-EN 15978 and NS 3720. In the FME-ZEN Centre, further work is carried out to clarify what should be the recommended minimum ambition level for ZEN pilot projects. Further work is done to clarify how to calculate CO2 emission gains from local renewable energy production, and the FME-ZEN does not currently bind to the method of emission calculations in NS-EN 15978 and NS 3720.Flexibility should facilitate the transition to a decarbonized energy system, low peak load capacity requirements in external grids and flexible energy exchanges with facilities in the surrounding area.
5) Flexibility should facilitate the transition to a decarbonized energy system and reduction of power and heat capacity requirements.

Pilot projects in FME ZEN are geographically limited areas in Norway where new solutions for the construction, operation and use of buildings and infrastructure are tested to cut the total greenhouse gas emissions towards zero on a neighbourhood level. Nine ZEN pilot areas are included in the ZEN

Research Centre. These are: Ydalir (Elverum), Furuset (Oslo), Campus Evenstad, Mære (Steinkjer), NTNU Campus and Sluppen (Trondheim), Zero Village Bergen, Nyby (Bodø), and Fornebu (Bærum).

Different assessment criteria and key performance indicators (KPIs) are used to measure the performance of the ZEN pilot areas against the ZEN definition. These assessment criteria and KPIs have been divided into the following seven categories:



- Greenhouse gas emissions (GHG)
- Energy (ENE)
- Power/load (POW)
- Mobility (MOB)
- Economy (ECO)
- Spatial qualities (QUA)
- Innovation (INN)

These categories were identified as important categories by ZEN stakeholders in the ZEN research centre through a series of ZEN definition workshops.

Figure 1. Seven categories in ZEN definition

Assessment criteria are different aspects within a category that is important to assess the performance. They can be measured by one or more key performance indicators (KPIs). The KPIs are sets of quantifiable performance measurements that define sets of values based on measured data from a project. In the current recommendations, it is proposed to distinguish between KPIs that can be compared directly against a target value and a reference project, and KPIs that are required as documentation of the pilot area. For the Energy (ENE) and Power (POW) categories, the following KPIs to be used for comparison against a target value are being considered:

Table 1. KPIs for Energy and Power in ZEN.

	KPI	Unit	Building (B), neighbourhood (N) or both (BN)	Standards & References
ENE	ENE2.1 Energy need in buildings	kWh/m^2 heated floor area (BRA)/yr	B	SN/TS 3031 [2] ISO 52000 [3] IEA EBC Annex 52 ZEN research centre[1][4]
	ENE2.2 Delivered energy	kWh/yr for each energy carrier and total.	BN	
	ENE2.3 Self-consumption and self-generation of electricity	%	BN	
POW	POW3.1 Peak load	kW	BN	Engineering practices, ZEN research centre [1], IEA EBC Annex 67 [5]
	POW3.2 Peak export	kW	BN	
	POW3.3 Utilisation factor	%	BN	
	POW3.4 Load flexibility	Currently not developed.		

To collect and calculate these KPIs, the following KPIs and documentation must be required from each pilot area:

Table 2. KPIs necessary for documentation for ENE and POW in ZEN.

Type	KPI	KPI (sub)	Building (B), neighbourhood (N) or both (BN)
Annual totals	Energy demand in buildings	Total /m2	B
Hourly profiles and annual totals	Energy demand	Thermal (space heating/heating and hot water) Electric	BN
	Energy use	Electricity District heating Bioenergy Other	BN
	Energy generated	Electricity	BN
	Energy net use	Electricity District heating Bioenergy Other	BN
	Energy imported	Electricity District heating Bioenergy Other	BN
	Energy exported	Electricity	BN
Colour coded carpet plot	Net energy use	Electricity District heating	BN
Typical daily profiles	Net energy use	Electricity	BN
Factors	Utilization factor	Electricity District heating	BN
	Self-consumption	Electricity	BN
	Self-generation	Electricity	BN

To evaluate the performance of each KPI, the KPIs from a pilot is often compared against a reference neighbourhood/reference project. A reference project is a base case for comparison of the pilot areas. The reference projects represent the business-as-usual case for the pilot areas. The reference project will not use any measures in order to reach zero emissions, but follow the minimum requirements set in a business as usual (BAU) case. A representative reference project should be tailored to each pilot area, with the same floor area and number of users as the pilot area.

The target value for the KPIs for ENE and POW have not yet been decided, and the definition and KPIs will be a subject throughout FME ZEN. In a report from 2020[6], the KPIs for Energy and Power were calculated and tested on the pilot area Ydalir. The report concluded that the testing of the KPIs for ENE and POW in Ydalir shows that there is need for further work on system boundaries, definition of the reference scenario, and finding standard methodologies. As a part of this work, the scope of this report is to test the KPIs on more pilot areas which are in different development stages, to get better grounds to establish system boundaries, methodologies and target values. The aim of this report is to collect the KPIs for documentation and test the target KPIs for energy and power on the 6 pilot areas listed in Table 3.

Table 3. Description of cases in the report

	Oksenøya	**Ydalir**	**Zero Village Bergen**	**Dolvik**	**Campus Evenstad**	**Mære**
Description	New neighbourhood in Bærum with a school, kindergarten and nursing home	New neighbourhood in Elverum with 700 housing units, a school, and a kindergarten.	New neighbourhood in Bergen, 800-1000 dwellings a kindergarten and service buildings	New neighbourhood in Bergen, ca. 260 dwellings are planned	Upgrading and further development of existing university campus in Stor-Elvdal	Upgrading of existing Mære Agricultural school
Phase	Implementation phase	Some buildings in operational phase, others in early planning/implementation	Early planning phase	Early planning phase	Operational phase	Buildings in operational phase, planning of upgrading of energy systems/control strategies
ZEN ambitions	Passive house standard, reduced parking capacity, local PV energy, heat pump.	Passive house standard, local PV energy, district heating from bio CHP, reduced use of private cars.	Part of a Zero Village concept: Passive house, local PV energy production.	Part of a Zero Village concept: Passive house, local PV energy production … to be continued…	Local energy production from PV and biobased CHP. Energy storage solutions and advanced control.	Buildings with Passive House standard solutions and/or ZEB-O level. Local District Heating and PV production.

2. Energy and Power – key performance indicators

2.1 Energy (ENE)

One of the most important goal for a zero emission neighbourhood is that it should be become highly **energy efficient**, as the most environmentally friendly energy is the energy not used. Thus, reducing energy demand and energy use should always be the first priority in the transition towards reaching a **decarbonised energy system**.

A zero emission neighbourhood shall be powered by smart, **renewable energy** sources. This means that design and operation of a ZEN pilot area must be focused on using renewables which operate in synergy with the surrounding energy system. To achieve this, there will be a focus on energy storage, power/load management, digitalisation, smart grids and system optimisation.

The KPIs in the energy category refer solely to the energy flows in the operational phase, and thus exclude embodied energy. This is because embodied energy is already covered indirectly by the GHG emission category. However, the operational energy flows will be modelled and/or estimated in all project phases. During the operational phase the KPIs should be evaluated directly from measurement, as far as possible. During the planning and design phases the KPIs should be estimated, e.g. by means of simulations. The energy demand and energy use of the neighbourhood should be calculated/-measured over one year with an hourly resolution. These measurements should be presented as graphical information, such as load profiles, load duration curves and color-coded carpet plots. There are three KPIs in the energy category which can award points to the ZEN, which are all presented as annual totals. The Energy KPIs must be calculated for both the ZEN-pilot and the pilot's reference area.

ENE2.1 Energy need in buildings

ENE2.1 shows the total simulated energy need of all the buildings in a pilot area per m^2. The net energy need in buildings is an indicator which must be simulated as it shows the energy need of the building envelope when the losses in the buildings' heating system is not accounted for. The energy need is calculated according to the *building assessment boundary*, which must be harmonised between ISO 52000 and SN-NSPEK 3031 This typically includes building energy need for: heating, cooling, ventilation, domestic hot water, lighting, and plug loads. The buildings are separated according to NS 3457-3 and SN-NSPEK 3031, which covers building categories, such as apartment buildings, schools and nursing homes .The net energy need in buildings is calculated as annual totals, and is not measured in the operational phase of the neighbourhood. Local energy generation is not considered, only the *calculated energy demand* of the buildings is considered. The purpose of ENE2.1 is to reduce the energy need of buildings as much as possible, and points will be awarded based on the reduction in net energy demand in the ZEN scenario compared to the energy demand in a reference scenario.

ENE2.2 Energy carriers - Delivered (imported) energy

ENE2.2 evaluates the delivered energy on the neighbourhood assessment level for all energy carriers individually. The delivered energy should be calculated on an hourly mismatch between energy use and energy generation. As ENE2.2 refers to the annual totals for delivered energy, it can be reported in a table format. The purpose of ENE2.2 is to reduce the delivered energy, and hence reduce climate gas emissions to the area. Points will be awarded based on the reduction in delivered energy per energy carrier in the ZEN scenario compared to the delivered energy in a reference scenario.

ENE2.3 Energy carriers – Self-consumption and self-generation

The self-consumption and self-generation key performance indicators tell us about the mismatch between energy generated locally and energy used in the neighbourhood. In this report, ENE2.3 is only calculated for electricity, not for district/local heating. The interaction between energy use and generation is considered on an hourly basis, and the overall result over the year is expressed numerically in terms of the two indicators selfconsumption and self-generation.

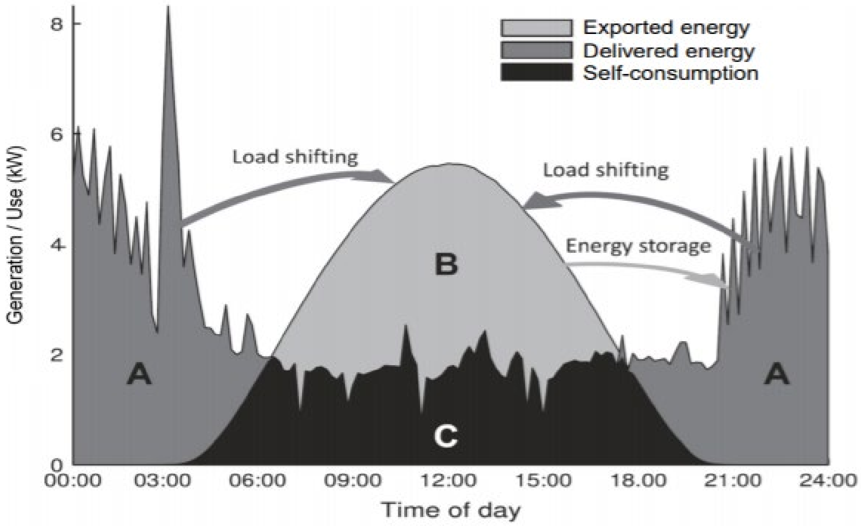


Figure 2. A schematic outline of the daily energy use (A + C), energy generation (B + C), and self-consumption (C) in a building with on-site PV. It also indicates the function of the two main options (load shifting and energy storage) for increasing self-consumption.[1]

The self-consumption KPI is the self-consumed part (area C) of locally generated energy relative to the total generation (area B+C), while the self-generation KPI is the self-consumed part (area C) relative to the total energy use (area A+C). Self-consumption is an indicator which tells us to what degree the electricity that is produced in an area is used directly in that area (and that does not need to be exported to the energy-grid). Self-generation tells us the share of the energy use in an area which is covered by self-generated energy. The purpose of ENE2.3 is to increase the degree of self-consumption and self-generation in an area. Points will be awarded based on threshold values for the self-consumption of the area in the ZEN scenario.

2.2 Power (POW)

A zero emission neighbourhood manages the energy flows within and between buildings and exchanges with the surrounding energy system in a **flexible** way, responding to signals from smart energy grids, and facilitates the transition towards a **decarbonised energy system**. Therefore, the ZEN definition shall have a strong focus on energy flows through energy grids (electricity and district heating). The KPIs in the power (POW) category refer solely to the energy flows between the neighbourhood and energy grids in the operational phase. However, the operational energy flows should be estimated in all project phases. During the operational phase, the POW-KPIs should be evaluated directly from measurement (as far as possible). During the planning and design phases the KPIs should be estimated, e.g. by means of simulations. All POW-KPIs are calculated with an hourly resolution.

There are 4 Power KPIs. The Power key performance indicators are calculated according to the *neighborhood assessment boundary* (see above), for electricity and district heating (which are energy carriers supplied by a grid). The supplementary documentation requirements for this category include yearly net load profile and the net load duration curve for electricity and district heating. The load duration curve for electricity/district heating in the neighbourhood contains all the information needed for POW3.1-POW3.3 as shown in Figure 3 and explained in the following paragraphs. In the load duration curve, the energy flow is shown in descending order of magnitude.

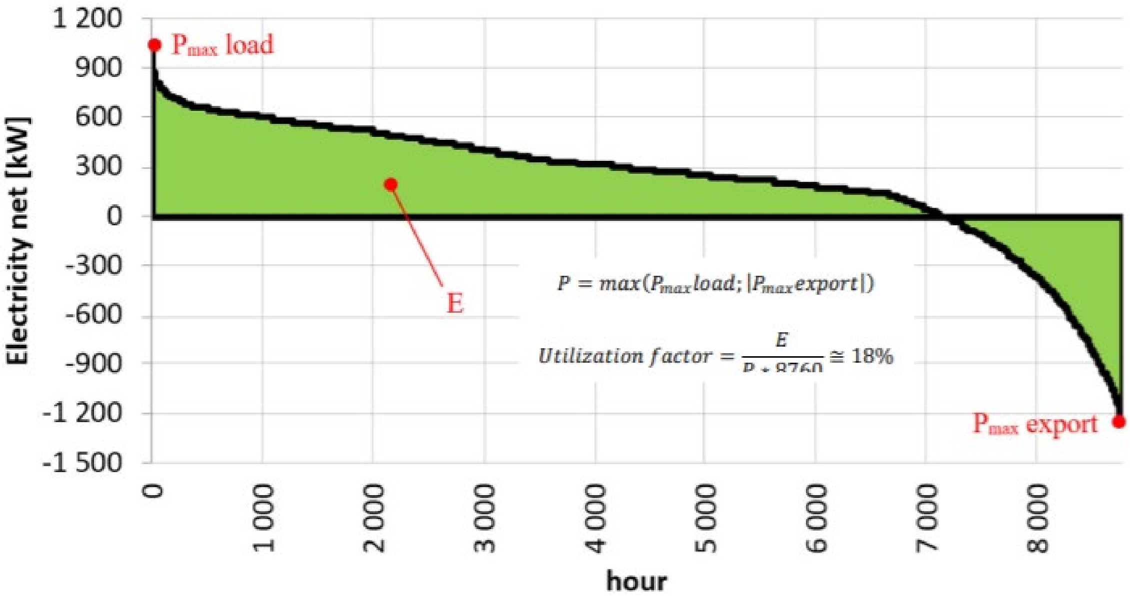


Figure 3. Graph showing the load duration curve, peak load, peak export and the utilization factor.

POW3.1 Peak load

The peak load KPI and the peak export KPI are simply the extreme values of the net duration curve. The peak load indicator refers to the maximum positive hourly import load of electricity/district heating to the neighbourhood during an operational year. Points will be awarded based on the reduction in peak loads per energy carrier (district heating and electricity) in the ZEN scenario compared to the peak loads in a reference scenario.

POW3.2 Peak export

The peak export indicator refers to the maximum net hourly export load of electricity (when the electricity production is higher than the electricity use) from the neighbourhood during an operational year. If there is no net export, then the peak export is equal to zero. Export of district heating is currently not considered in POW3.2 as export of heat is more complicated than the export of electricity, but it may become relevant in future versions of the zen definition. Points will be awarded if the peak export is smaller than the peak load in the zen scenario.

POW3.3 Utilization factor

The utilization factor shows how much of the maximum grid connection capacity is required by the neighbourhood and is calculated for electricity and district heating. The utilization factor is calculated as the sum of the annual delivered and exported energy (with a positive sign) divided by the maximum grid capacity (given by the highest point between the peak load and peak export) multiplied by 8760 hours/year (or the total number of hours with available measurements if there are missing values). A high utilization factor reflect high utilization of the grid. Points will be awarded based on threshold values for the utilization factor of the area in the ZEN scenario for electricity and district heating.

POW3.4 Load flexibility

The load flexibility indicator(s) will reflect how well the neighborhood exchanges energy with the surrounding energy system (electric and district heating) in a **flexible** way. These KPI will be developed in subsequent versions of the ZEN definition and will likely be calculated at either the neighborhood assessment level or building assessment level, with an hourly or sub-hourly resolution.

Since the coordination of energy flows with smart grids (both electric and thermal) occur at an hourly or sub-hourly level, the focus is on the optimisation of the net load profiles on typical days, distinguishing between seasons (e.g. winter, summer) and weekdays (e.g. weekday, weekend). The load flexibility indicators will reflect the difference in load profiles in a reference scenario, where there is limited control and demand response.

Key performance indicators for 'load flexibility' will be tested and eventually included in the ZEN definition, as they emerge either from in-house development during the ZEN research centre or from external sources, such as the ongoing work from the IEA EBC Annex 67 on 'energy flexible buildings' [5].

2.3 FME ZEN KPI Vizualisation Tool

FME ZEN KPI Vizualization Tool (KPI Tool) has been used to generate figures in this report. The KPI Tool is a visualization tool created in Python 3.7 (Spyder), and was developed by Kamilla Heimar Andersen (SINTEF Community), Hicham Johra (Aalborg University), Igor Sartori (SINTEF Community) and Synne K. Lien (SINTEF Community). The KPI Tool was inspired by DESTEST Comparison Tool: https://github.com/ibpsa/project1-destest. KPI Tool can also be used to illustrate timeseries analysis for energy demand, energy use, thermal energy, electricity or similar.

3. Case: Ydalir

3.1 Description of the area

Ydalir is a ZEN Pilot area which is a new neighbourhood located 1.5-2 km to the northeast of the centre of Elverum. At the end of the construction period the area will have a new school (sized 6,000 m^2 for 350 pupils), a kindergarten (sized 1700 m^2 for 100 children), and about 700 residential units. The development of Ydalir will take place over a period of 10-15 years and is scheduled to be completed between 2030-2035. The school and the kindergarten opened in august 2019[6]. The residential units will be constructed on different plots located around the school and kindergarten. These lots will be developed into residential apartment blocks and detached houses by different developers who have committed to the joint master plan that has been developed for the area. The total area of Ydalir is estimated to be 77 039 m^2. There are high ambitions for the development of Ydalir. For Ydalir to fulfil the ZEN definition, it must be energy efficient, and the emissions from the area must be reduced. The emission reductions in Ydalir is planned to be achieved through building according to the Norwegian passive house standard (NS 3700/NS3701), by using district heating, and by installing photovoltaic (PV) solar panels.

Figure 4. Illustration of Ydalir (Courtesy of Nordbolig)

3.2 Scenarios

The suggested energy KPIs and power KPIs have been estimated for Ydalir in the year 2035 for three different scenarios. It is assumed that the area will be fully operational by this time. In the report [6], two scenarios were created for Ydalir, 2035: the first scenario represented the expectations for the pilot area and was called the "ZEN scenario". In this scenario, the buildings in Ydalir are constructed as passive houses, get heating from biobased district heating and have local electricity production from PV (as according to the master plan for Ydalir). The second scenario was meant to represent the reference scenario for Ydalir. The building area, the number of users, and the transport demand were the same in both scenarios, but in this scenario it was assumed that the buildings were not passive houses, did not have any PV and used direct electricity for heating purposes. A third scenario has been added in this report, and will represent the reference scenario when district heating is used for heating purposes (instead of electric heating). A summary of the three different scenarios estimated in this report is shown in Table 4.

Table 4. Scenario descriptions for Ydalir.

	ZEN	**Reference**	
		1. Electric heating	**2. District heating**
Building standard	Passive houses	TEK-17 minimum requirements	
Energy storage solutions	None.	None.	
Local energy production	PV panels with annual generation of energy equal to 10 kWh/ m^2 GFA.	None.	
Heating	District heating	Electric boiler	District heating
Cooling	Electric cooling machine	Electric cooling machine	Electric cooling machine
Transport habits [7]	32 % walking/cycling 3 % rail 35 % bus 30 % car	32 % walking/cycling 3 % rail 6 % bus 59 % car	
Transport technologies	100 % of all buses are electric in 2035.	50 % of all buses are electric in 2035	

3.3 Methodology

While the school and kindergarten have been fully operational since 2019, the Energy and Power KPIs have been estimated (through simulations) for the three scenarios in Ydalir in this report. The methodology has previously been described in [6] in full detail, but is summed up in this chapter. The simulations for the new reference scenario with district heating have been obtained using the same methods as for the other scenarios.

Annual net energy demand and annual energy use of the buildings (kWh/m^2)

PI-SEC Scenario Calculator[8] was used to estimate the annual net energy demand and annual energy use for Ydalir in the ZEN scenario and in the reference scenarios.

Annual and hourly energy use for infrastructure

Annual energy use for street lighting in Ydalir was estimated in [6] to be 80 000 kWh/year (electricity). Street lighting is usually only turned on between sunset and sunrise. Based on the solar radiation profiles for the area, it was assumed that the annual energy use for street lighting was distributed equally between all the hours of the year between sunset and sunrise.

Hourly profile for charging of electric vehicles

Energy use for transport on the neighbourhood boundary level only includes charging of electric vehicles within the pilot area. For Ydalir, this was calculated in an additional step outside of PI-SEC based on a report by NVE [9]. A full description of the calculation of charging load profiles in Ydalir can be found in [6].

Hourly profile for electric generation

The target for annual generation of energy in Ydalir is 10-15 kWh/m^2 from local PV panels [10], resulting in a minimum annual generation of 770 360 kWh electricity in Ydalir in the ZEN-scenario. An hourly profile of solar radiation and energy generation in Ydalir was created using PVGIS[10]. Ydalir's location was plotted into the program at the following coordinates: 60.891335, 11.579968 A sample panel of 682 kWp range with 14% system loss with "Optimize slope and azimuth" was then added in PVGIS. An hourly profile for energy generation from the solar panels was created for all hours between the 1.1.2005 and 31.12.2016 based on local solar radiation profiles. The profile for 2012 was then chosen as an example profile as the maximum peak production occurred this year, and this profile also contained values for all hours of the year. The chosen hourly profile was then adjusted so that the sum of annual energy production in all hours over the year equalled 770 360 kWh.

Hourly profiles for building energy demand and energy use in buildings.
Hourly profiles for electric services and thermal (room heating and heating of tap water) energy demand for the buildings in Ydalir were created using a load profile generator, called PROFet based on load profiles from measured energy use in buildings [11][12]. The load profile generator available in 2019 separated between 11 different building categories and 2 building standards; "Regular" (average of buildings from before 2017) and "Efficient" (TEK-17 or better). The profiles generated for Ydalir in the two scenarios were then scaled to equal the annual energy demand for the buildings in PI-SEC. The reader should be aware that this can create artificially low power peaks in the scenarios.

It was assumed that all electric services have an efficiency of 1. This means that the energy use for electric services is assumed to be equal to the energy demand for electric services. Energy use for heating is equal to the thermal demand, plus the losses in the heating distribution system. The hourly profiles for energy for heating is calculated using the hourly demand profile for heating and multiplying it by weighted efficiencies for the heating system as used in PI-SEC.

3.4 Results

The energy and power KPIs calculated for each of the three scenarios in Ydalir and are presented in this chapter. Except for ENE2.1 (energy demand in buildings), all other KPIs have been calculated for Ydalir at the neighbourhood level, which includes energy use in buildings, charging of electric vehicles (within the area) and outdoor lighting.
Figure 5 shows the hourly load profiles and load duration curves for net delivered electricity in Ydalir in the 3 different scenarios. The load profile shows the hourly net energy use for each hour throughout one year of operation. The load duration curve show the same values, but sorted in descending order of magnitude.

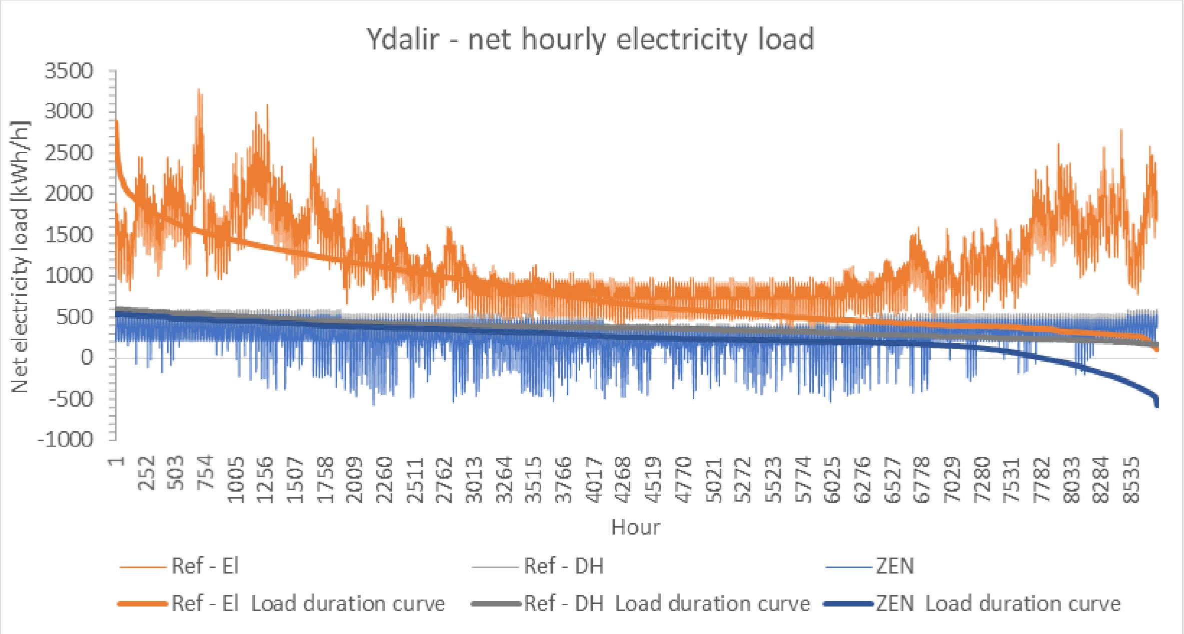


Figure 5. Hourly load profiles and load duration curves for net delivered electricity in Ydalir for the 3 scenarios.

In the reference scenario with district heating, there is little seasonal and daily variation in the net use of electricity. In this scenario, electricity is only used for electric specific purposes in the houses, charging of EVs and outdoor lighting, and there is no generation of electricity. The referensce scenario with electric heating have these same loads, but in addition, electricity is used for heating purposes in this scenario. This causes higher peaks in the electricity use, and large daily and seasonal variations linked to the outdoor temperature. The difference between the reference scenarios during the summer months is due to heating of domestic hot water. In the ZEN scenario, the electricity use in buildings is somewhat equal to that of the reference scenario with district heating, but the electricity use for charging of electric vehicles is lower in this scenario due to less use of private cars for transportation in the scenario. In addition, there is several hours with net export of electricity in the ZEN scenario (negative hourly values) due to generation of electricity from PV-panels being greater than the consumption of electricity in some hours. The export peak for electricity is larger than the import peak (or net delivered electricity peak) in the ZEN scenario. An alternative presentation of the net electricity load is the colour coded carpet plot. Figure 6 and Figure 7 show the net electricity flow in the reference scenario (with electric heating) and ZEN-scenario for Ydalir. The colour coded carpet plot show both the variation in energy use throughout the day and seasons. In Figure 6 (carpet plot for the reference scenario with electric heating) one can observe daily peaks in the morning and afternoon, as well as an increased demand for electricity during the winter months. In Figure 7 one can observe less seasonal variations (due to not using electricity for heating), and in addition export of electricity from PV panels during the middle of the day, and with high export during the summer months.

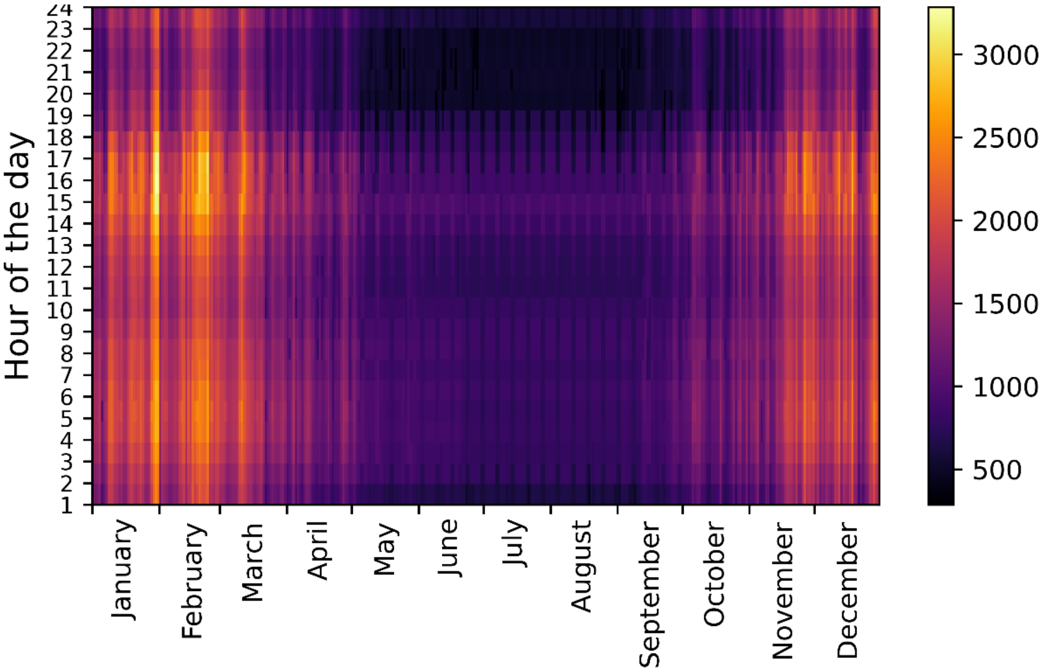


Figure 6. Carpet plot showing the net electricity import for Ydalir in the reference scenario (with electric boiler).

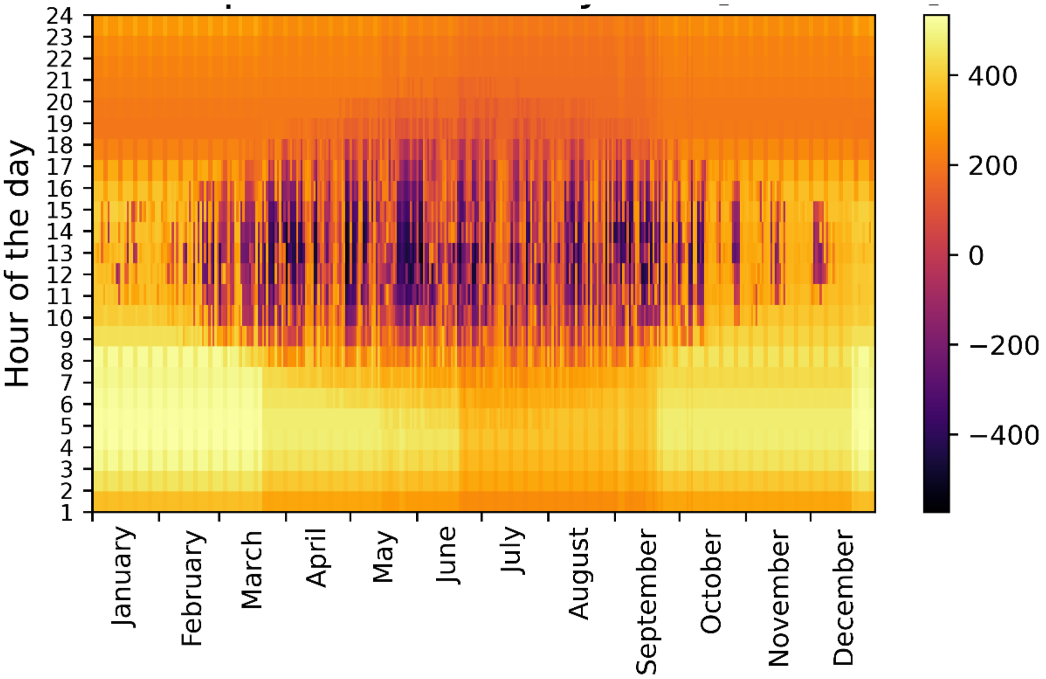


Figure 7 Carpet plot showing the net electricity import for Ydalir in the ZEN scenario.

Figure 8 shows the hourly load profiles and load duration curves for energy use from district heating over one year in Ydalir in the ZEN scenario, and in the reference scenario with district heating. The user pattern is the same in both scenarios, as they are based on the same model results from PROFet, but they are shifted to equal the annual totals calculated in the PI-SEC model. The energy demand for heating is lower in the ZEN scenario compared to the reference scenario due to more insulated buildings (passive house standard).

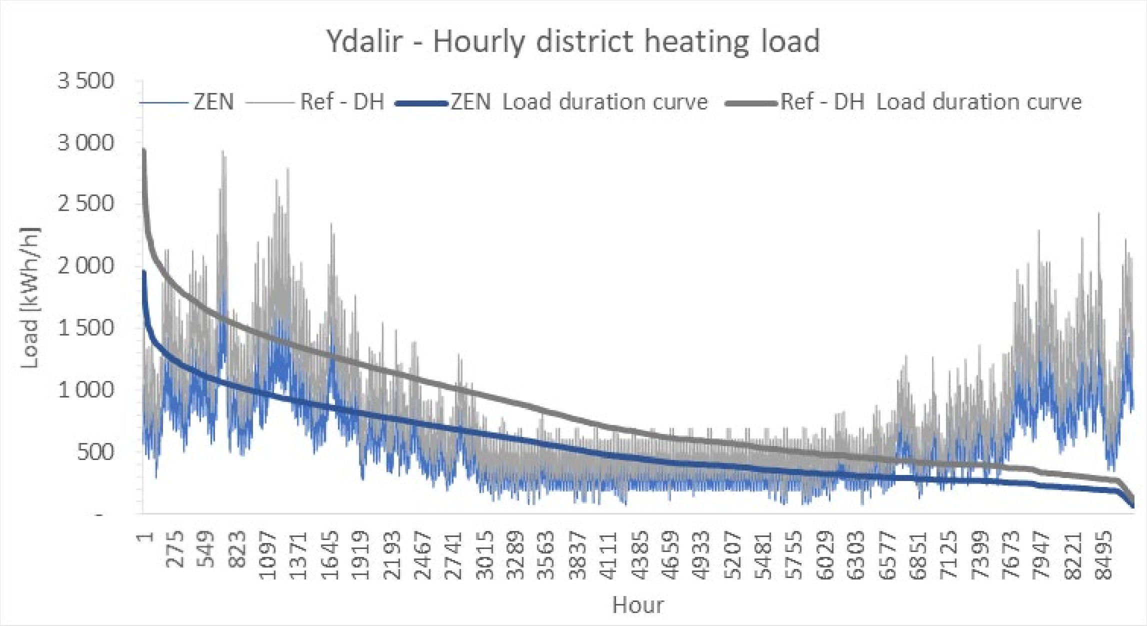


Figure 8. Hourly load profiles and load duration curves for energy use from district heating in Ydalir in the ZEN scenario and in the reference scenario with district heating.

Figure 9 shows the annual energy use (both electricity and district heating) in Ydalir in the three scenarios. The net energy use in buildings is equal to the area under the graphs in Figure 5 and Figure 8.

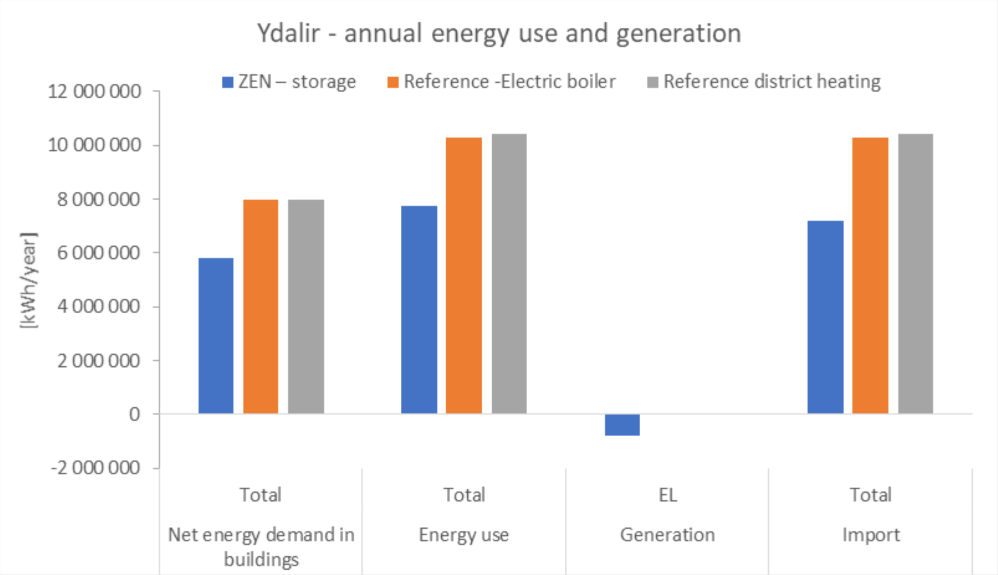


Figure 9. Annual energy use (both electricity and district heating) in Ydalir in the three scenarios.

Figure 10 shows a comparison of the peak values in the three scenarios in Ydalir for electricity (EL), district heating (DH) and combined peaks (DHpeak+ELpeak). The peaks are the extremes on the hourly load profiles.

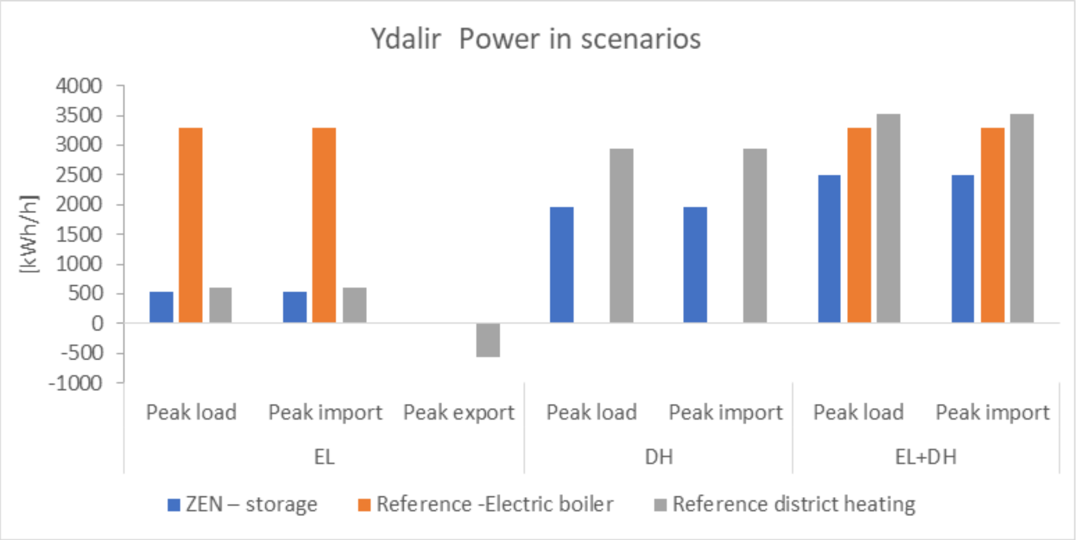


Figure 10. Comparison of the peak values in the three scenarios in Ydalir for electricity (EL), district heating (DH) and combined peaks (DHpeak+ELpeak).

Table 5 and Table 6 gives a summary of all the KPIs (annual values, peaks and factor) estimated for Ydalir in each of the three scenarios.

Table 5. Summary of all documentational KPIs and main KPIs (annual values, peaks and factor) for Ydalir in each of the three scenarios.

		ZEN	**Reference 1 - Electric boiler**	**Reference 2 -District heating**
Net energy demand in buildings [kWh/year]	Total	5 804 253	7 989 140	7 989 140
Energy use [kWh/year]	EL	2 901 929	10 301 991	3 222 779
	DH	4 868 096	0	7 214 933
	Total	7 770 025	10 301 991	10 437 712
Generation [kWh/year]	EL	-770 390	0	0
Import [kWh/year]	EL	2 317 801	10 301 991	3 222 779
	DH	4 868 096	0	7 214 933
	Total	7 185 897	10 301 991	10 437 712
Export [kWh/year]	EL	-186 261	-	-
Peak load [kWh/h]	EL	533.8	3285.1	598.6
	DH	1953	0	2934.2
	EL+DH	2486.8	3285.1	3532.8
Peak import [kWh/h]	EL	533.8	3285.1	598.6
	DH	1953	0	2934.2
	EL+DH	2486.8	3285.1	3532.8
Peak export [kWh/h]	EL	-572.9	-	-
Utilization factor	EL	50 %	37 %	61 %
	DH	28 %	0 %	28 %
Self-generation	EL	20 %	-	-
Self-consumption	EL	76 %	-	-

Table 6. Summary of all energy and power KPIs for Ydalir in each of the three scenarios per m^2.

Per m^2 (total 77039 m^2)		ZEN	Reference 1 - Electric boiler	Reference 2 - district heating
Net energy demand in buildings [kWh/m^{2}year]	Total	75	104	104
Energy use [kWh/m^{2}year]	EL	38	134	42
	DH	63	0	94
	Total	101	134	135
Generation [kWh/m^{2}year]	EL	-10	0	0
Import [kWh/m^{2}year]	EL	30	134	42
	DH	63	0	94
	Total	93	134	135
Export [kWh/m^{2}year]	EL	-2	-	-

The main KPIs for the Energy (ENE) and Power (POW) categories to be used for comparison against target values have been calculated for Ydalir as shown in Table 7. The table shows the indicator value for the ZEN scenario, and the comparison of the ZEN scenario value and the reference scenario values.

Table 7. Main KPIs calculated for the ZEN scenario in Ydalir.

KPI	**Indicator**	**ZEN scenario value**	**Reduction in the scenario value in the ZEN-scenario compared to the Reference scenarios**	
			1. Electric boiler	**2. District heating**
ENE2.1 Net energy use	/m^2	75	-27 %	-27 %
ENE2.2 Delivered energy /m^2	EL	30	-78 %	-28 %
	DH	63	-	-33 %
	Total	93	-30 %	-31 %
ENE2.3 Self-consumption and self-generation	Self generation	20 %	-	-
	Self consumption	76 %	-	-
POW 3.1 Peak load	EL	534	-84 %	-11 %
	DH	1953	-	-33 %
	EL+DH	2487	-24 %	-30 %
POW 3.2 Peak export	EL	-573	-	-
POW3.3 Utilization factor	**Indicator**	**ZEN scenario value**	**1. REF electric boiler scenario value**	**2. REF district heating scenario value**
	EL	50 %	37 %	61 %
	DH	28 %	0 %	28 %

3.5 Flexibility: Typical days

A zero emission neighbourhood manages the energy flows within and between buildings and exchanges with the surrounding energy system in a flexible way, responding to signals from smart energy grids, and facilitates the transition towards a decarbonised energy system. A flexibility indicator has not yet been developed in ZEN, but in this chapter, typical daily profiles are explored as these might be useful for establishing such an indicator. Bottle necks in the electricity and heating grids typically occur during winter workdays. Due to this, studying the typical winter workdays may help give a better understanding of the flexibility potential on winter days aimed at reducing peak loads during peak hours. Similarly, the peak export of electricity typically occur during summer workdays. Here, the electricity use on typical days for winter and summer workdays, as well as the typical district heating energy use on typical winter workdays are shown for each scenario. The typical daily profile for net delivered electricity (electricity use – electricity production) on winter workdays for each of the scenarios in Ydalir is shown in Figure 11.

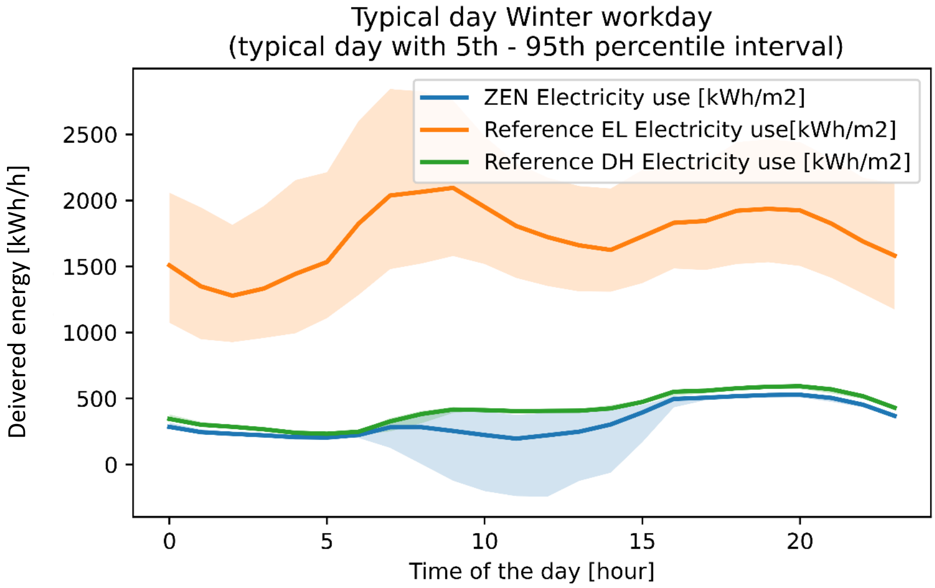


Figure 11. Typical net delivered electricity in Ydalir on winter workdays.

The lines show the average winter workday net electricity profile, while the shaded area around these lines show the variation in electricity use (on winter workdays) from the 5th-95th percentile interval. The figure shows that the typical net delivered electricity on winter workdays have a morning peak and an afternoon peak. This is due to the high share of residential buildings in Ydalir, where there are typically a morning peak caused by energy use before the residents leave for work, and the afternoon peak caused by cooking, lighting, equipment, charging of electric vehicles and heating (in the Reference EL-scenario).The Reference scenario with electric heating show a much higher electricity use during winter workdays compared to the other scenarios. This is due to the electricity being used for for heating in this scenario. There is also a larger variation in daily electricity use in this scenario due to the link between electricity used for heating and the outdoor temperature. The ZEN-scenario and reference DH-scenario have a similar typical electricity use profile on winter weekdays, but the net delivered electricity is lower in the ZEN scenario during the middle of the day due to electricity generation from PV. On some days, there is even export of electricity during winter workdays in the ZEN-scenario.

The typical daily profile for net delivered electricity (electricity use – electricity production) on summer workdays for each of the scenarios in Ydalir is shown in Figure 12.

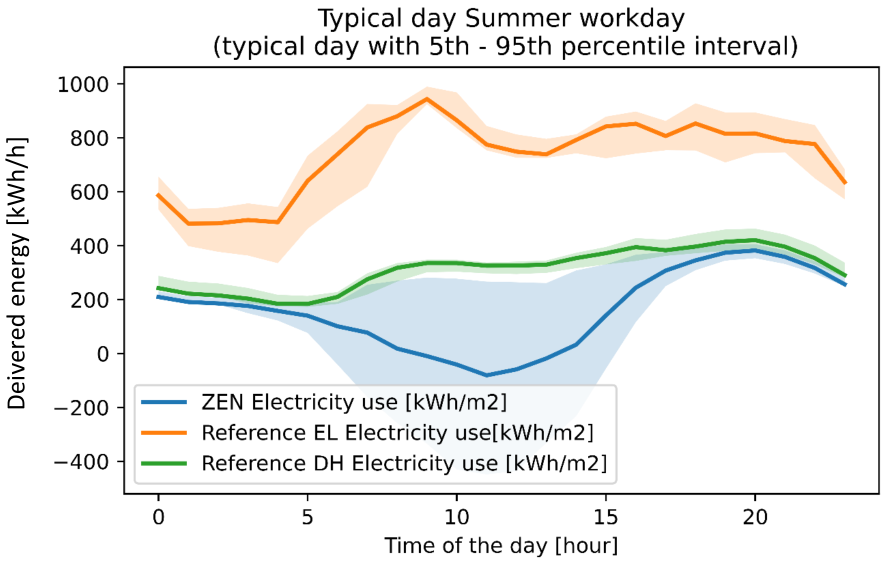


Figure 12. Typical net delivered electricity in Ydalir on summer workdays.

The reference scenario with district heating have a somewhat similar net delivered electricity profile during typical summer workdays and winter workdays. The profile is slightly lower during the summer compared to the winter, likely due to a lower demand for electricity for lighting during the summer. The reference scenario with electric heating use electricity for heating of domestic hot water and have a higher electricity use compared to the other reference scenario as expected. In the ZEN scenario, there is typically net export of electricity during the day during summer workdays (although with large variations) due to a high electricity production from PV during the summer.

The typical daily profile for district heating energy use on winter workdays for the ZEN scenario and the reference scenario with district heating is shown in Figure 13. The typical days have a morning peak due to the demand for heating (both room heating and domestic hot water heating) in the morning. The shape of the curves in the two scenarios are similar as they have been created from the same model which have been scaled against a yearly total of energy use for heating.

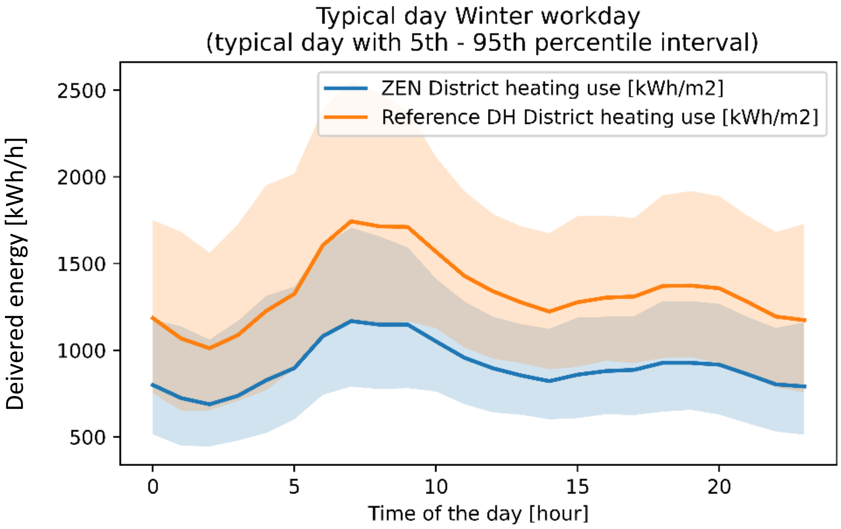


Figure 13. Typical district heating energy use in Ydalir on winter workdays

4. Case: Bærum – Fornebu, Oksenøya

4.1 Description of the area

The Fornebu pilot in FME ZEN consists of two areas; Oksenøya and Flytårnet. In this report, the energy and power KPIs for the area Oksenøya are evaluated. Oksenøya is a new construction area in Forneby, where a school, a kindergarten, a nursing home facility and a sports hall are under construction. The construction of the area started in 2020, and will be finished in 2022-2023. The area will be built near new residential areas with both multi family houses and single family houses. The ambition for Oksenøya is to develop the area as a zero emissions neighbourhood through constructing the buildings as passive houses with PV-panels mounted on the roof of the buildings. Parking for private cars will be limited, while the area will be easily accessible by bike . Heat will be supplied through the district heating network. Oksenøya will utilize load control and electricity storage solutions, and both batteries and vehicle to grid solutions are being considered.

Figure 14. Oksenøya centre with a school, nursing home and kindergarten. Source: Veidekke

4.2 Scenarios

The suggested energy KPIs and power KPIs have been estimated for Oksenøya for three different scenarios: a ZEN-scenario (as planned) and two reference scenarios (with electric heating and with district heating). In this report (written in 2020), the energy storage and load control solutions are ignored in the ZEN-scenario as the storage solution and control strategies have not yet been established. In the reference scenarios, it is assumed that the buildings are built according to the minimum requirements in TEK-17, and that there is no local energy production. Due to lack of information, it's assumed that there is the same number of parking lots with chargers in both the ZEN scenario and the reference scenarios. Table 8 gives an overview of the buildings which are being constructed in Oksenøya. Table 9 shows a summary of the assumption made in each of the scenarios. The total area of Oksenøya is estimated to be 29 250 m^2.

Table 8. Buildings in Oksenøya

Building	Year of construction	Area (heated)	Users	Employees	Net energy demand (regardless of energy supply)		Local energy production
					ZEN	**Reference**	**ZEN**
Oksenøya nursing home[13]	2023	12650	150	145	147,5 kWh/m^{2}yr	230 kWh/m^{2}yr	-16,6 kWh/m^{2}yr
Oksenøya School[14]	2022	12950	1050	123	81 kWh/m^{2}yr	110 kWh/m^{2}yr	-8,6 kWh/m^{2}yr PV
Oksenøya Kindergarten[15]	2022	3650	300	75	83,5 kWh/m^{2}yr	135 kWh/m^{2}yr	- 9,6 kWh/m^{2}yr

Table 9. Scenario descriptions for Oksenøya

	ZEN	Reference	
		1. Direct electric	**2. District heating**
Building standard	Passive houses	TEK-17 minimum requirements	
Local energy production	PV panels (see Table 8)	None.	
Heating	District heating	Electric boiler	District heating
Cooling	District cooling	Electric cooling machine	District cooling
Transport habits	127 parking lots, 50 % with electric chargers.		

4.3 Methodology

Oksenøya is currently in the construction phase, and will be operational from 2022/2023. The Energy and Power KPIs have been estimated (through simulations) for the three scenarios in Oksenøya.

Annual net energy demand and annual energy use of the buildings (kWh/m^2)

The annual net energy demand and for the buildings was calculated by the contractor, Veidekke, according to the methodology NS3031 in 2020 [13]–[15].

Hourly profiles for building energy demand and energy use in buildings.

As for Ydalir, hourly profiles for electric services and thermal (room heating and heating of tap water) energy demand for the buildings in Oksenøya were created using a load profile generator, called PROFet based on load profiles from measured energy use in buildings [11][12]. The load profile generator available in 2020, when the load profile for Oksenøya was made, separated between 11 different building categories and 2 building standards; "Regular" (average of buildings from before 2017) and "Efficient" (TEK-17 or better). The profiles generated for Oksenøya in the two scenarios were then scaled to equal the annual energy demand for the buildings estimated by the contractor. The reader should be aware that this can create artificially low power peaks.

It was assumed that all electric services have an efficiency of 1. This means that the energy use for electric services is assumed to be equal to the energy demand for electric services. Energy use for heating is equal to the thermal demand, plus the losses in the heating distribution system. The hourly profiles for energy for heating is calculated using the hourly demand profile for heating and multiplying it by weighted efficiencies for the heating system as assumed in the Veidekke reports [13]–[15].

Annual and hourly energy use for infrastructure

Energy use for infrastructure (outdoor lighting, elevators and snow melt systems etc.) in Oksenøya has not been considered in this report.

Hourly profile for electric generation

Annual energy production for Oksenøya has been simulated by Veidekke, and is estimated to become approximately 356 000 kWh/year. To convert the annual energy production to an annual hourly profile, an hourly profile of solar radiation and energy generation was created using PVGIS[10], using the same methodology as explained in the chapter 3.3. This profile was then scaled to equal the annual total of energy production in Oksenøya in the ZEN scenario.

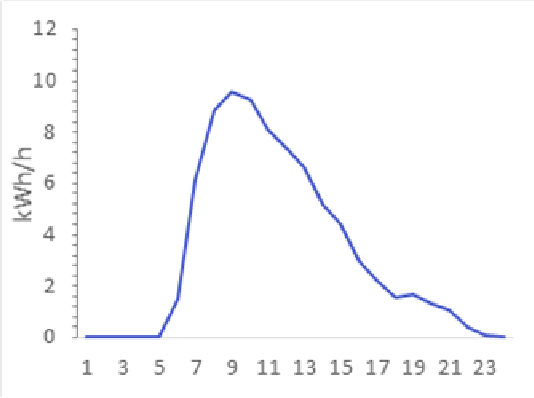
Hourly profile for charging of electric vehicles

Energy use for transport on the neighbourhood level only includes charging of electric vehicles within the pilot area. In Oksenøya, it is planned to have 63-64 parking lots with electric chargers in Oksenøya. Information about the typical number of parking lots per building, and the typical share of chargers for municipal buildings is unavailable for Bærum. It is assumed that the number of chargers for electric vehicles is the same for all scenarios. To generate a charging profile for Oksenøya, it is assumed that the typical charging pattern is as for offices in the NVE report [9]. As the area has a nursing home, it is assumed that the daily charging pattern is the same on both weekdays and weekends. The assumptions for the daily charing pattern is shown in Table 10, and the resulting charging load profile is shown in Figure 15.

Table 10. Assumptions for charging of electric vehicles in Oksenøya

Assumptions	
Share of charging at home	75 %
Share of charging at work	15 %
Share of charging at fast chargers	10 %
Number of parking lots	127
Share of lots with chargers	50 %
Distance per year for average car [km]	15000
Typical energy use per km [kWh/km]	0.2
Total energy use for work charging for 127/2 cars [kWh]	190 500
Daily energy use for work charging for 127/2 cars [kWh]	78

Figure 15. Daily charging pattern Oksenøya



4.4 Results

The energy and power KPIs calculated for each of the three scenarios in Oksenøya are presented in this chapter. Except for ENE2.1 (energy demand in buildings), all other KPIs have been calculated for Oksenøya at the neighbourhood level, which includes energy use in buildings, charging of electric vehicles (within the area) and outdoor lighting. Figure 16 shows the hourly load profiles and load duration curves for net delivered electricity in Oksenøya in the 3 different scenarios. The load profile shows the hourly net energy use for each hour throughout one year of operation. The load duration curve show the same values, but sorted in descending order of magnitude.

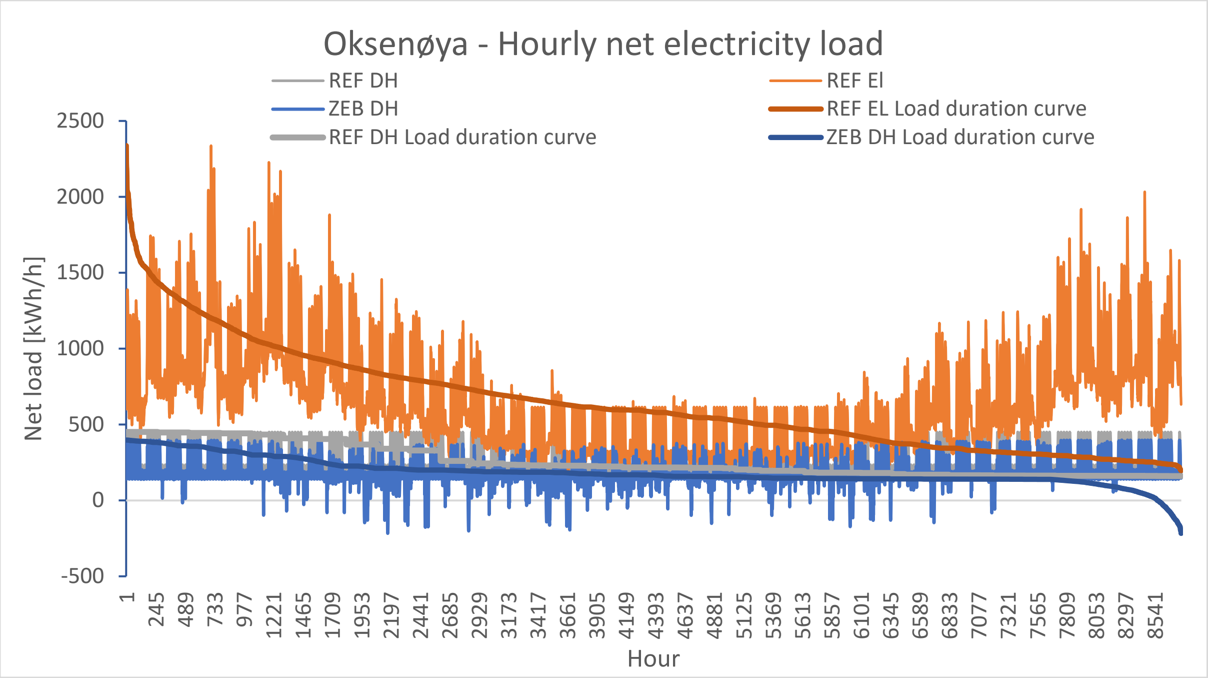


Figure 16. Hourly load profiles and load duration curves for net delivered electricity in Oksenøya for the 3 scenarios.

In the reference scenario with district heating, there is little seasonal and daily variation in the net use of electricity. In this scenario, electricity is only used for electric specific purposes in the houses, charging of EVs and outdoor lighting, and there is no generation of electricity. The reference scenario with electric heating have these same loads, but in addition, electricity is used for heating purposes in this scenario. This causes higher peaks in the electricity use, and large daily and seasonal variations linked to the outdoor temperature. The differences between the reference scenarios during the summer months is due to heating of domestic hot water. In the ZEN scenario, the electricity use in buildings is somewhat equal to that of the reference scenario with district heating, but the ZEN scenario is slightly lower due to a lower energy demand. In addition, there is several hours with net export of electricity in the ZEN scenario (negative hourly values) due to generation of electricity from PV-panels being greater than the consumption of electricity in some hours. Storage solutions and control solitions for electric loads and electricity production is being considered for Oksenøya. There is no extreme peaks in electricity use, as electricity will not be used for heating in Oksenøya (ZEN scenario). Storage and controls can be used to reduce the electiricy demand of Oksenøya in the hours when the demand is high in the Fornebu area outside Oksenøya, and to increase self-consumption of locally produced electricity. The colour coded carpet plot show both the variation in energy use throughout the day and seasons. In Figure 17 (carpet plot for the reference scenario with electric heating) one can observe daily peaks in the morning and afternoon, as well as an increased demand for electricity during the winter months. In Figure 18 one can observe less seasonal variations (due to not using electricity for heating), and in addition export of electricity from PV panels during the middle of the day, and with high export during the summer months.

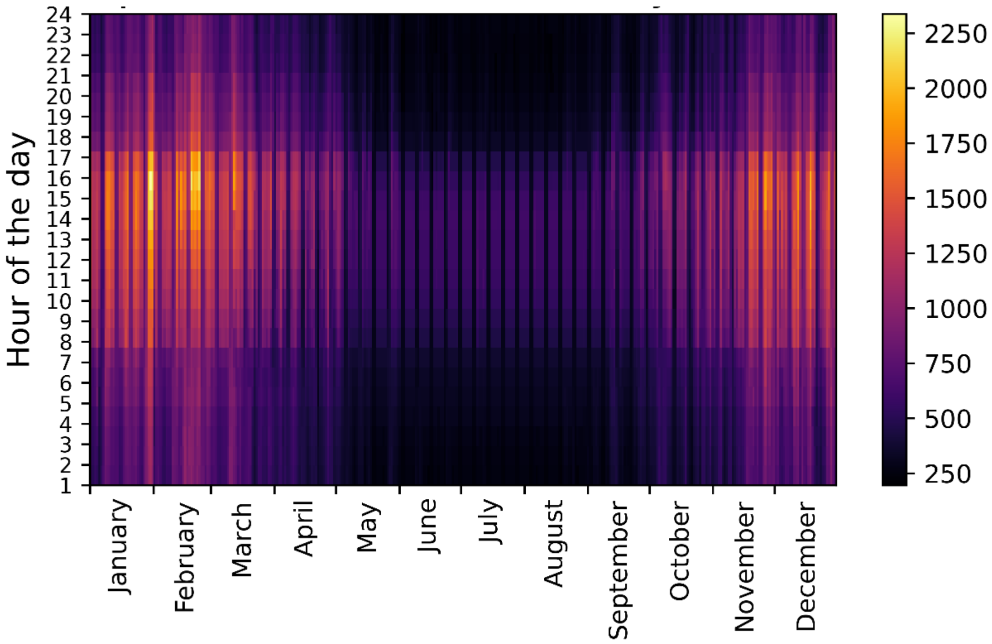


Figure 17. Carpet plot showing the net electricity import [kWh/h] for Oksenøya in the reference scenario (with electric boiler).

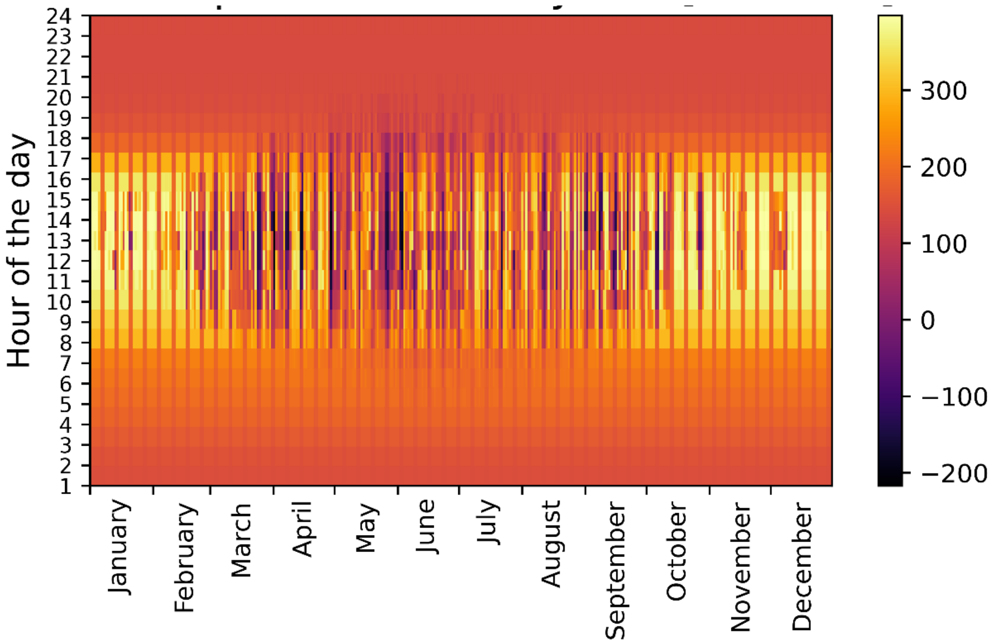


Figure 18. Carpet plot showing the net electricity import [kWh/h] for Oksenøya in the ZEN scenario.

Figure 19 shows the hourly load profiles and load duration curves for energy use from district heating over one year in Oksenøya in the ZEN scenario and in the reference scenario with district heating. The user pattern is the same in both scenarios, as they are based on the same model results from PROFet, but they are shifted to equal the annual totals calculated by Veidekke. The energy demand for heating is lower in the ZEN scenario compared to the reference scenario due to more insulated buildings (passive house standard).

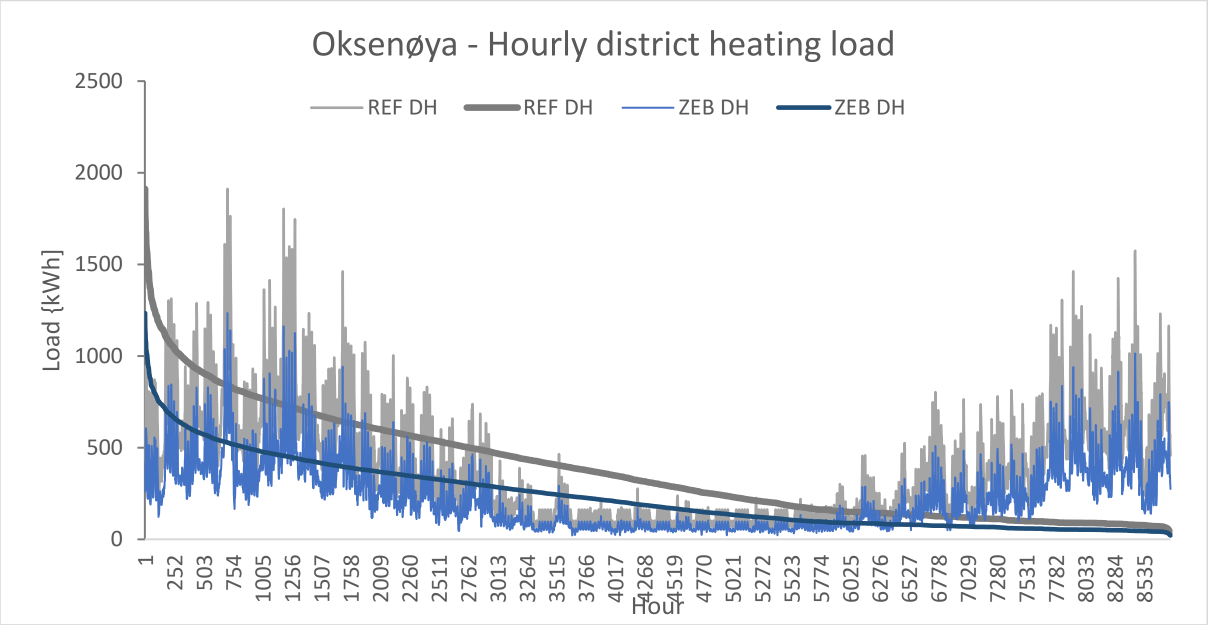


Figure 19. Hourly load profiles and load duration curves for energy use from district heating in Oksenøya in the ZEN scenario and in the reference scenario with district heating.

Figure 20 shows the annual energy use (both electricity and district heating) in Oksenøya in the three scenarios.

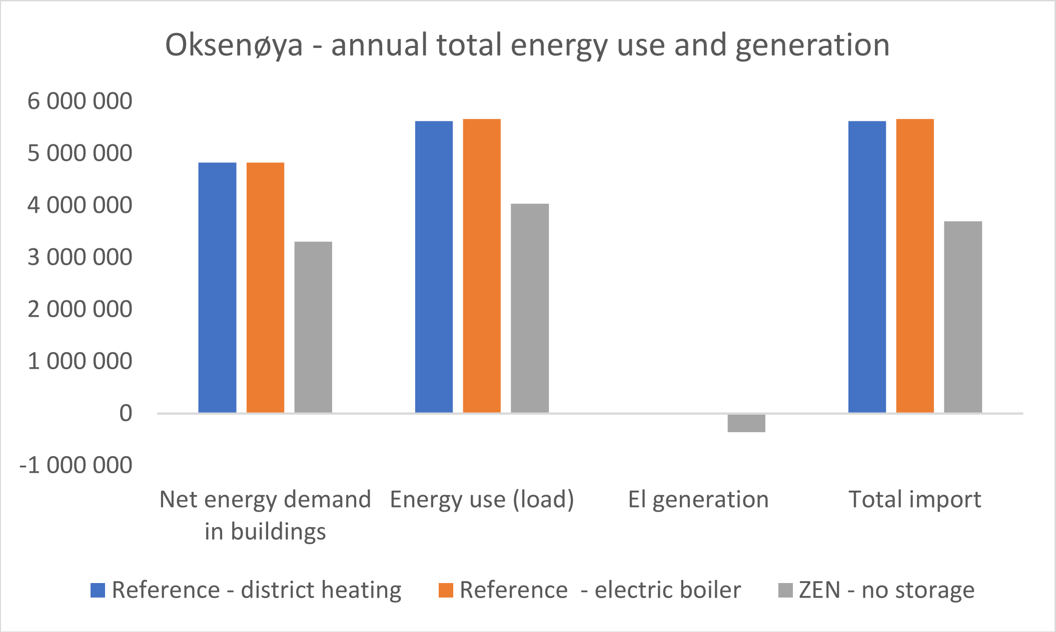


Figure 20. Annual energy use (both electricity and district heating) in Oksenøya in the three scenarios.

Figure 21 shows a comparison of the peak values in the three scenarios in Oksneøya for electricity (EL), district heating (DH) and combined peaks (DHpeak+ELpeak). The peaks are the extremes on the hourly load profiles.

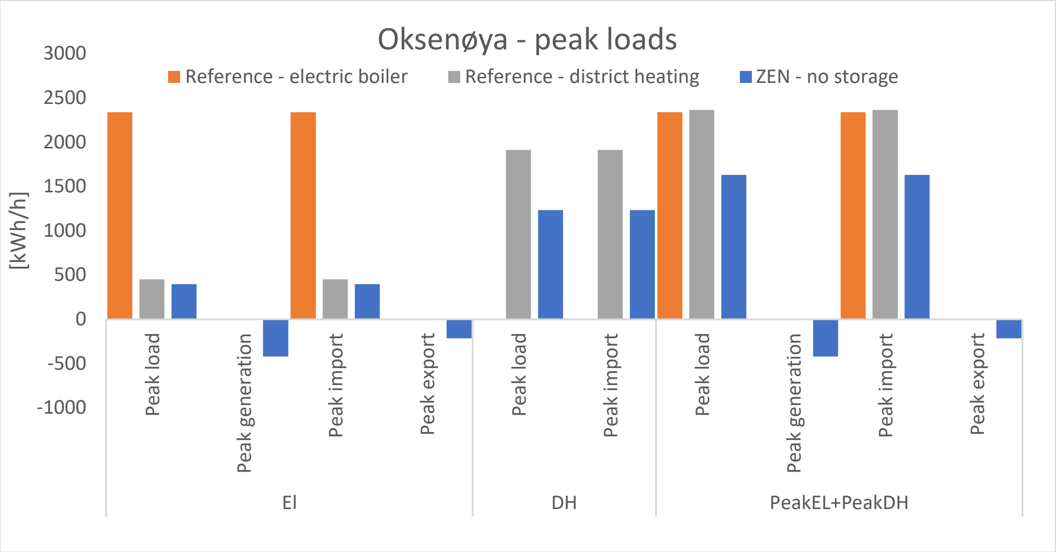


Figure 21. Comparison of the peak values in the three scenarios in Oksenøya for electricity (EL), district heating (DH) and combined peaks (DHpeak+ELpeak).

Table 11 and Table 12 give a summary of all the KPIs (annual values, peaks and factor) estimated for Oksenøya in each of the three scenarios.

Table 11 Summary of all documentational KPIs and main KPIs (annual values, peaks and factor) for Oksenøya in each of the three scenarios.

		ZEN	**Reference**	
			Reference 1 - Electric boiler	**Reference 2 -district heating**
Net energy demand in buildings [kWh/year]	Total	3 303 368	4 826 750	4 826 750
	/m^2	113	165	165
Energy use [kWh/year]	EL	1 976 393	5 660 988	3 360 499
	DH	2 057 997	0	2 263 961
	Total	4 034 391	5 660 988	5 624 461
Generation [kWh/year]	EL. PV	-356 000	0	0
	EL. CHP	-12.2	0	0
Import [kWh/year]	EL	1 636 094	5 660 988	3 360 500
	DH	2 057 998	0	2 263 962
	Total	3 694 091	5 660 988	5 624 461
Export [kWh/year]	EL	15 700	0	0
Peak load [kWh/h]	EL	397	2 337	451
	DH	1 234	0	1 912
	EL+DH	1 632	2 337	2 363
Peak import [kWh/h]	EL	398	2 337	451
	DH	1 234	0	1 912
	EL+DH	1 632	2 337	2 363
Peak export [kWh/h]	EL	-217	0	0
Utilization factor	EL	47 %	30 %	57 %
	DH	19 %	0 %	20 %
Self-generation	EL	17 %	0 %	0 %
Self-consumption	EL	96 %	0 %	0 %

Table 12. Summary of all energy and power KPIs for Oksenøya in each of the three scenarios per m^2.

Per m^2 (Total area 29250 m^2)		**ZEN**	**Reference**	
			Reference 1-Electric boiler	**Reference 2 -district heating**
Net energy demand in buildings [kWh/m^{2}year]	Total	113	165	165
Energy use [kWh/m^{2}year]	EL	68	194	115
	Bio	0	0	0
	DH	70	0	77
	Total	138	194	192
Generation [kWh/m^{2}year]	EL	-12	0	0
Import [kWh/m^{2}year]	EL	56	194	115
	Bio	0	0	0
	DH	70	0	77
	Total	126	194	192
Export [kWh/m^{2}year]	EL	1	-	-

The main KPIs for the Energy (ENE) and Power (POW) categories to be used for comparison against target values have been calculated for Oksenøya as shown in Table 13. The table shows the indicator value for the ZEN scenario, and the comparison of the ZEN scenario value and the reference scenario values. In summary, there is a plan to implement a control system and storage solution for Oksenøya. The storage and controls can be used to reduce the electiricy demand of Oksenøya in the hours when the demand is high in the Fornebu area outside Oksenøya, and to increase self-consumption of locally produced electricity. The simulations conducted for Oksenøya have been based on the simulations and work for calculating the KPIs for Ydalir, which is a similar area, as these areas are both in the construction phase with all new buildings. However, new simulations should be conducted for Oksenøya using better simulations for charging patterns for the electric vehicles and to consider the effects of control strategies and storage solutions.

Table 13. The main KPIs for the Energy (ENE) and Power (POW) categories, be used for comparison against target values have been calculated for Oksenøya.

KPI	**Indicator**	**ZEN scenario value**	**Reduction in the scenario value in the ZEN-scenario compared to the Reference scenarios**	
			1. Electric boiler	**2. District heating**
ENE2.1 Net energy use	/m^2	113	-32 %	-32 %
ENE2.2 Delivered energy /m^2	EL	56	-71 %	-51 %
	Bio	0	-	-
	DH	70	-	-9 %
	Total	126	-35 %	-34 %
ENE2.3 Self-consumption and self-generation	Self generation	17 %	-	-
	Self consumption	96 %	-	-
POW 3.1 Peak load	EL	397	-83 %	-12 %
	DH	1234	-	-35 %
	EL+DH	1632	-30 %	-31 %
POW 3.2 Peak export	EL	-217	-	-

POW3.3 Utilization factor	**Indicator**	**ZEN scenario value**	**1. REF electric boiler scenario value**	**2. REF district heating scenario value**
	EL	47 %	30 %	57 %
	DH	19 %	0 %	20 %

4.5 Flexibility: Typical days

Studying the typical hourly energy use on winter and summer workdays may give a better understanding of the flexibility potential and the potential for reducing peak loads during peak hours. In this chapter the typical electricity use on winter and summer workdays, as well as the typical district heating energy use on winter workdays are shown for each scenario in Oksenøya.

The typical daily profile for net delivered electricity (electricity use – electricity production) on winter workdays is shown in Figure 22.

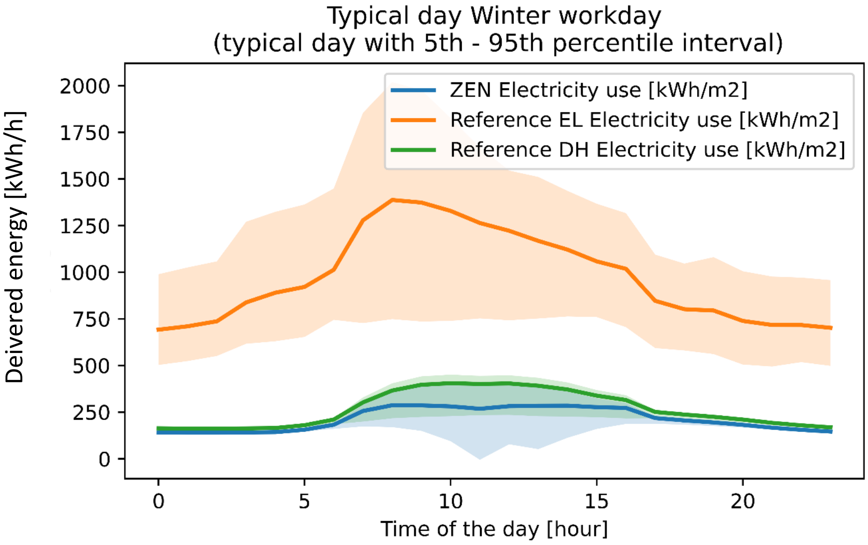


Figure 22. Typical net delivered electricity in Oksenøya on winter workdays.

The lines show the average winter workday net electricity profile, while the shaded area around these lines show the variation in electricity use (on winter workdays) from the 5th-95th percentile interval. The figure shows that the typical net delivered electricity on winter workdays have a high peak during the middle of the day. This is typical for areas with service buildings, as the activity in these buildings is highest during the day. The Reference scenario with electric heating show a much higher electricity use during winter workdays compared to the other scenarios. This is due to the electricity being used for for heating in this scenario. There is also a larger variation in daily electricity use in this scenario due to the link between electricity used for heating and the outdoor temperature. The ZEN-scenario and reference DH-scenario have a similar typical electricity use profile on winter weekdays, but the net delivered electricity is lower in the ZEN scenario during the middle of the day due to electricity generation from PV.

The typical daily profile for net delivered electricity (electricity use – electricity production) on summer workdays for each of the scenarios in Ydalir is shown in Figure 23.

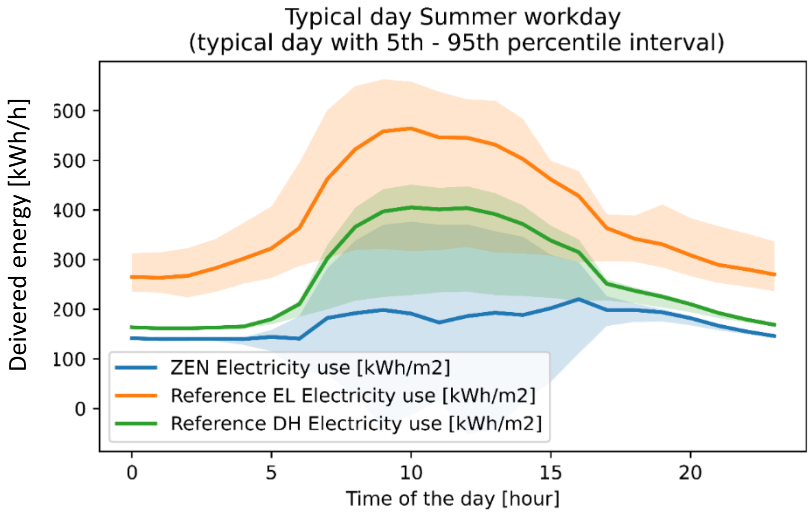


Figure 23. Typical net delivered electricity in Oksenøya on summer workdays.

The reference scenario with district heating have a somewhat similar net delivered electricity profile during typical summer workdays and winter workdays. The profile is slightly lower during the summer compared to the winter, likely due to a lower demand for electricity for lighting during the summer. The reference scenario with electric heating use electricity for heating of domestic hot water and have a higher electricity use compared to the other reference scenario as expected. In the ZEN scenario, there is a high local production of electricity from PV during the middle of the day, which outweighs the daily peak of electricity. There are a few days during the summer when net export of electricity is expected from Oksenøya.

The typical daily profile for district heating energy use on winter workdays for the ZEN scenario and the reference scenario with district heating is shown in Figure 24. The typical days have a morning peak due to the demand for heating (both room heating and domestic hot water heating) in the morning. The shape of the curves in the two scenarios are similar as they have been created from the same model which have been scaled against a yearly total of energy use for heating.

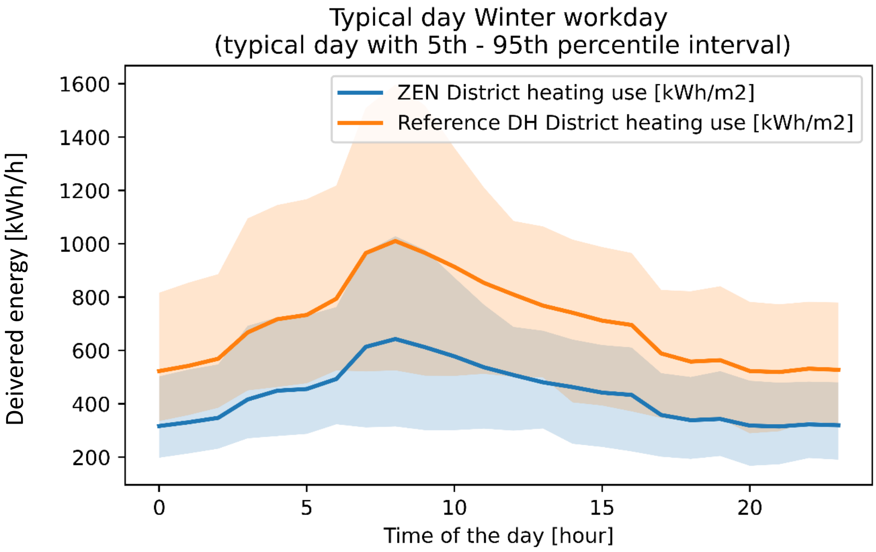


Figure 24. Typical district heating energy use in Oksenøya on winter workdays.

5. Case: Zero Village Bergen

5.1 Description of the area

Zero Village Bergen (ZVB) is a ZEN pilot located in Ådland, approximately 30 minutes from Bergen city centre. ZVB is planned to consist of residential buildings, a kindergarten and additional services. The residential buildings will consist of a mix between apartments and single/double family houses making up approximately 800-1000 dwellings of 92 000 m^2 in total.

The stakeholders involved in ZVB are ByBo (the developer and pilot owner), Multiconsult, Snøhetta, and Bergen municipality. The goal of ZVB is to develop a neighborhood with environmentally friendly housing that people want and can afford to live in, through developing a Zero Village Concept. The buildings within the area will be built according to the passive house standard and be equipped with PV panels. ZVB is currently in the planning and development phase. An illustration of the preliminary ZVB concept is shown in Figure 25 and Figure 26.

Figure 25. Conceptual photo of ZVB created by Snøhetta. [Photo: Snøhetta]

Figure 26. Preliminary planned ZVB area. The blue line indicates the South and North area for development purposes. [Photo: ByBo]

5.2 Scenarios

In this report, one ZEN-scenario and two references scenarios are investigated for ZVB. The ZEN scenario represent the area as planned, and consists of buildings built according to the passive house standard NS 3700:2013[16] with PV panels, and where heat is supplied from district heating. Energy storage solutions and control strategies are still in the planning phase and are not evaluated in this report. The reference scenarios represent ZVB built according to minimum requirements for new neighbourhoods, where the buildings satisfying the building standard "TEK17, energitiltak" (energy initiative)[17]. In the first reference scenario, heat is supplied from direct electricity. In the second reference scenario, district heating is used. There is no local energy production in the reference scenarios. A short summary of these scenarios is shown in Table 14.

Table 14. Summary of scenarios for ZVB investigated in this report.

	ZEN	**Reference**	
		1. Direct electricity	**2. District heating**
Heating	District heating	Direct electricity	District heating
Building standard	Passive house (NS 3701)	TEK-17 energy initiative	
Energy storage solutions	None.	None.	
Local energy production	Photovoltaic.	None.	
Heating	District heating	Electric boiler	District heating
Cooling	District cooling	Electric cooling machine	District cooling
Transport habits	Energy use for transport in ZVB has not been investigated in this report, as the planning of ZVB and transportation solutions is in an early planning phase. For more information regarding investigations of the transport habits and technologies in ZVB, the report "*ZEN mobility case Zero Village Bergen – development and implementation of methodology for urban housing projects*" written by Solveig Meland and Hampus Karlsson from SINTEF Community, Mobilitet og samfunnsøkonomi is currently under development and will be published in the near future.		
Transport technologies			

5.3 Methodology

Delimitation

ZVB is in the early planning phase, and so, the KPIs must be estimated by the means of simulation. The load profiles for apartments and single-family houses in ZVB have beern modeled in the IDA ICE building performance tool. The load profiles for the kindergarten and local shops' have been gathered from PROFet [18]. Load profiles for for the area infrastructure, electric vehicles, and area transportation have been neglected in this study. Table 15 gives a summary of the assumptions made about the building sizes in the ZVB area and the methodology used.

Table 15. Aggregated profiles for ZVB area.

	Single building	**Aggregated building area**	**Methodology**
Apartments (APT)	70 m^2 x 24 apt = 1680 m^2	51 apt buildings = 85 680 m^2	IDA ICE
Single family house (SFH)	162 m^2	25 SFH = 4020 m^2	IDA ICE
Kindergarten	-	1500 m^2	PROFet
Shop	-	500 m^2	PROFet
Total area size	-	**91 700 m^2**	-

IDA ICE Building Performance Simulations

The archetypes in IDA ICE for apartments and single family houses used in this study, were previously developed by Rønneseth et al. in 2019 [19], [20]. The archetypes have adopted the TABULA/-EPISCOPE[1] approach for the model with 80-60°C supply and return temperatures at the dimensioning outdoor temperature -20 °C with variant 1 for the district heating scenarios. The climate file for Bergen, Flesland 013110 (IW2) was used for the simulations [21].

Apartments

The floor area of one apartment block is 1672 m^2 and consists of 24 apartments divided into four floors. Each apartment is approximately 70 m^2. Other input data such as ventilation, domestic hot water (DHW), heating/cooling setpoints, internal gains such as occupants, equipment, and lights can be found here: [19], [20]. The losses for the heating to zones are set to 10 %. The supply air duct losses are set to 2,7 $w/m^{2,}$ and the DHW loss is set to 2 W/m^2. The total area of the solar panels is set to 5 760 m^2.

Figure 27 shows a snip of the apartments developed in IDA ICE.

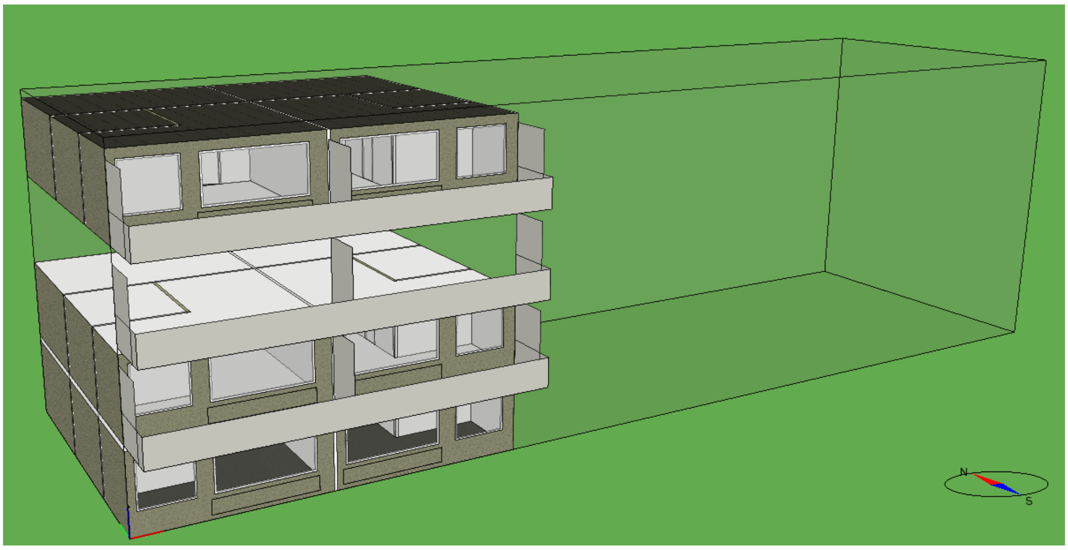


Figure 27. Apartments developed in IDA ICE (snip from IDA ICE).

There are three zones in each apartment: one bedroom, one day room, and one bathroom. Figure 28 shows two adjacent apartments (apt 1 and apt 2).

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[1] More information about the TABULA/EPISCOPE project can be found here: https://episcope.eu/building-typology/country/no/.

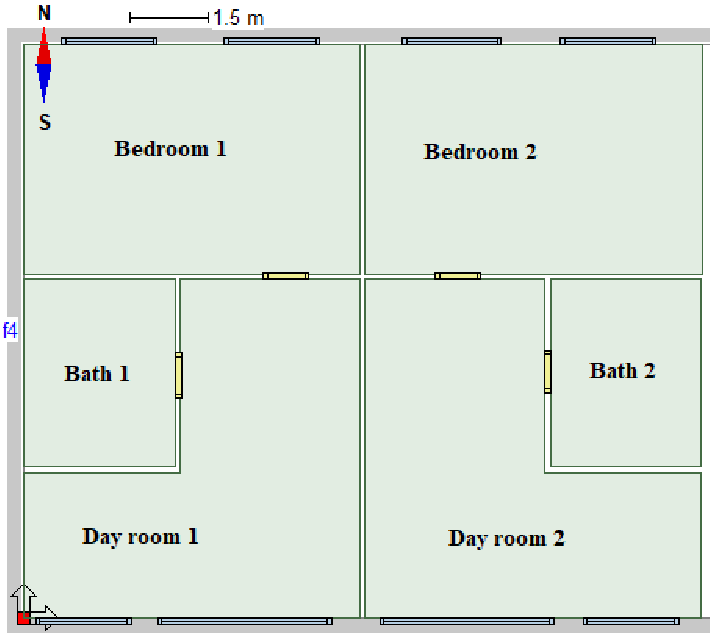

Figure 28. Floor plan for apartments in IDA ICE (snip from IDA ICE). One apartment consists of one bathroom, one living room, and one bedroom.

Single-family house

The total floor area of the single-family house is 162.3 m^2 and consists of two zones, one per floor.

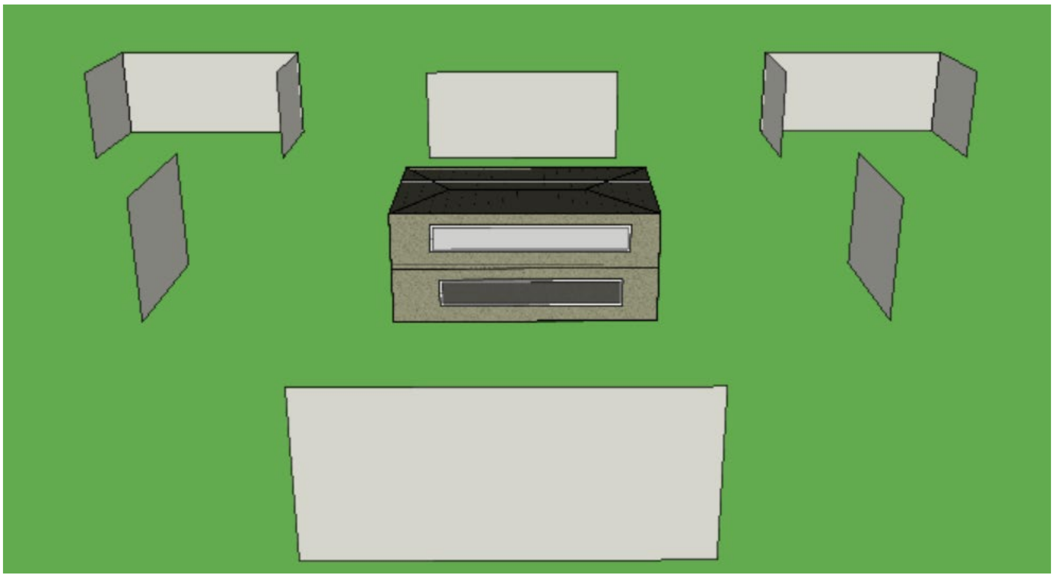

Figure 29. Snip from the single-family houses in IDA ICE.

Zones in SFH are treated as a single zone for both floors, and floor drawings are therefore not included. Other input data such as ventilation, domestic hot water (DHW), heating/cooling setpoints, internal gains such as occupants, equipment, and lights can be found here: [19], [20]. The losses for the heating to zones are set to 10 %. The supply air duct losses are set to 2,7 w/m^{2,} and the DHW loss is set to 2 W/m^2. The total area of the solar panels is set to 1680 m^2.

PROFet

PROFet was used to generate load profiles for a kindergarten with an area of 1500 m^2 and a shop with the area 500 m^2. The buildings were are assumed to be "efficient" in all scenarios. The climate profile for Bergen[21] was used for the simulations. In all scenarios, the heating systems were assumed to have an efficiency of 1. More information about the PROFet load profile calculator can be found here: [18] and in Section 4.3.

5.4 Results

The energy and power KPIs calculated for each of the three scenarios in ZVB and are presented in this chapter.

Annual energy demand and energy production

Table 16 gives an overview over the total net energy demand and local energy production of the buildings which are planned in ZVB in each of the scenarios. The energy demand of the kindergarten and shop is assumed to be the same in all of the scenarios due to the availability of data in PROFet. This has little effect on the results.

Table 16. Overview of the buildings which are planned erected at ZVB.

Building	**Year of construction**	**Area m^2 (heated)**	**Net energy demand (regardless of energy supply) kWh**			**Local energy production kWh**
			ZEN	**Ref. 1* (EL)**	**Ref. 2* (DH)**	**ZEN**
Apartments	Planning phase	85 690	6 752 521	7 090 296	7 432 554	1 844 425
Single family houses	Planning phase	4 020	288 062	334 186	321 523	69 001
Kindergarten	Planning phase	1 500	157 690	157 690	157 690	-
Shop	Planning phase	500	20 2408	20 2408	20 2408	-
Sum	-	**91 700**	**7 166 434**	**7 776 956**	**7 873 092**	**1 913 427**

* The net energy demand (regardless of energy supply) is expected to achieve the same results for Ref. 1 and Ref. 2. However, due to the numerical modelling in the IDA ICE software, the results for Ref. 1 and Ref. 2 will achieve to some extent minor differences in the net energy demand. This is due to the energy carrier for the heating systems differences as the Ref. 1 has 100 % electricity and Ref. 2 uses district heating for the heating system and an electic boiler to supply electricity for plug loads, lights and equipment.

Hourly net electricity load (yearly) and load duration

Figure 30 shows the hourly net electricity load and load duration curves for the reference scenarios and the ZEN scenario for one year (8760 hours). As one can observe in the figure, the reference scenario with the electric boiler (REF1) is the scenario with the highest electricity peak and total electricity use. The reference scenario with district heating (REF2) shows a is distinctively lower peak and total electricity use throughout the year, due to not using electricity for heating. In the ZEN scenario, district heating is being used to cover the heating demand, and PV panels are used to generate local electricity which can be exported during surplus hours. In the ZEN scenario, electricity is being exported during several hours throughout the year.

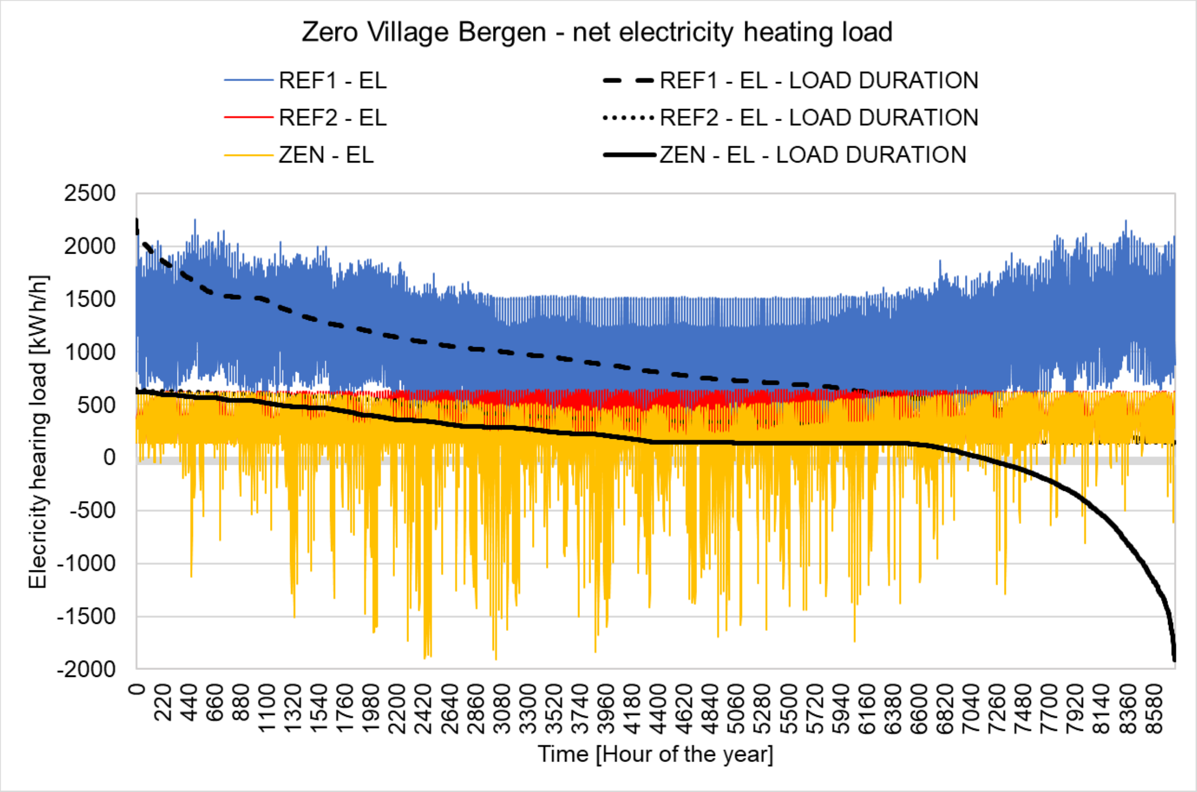

Figure 30. Hourly net electricity load (yearly) and load duration for references 1 and 2, and the ZEN scenario for the ZVB area.

An alternative presentation of the net electricity load is the colour coded carpet plot. The colour coded carpet plot show both the variation in energy use throughout the day and seasons. Figure 31 shows the carpet plot for net delivered electricity for reference 1 – electric boiler. The results from the carpet plot for REF1 show that the peak energy use occurs in the morning around 06-08 and the afternoon around 16-18, as well as an increased demand for electricity during the winter months (due to increased heating demand). The shift in energy use in March and October is due to the summer/wintertime changes.

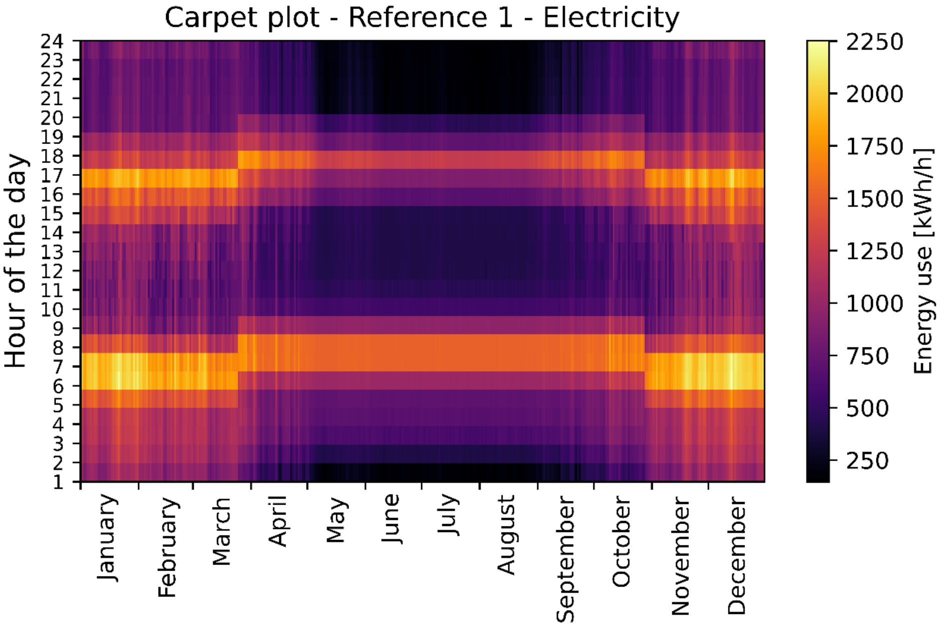

Figure 31. Carpet plot showing the net electricity import [kWh/h] for ZVB in the reference scenario (with electric boiler).

Figure 32 shows the carpet plot from the ZEN scenario PV production. The results show that the import of energy from the grid occurs mainly from 17 to 07. The energy export to the grid occurs mainly from 07 to 17 in the spring, summer, and autumn periods (April-September). However, some export of electricity can be seen in the winter period (October-March).

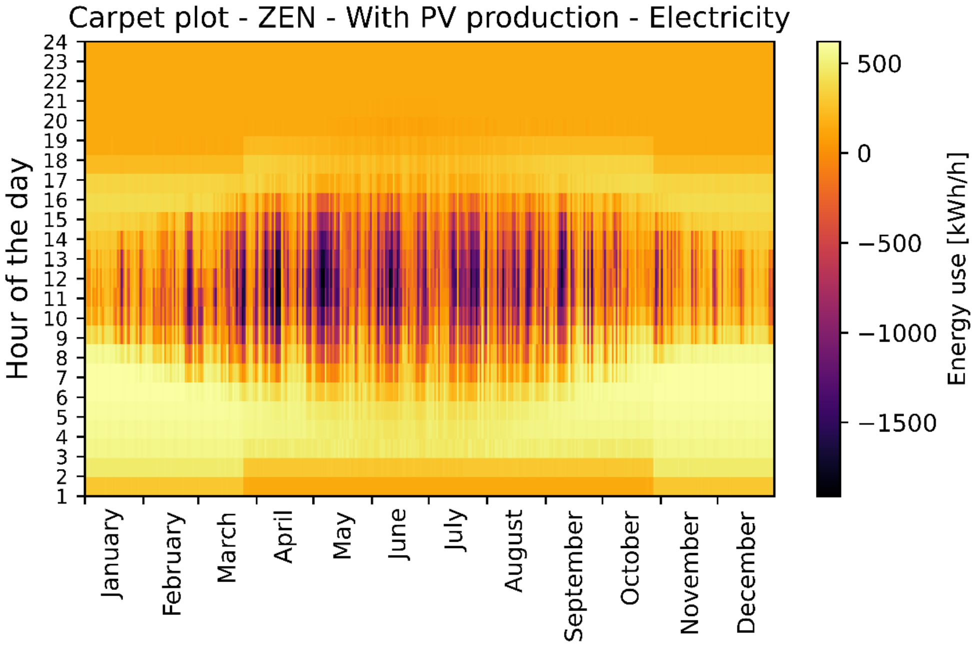

Figure 32. Carpet plot showing the net electricity import [kWh/h] for ZVB in the ZEN scenario.

Figure 33 shows the hourly net district heating load and load duration curves for the reference scenario with district heating (REF2) and the ZEN scenario for ZVB. As one can observe in the figure, the district heating energy use is higher in the reference scenario compared to the ZEN scenario. This is due to more efficient buildings with a lower heating demand in the ZEN scenario. The efficiency of the buildings reduces both the total energy use for heating aswell as the peak load.

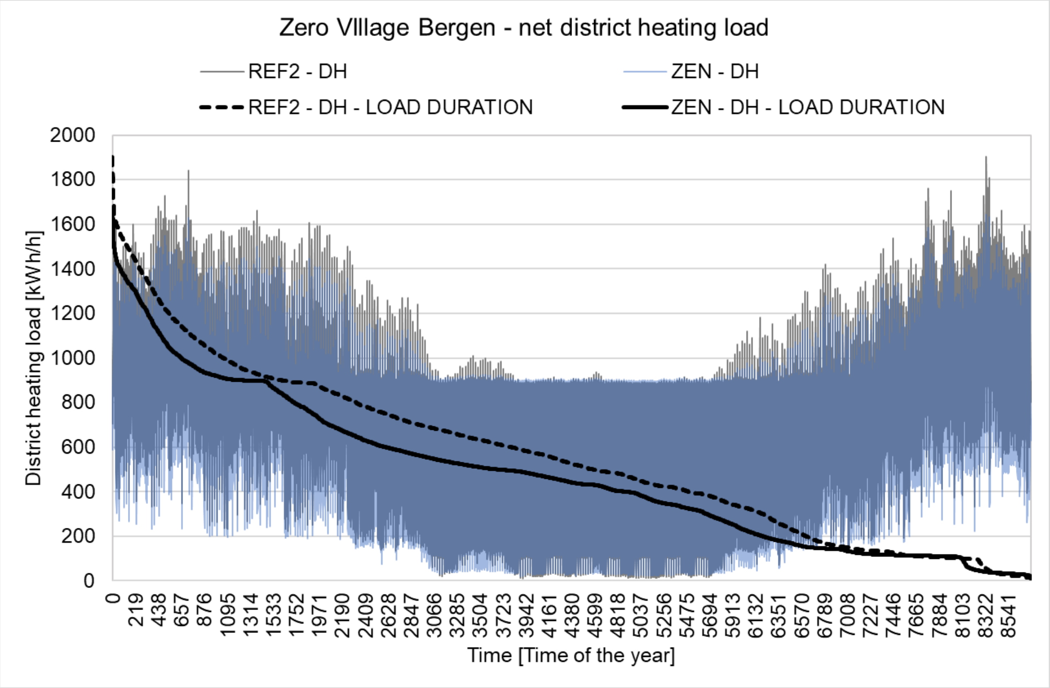

Figure 33. Hourly net district heating load (yearly) and load duration curves for references 1 and 2, and the ZEN scenario for the ZVB area.

Annual energy use (both electricity and district heating)

Figure 34 gives an overview of the the annual energy use (both electricity and district heating) for references 1 and 2 and the ZEN scenario for the ZVB area. The REF2 is the scenario with the highest energy use in total, both for the net energy demand and energy use. The ZEN scenario has the lowest energy use due to the assumption of more efficient buildings with lower heating demand. The ZEN scenario is the only scenario with local energy production (generation).

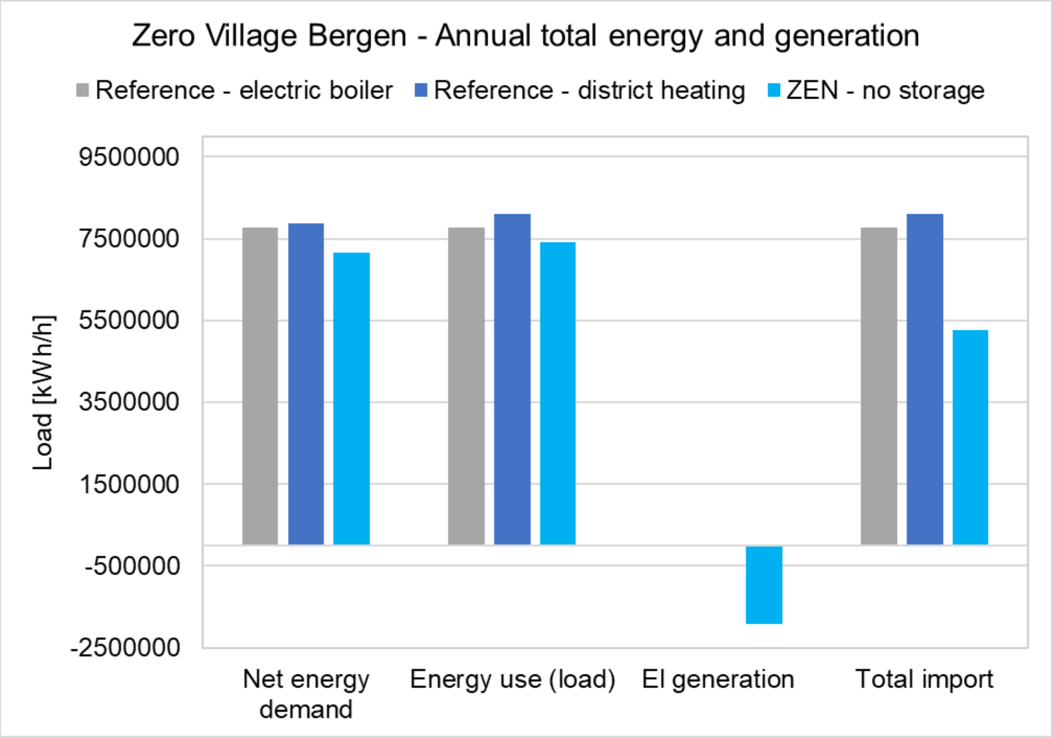

Figure 34. Annual total energy and generation for all scenarios for the ZVB area.

Peak values all scenarios

Figure 35 gives an overview of the peak loads for all scenarios for the ZVB area. As one can observe in the figure below, the highest peak load for electricity occurs in the reference scenario with electric heating (REF1).

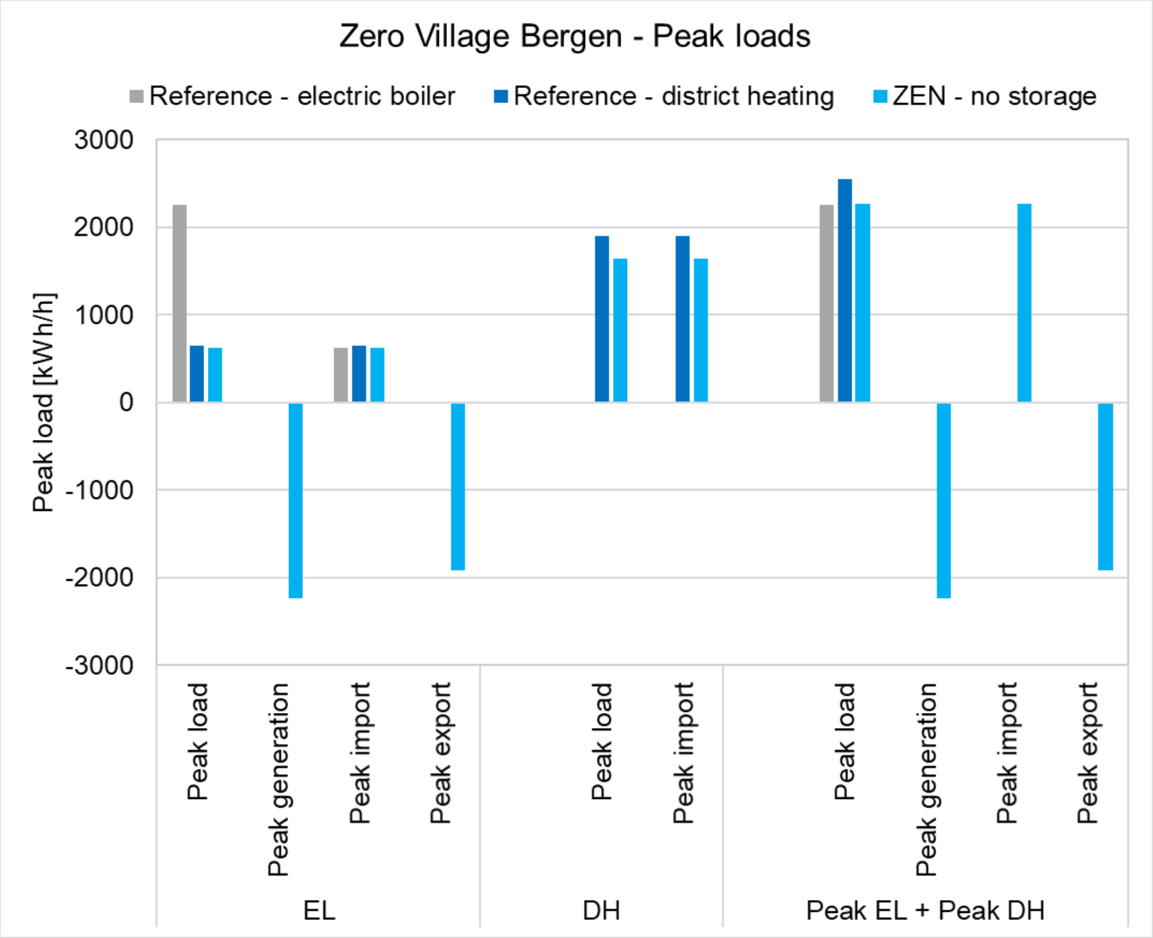

Figure 35. Peak loads for all scenarios for the ZVB area.

Summary

Table 17 and Table 18 gives a summary of all the KPIs (annual values, peaks and factor) estimated for ZVB in each of the three scenarios.

Table 17. Summary of the KPI scenarios analysis for Zero Village Bergen.

		ZEN	Reference	
			Reference 1 - Electric boiler	Reference 2 - district heating
Net energy demand in buildings [kWh/year]	Total	7 166 434	7 776 956	7 873 092
	/m^2	78	85	86
Energy use [kWh/year]	EL	4 187 066	7 762 481	4 879 824
	DH	3 225 812	-	3 213 240
	Total	7 412 878	7 762 481	8 093 064
Generation [kWh/year]	EL	-1 913 427	-	-
Import [kWh/year]	EL	2 047 174	7 762 481	4 879 824
	DH	3 225 812	0	3 213 240
	Total	5 272 896	7 762 481	8 093 064
Export [kWh/year]	EL	-821 614	-	-

		ZEN	**Reference**	
			Reference 1 - Electric boiler	**Reference 2 - district heating**
Peak load [kWh/h]	EL	629	2252	644
	DH	1641	-	1903
	EL+DH	2270	2252	2547
Peak import [kWh/h]	EL	629	2252	644
	DH	1641	-	1903
	EL+DH	2270	2252	2547
Peak export [kWh/h]	EL	-1 909	-	-
Utilization factor [%]	EL	37 %	40 %	57 %
	DH	30 %	-	30 %
Self-generation [%]	EL	46 %	-	-
Self-consumption [kWh/h / %]	EL	51 %	-	-

Table 18. Summary of all energy and power KPIs for ZVB in each of the three scenarios per m^2.

Per m^2	**91700**	**ZEN**	**Reference**	
			Reference 1 - Electric boiler	**Reference 2 - district heating**
Net energy demand in buildings [kWh/m^{2}year]	Total	78	85	86
Energy use [kWh/m^{2}year]	EL	46	85	53
	DH	35	0	35
	Total	81	85	88
Generation [kWh/m^{2}year]	EL	-21	-	-
Import [kWh/m^{2}year]	EL	22	85	53
	DH	35	0	35
	Total	58	85	88
Export [kWh/m^{2}year]	EL	-9	-	-

The main KPIs for the Energy (ENE) and Power (POW) categories to be used for comparison against target values have been calculated for ZVB as shown in Table 19 The table shows the indicator value for the ZEN scenario, and the comparison of the ZEN scenario value and the reference scenario values.

Table 19. Final results of the KPI analysis for ZVB.

KPI	**Indicator**	**ZEN**	**Reduction in the scenario value in the ZEN-scenario compared to the Reference scenarios**	
			1. Electric boiler	**2. District heating**
ENE2.1 Net energy use	/m^2	78	-8 %	-9 %
ENE2.2 Delivered energy /m^2	EL	22	-74 %	-58 %
	DH	35	-	0 %
	Total	58	-32 %	-35 %
ENE2.3 Self-consumption and self-generation	Self generation	46 %	-	-
	Self consumption	51 %	-	-
POW 3.1 Peak load	EL	629	-72 %	-2 %
	DH	1641	-	-14 %
	EL+DH	2270	1 %	-11 %
POW 3.2 Peak export	EL	-1909	-	-
POW3.3 Utilization factor	**Indicator**	**ZEN scenario value**	**1. REF electric boiler scenario value**	**2. REF district heating scenario value**
	EL	37 %	40 %	57 %
	DH	30 %	-	30 %

5.5 Flexibility: Typical days

In this chapter, the typical days for winter workdays for electricity and district heating are shown for each scenario. Bottle necks in the electricity and heating grids typically occur during winter workdays. Due to this, studying the typical winter workdays may help give a better understanding of the flexibility potential on winter days aimed at reducing peak loads during peak hours. The typical days are calculated as the average winter workday from November – February with the respective weather file.

Figure 36 presents the typical days for net delivered electricity in ZVB on winter workdays 5th and 95th percentile. This means that the figure below shows 90 % of the data points; 90 % below and above the median solid line, which are presented with a shaded color. Reference 1 uses direct electricity for heating. This scenario has a clear morning and evening peak for net delivered electricity. This is due to the occupant's behavior and night setback on ventilation and heating. It is also clearly demonstrated that reference 2 and the ZEN scenario have a lower energy use, as electricity is not used for heating in these scenarios. The ZEN scenario has a clear valley from 09 until 15. This is mainly due to solar energy production. A net export of electricity is expected during the middle of the day in ZVB, with large daily variations. However, it also should be mentioned that this is an average profile over the selected winter month. The results may vary depending on the solar radiation.

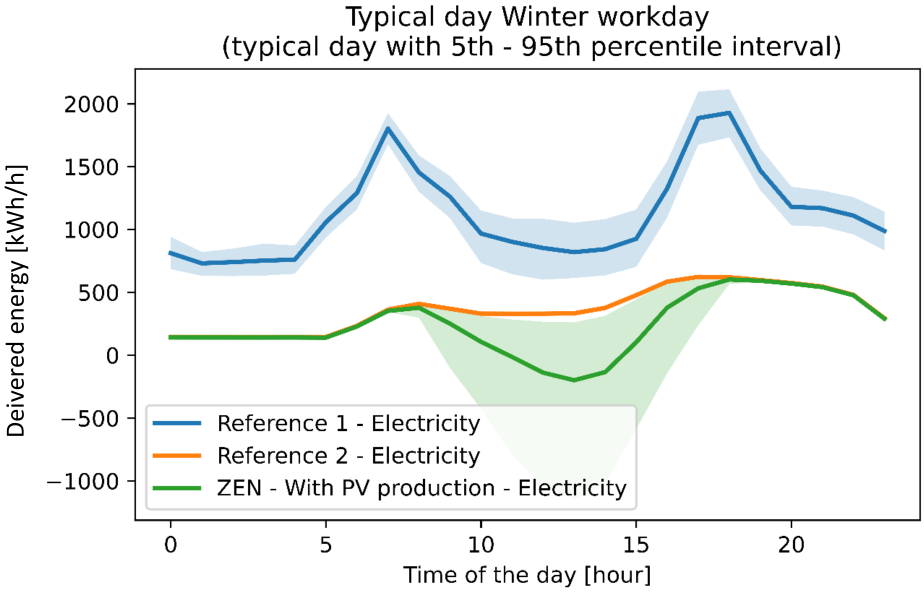

Figure 36. Typical net delivered electricity in ZVB on winter workdays.

The net delivered electricity on summer workdays in ZVB is shown in Figure 37. The reference scenario with district heating have a somewhat similar net delivered electricity profile during typical summer workdays and winter workdays. The reference scenario with electric heating use electricity for heating of domestic hot water and have a higher electricity use compared to the other reference scenario as expected. In the ZEN scenario, there is typically net export of electricity during the day during summer workdays (although with large variations) due to a high electricity production from PV during the summer.

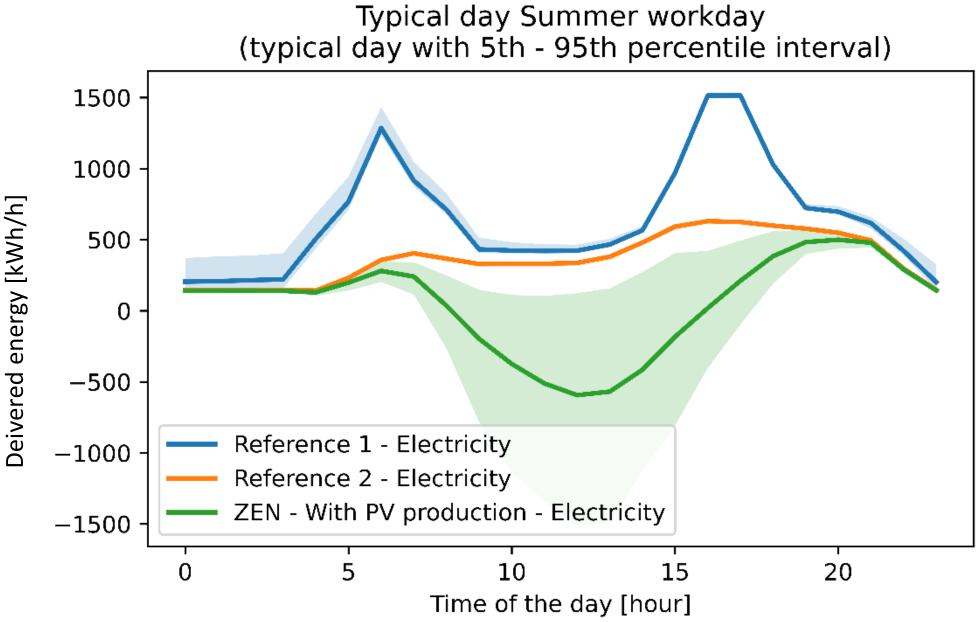

Figure 37. Typical net delivered electricity in ZVB summer workdays.

The typical daily profile for district heating energy use on winter workdays for the ZEN scenario and the reference scenario with district heating is shown in Figure 38. The typical days have a morning peak due to the demand for heating (both room heating and domestic hot water heating) in the morning. The daily variations are caused by variations in the outdoor temperature.

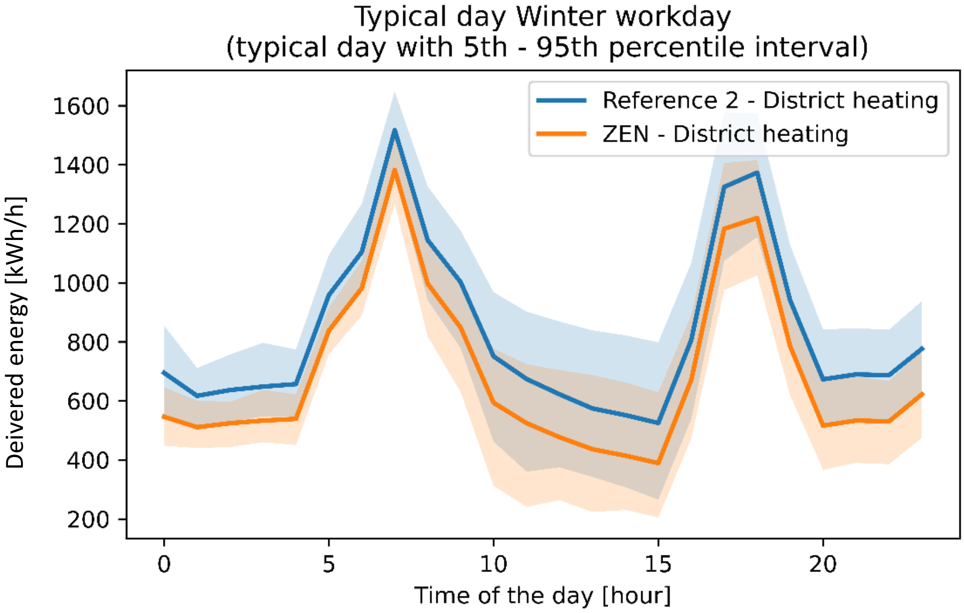

Figure 38 .Typical district heating energy use in ZVB on winter workdays.

6. Case: Dolvik

6.1 Description of the area

Dolvik is a plot located approximately 10 km south of Bergen where the developer (ByBo) plans to construct a car free residential area with apartments and single family houses. Dolvik is not a ZEN pilot, but it's been selected for this case study as the area will be developed following the principles for ZVB. Dolvik is located 700 meters from the nearest school and less than 400 m to Dolvik public transport terminal, with very good public transport coverage both towards Flesland, Bybanen and Bergen city center. Figure 39 and Figure 40 show the preliminary conceptual area development of Dolvik. The area is currently in the early planning phase.

Figure 39. Preliminary conceptual picture of Dolvik created by Snøhetta. [Photo: Snøhetta]

Figure 40. Preliminary suggestion for the Dolvik area. [Photo: ByBo]

6.2 KPI Scenarios

In this report, one ZEN-scenario and two references scenarios are investigated for Dolvik. The ZEN scenario represent the area as planned, and consists of buildings built according to the passive house standard NS 3700:2013[16] with PV panels, and where heat is supplied from district heating. Energy storage solutions and control strategies are still in the planning phase and are not evaluated in this report. The reference scenarios represent Dolvik built according to minimum requirements for new neighbourhoods, where the buildings satisfying the building standard "TEK17, "energitiltak" (energy initiative)[17]. In the first reference scenario, heat is supplied from direct electricity. In the second reference scenario, district heating is used. There is no local energy production in the reference scenarios. A short summary of these scenarios is shown in Table 20.

Table 20. Summary of scenarios for Dolvik investigated in this report.

	ZEN	**Reference**	
		1. Direct electricity	**2. District heating**
Heating	District heating	Direct electricity	District heating
Building standard	Passive house (NS 3701)	TEK-17 energy initiative	
Energy storage solutions	None.	None.	
Local energy production	Photovoltaic.	None.	
Heating	District heating	Electric boiler	District heating
Cooling	District cooling	Electric cooling machine	District cooling
Transport habits	This was not investigated in this report.		
Transport technologies			

6.3 Methodology

Dolvik is in the early planning phase, and so, the KPIs must be estimated by the means of simulation. The load profiles for apartments and single-family houses in Dolvik have beern modeled in the IDA ICE building performance tool. See Chapter 5 for details about the models. The load profiles for the kindergarten and local shops' have been gathered from PROFet [18]. Load profiles for for the area infrastructure, electric vehicles, and area transportation have been neglected in this study. Table 21 gives a summary of the assumptions made about the building sizes in the Dolvik area.

Table 21. Aggregated profiles for the Dolvik area.

	Single building	**Aggregated building area**	**Methodology**
Apartments (APT)	70 m^2 x 24 apt = 1680 m^2	7 * 24 units = 168 apt. 1.680 m^2 * 7 apt buildings = **11.760 m^2**	IDA ICE
Single family house (SFH)	162 m^2	90 units a 162 m^2 = **14.580 m^2**	IDA ICE
Total area size	**26.340 m^2**		

6.4 Results

The energy and power KPIs calculated for each of the three scenarios in Dolvik are presented in this chapter.

Annual energy demand and energy production

Table 22 gives an overview of the total energy production and the total net energy demand of the buildings which are planned in Dolvik in each of the scenarios.

Table 22. Overview of the buildings which are planned erected at Dolvik.

Building	**Year of construction**	**Area m^2 (heated)**	**Net energy demand (regardless of energy supply)**			**Local energy production**
			ZEN	**Ref. 1[*] (EL)**	**Ref. 2[*] (DH)**	**ZEN**
Apartments	Planning phase	11.760	899 821	975 284	992 438	253 156
Single family houses	Planning phase	14.580	981 340	1 199 939	1 096 091	248 405
Sum	-	**26.340**	**1 881 161**	**2 175 223**	**2 088 529**	**501 561**

[*] The net energy demand (regardless of energy supply) is expected to achieve the same results for Ref. 1 and Ref. 2. However, due to the numerical modelling in the IDA ICE software the results for Ref. 1 and Ref. 2 will achieve to some extent minor differences in the net energy demand. This is due to the energy carrier for the heating systems differences as the Ref. 1 has 100 % electricity and Ref. 2 uses district heating for the heating system and an electic boiler to supply electricity for plug loads, lights and equipment.

Hourly net electricity load (yearly) and load duration

Figure 41 shows the hourly net electricity load and load duration curves for the reference scenarios and the ZEN scenario for one year (8760 hours). As one can observe in the figure, the reference scenario with the electric boiler (REF1) is the scenario with the highest electricity peak and total electricity use use. The reference scenario with district heating (REF2) shows a is distinctively lower peak and total electricity use throughout the year due to not using electricity for heating. In the ZEN scenario, district heating is being used to cover the heating demand and PV panels are used to generate local electricity which can be exported during surplus hours. In the ZEN scenario, electricity is being exported during several hours throughout the year.

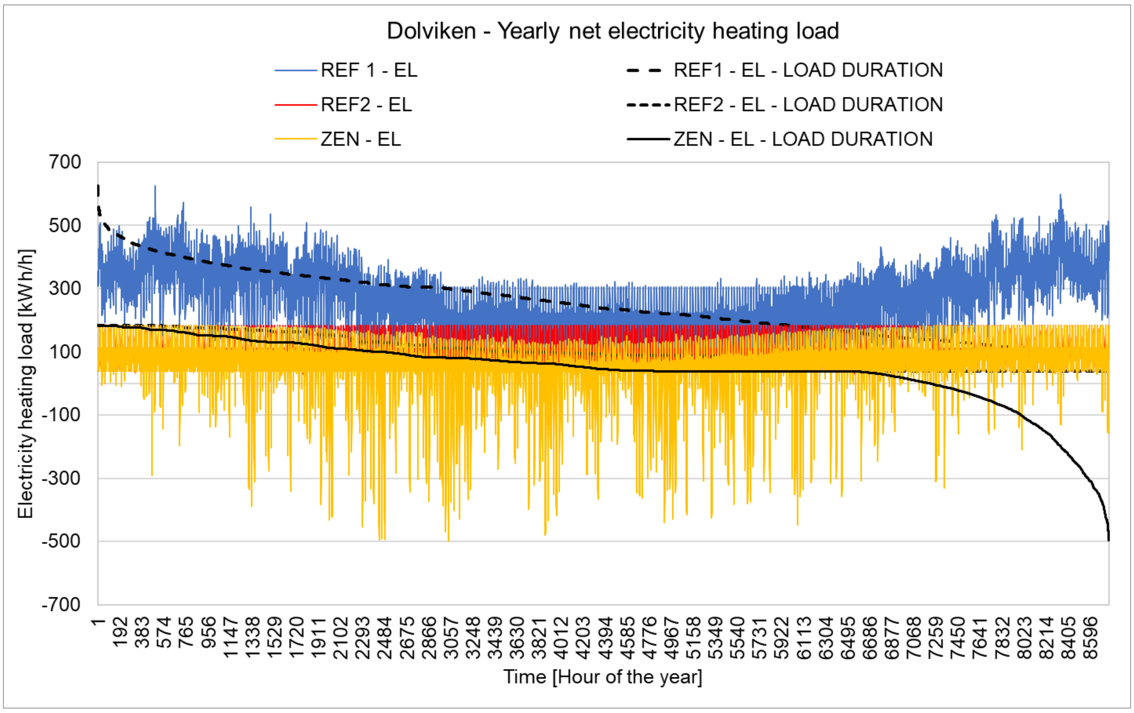

Figure 41. Hourly net electricity load (yearly) and load duration for references 1 and 2, and the ZEN scenario for the Dolvik area.

An alternative presentation of the net electricity load is the colour coded carpet plot. The colour coded carpet plot show both the variation in energy use throughout the day and seasons Figure 42 shows the carpet plot for reference 1 – electric boiler. The results from the carpet plot for REF1 show that the peak net delivered electricity occurs in the morning around 06-08 and the afternoon around 16-18. The shift in electricity use in March and October is due to the summer/wintertime changes. There are seasonal variations in the net delivered electricity due to increased heating demand during the cold winter monts.

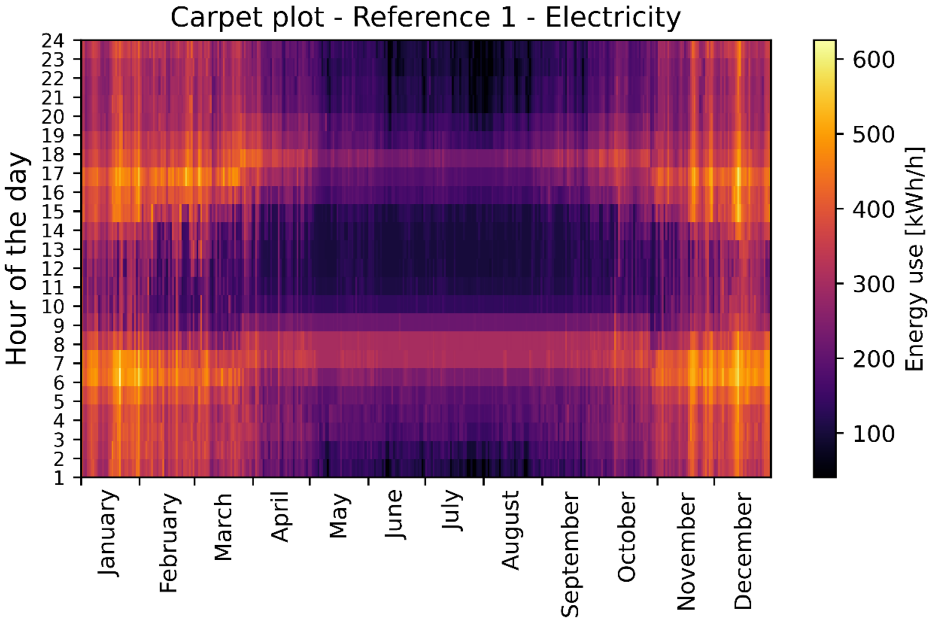

Figure 42. Carpet plot showing the net electricity import [kWh/h] for Dolvik in the reference scenario (ref 1with electric boiler).

Figure 43 shows the carpet plot for net delivered electricity in the ZEN scenario. The results show that the import of energy from the grid occurs mainly from 17 to 07. The energy export to the grid occurs mainly from 07 to 17 in the spring, summer, and autumn periods (April-September). However, some export of electricity can also be seen in the winter period (October-March).

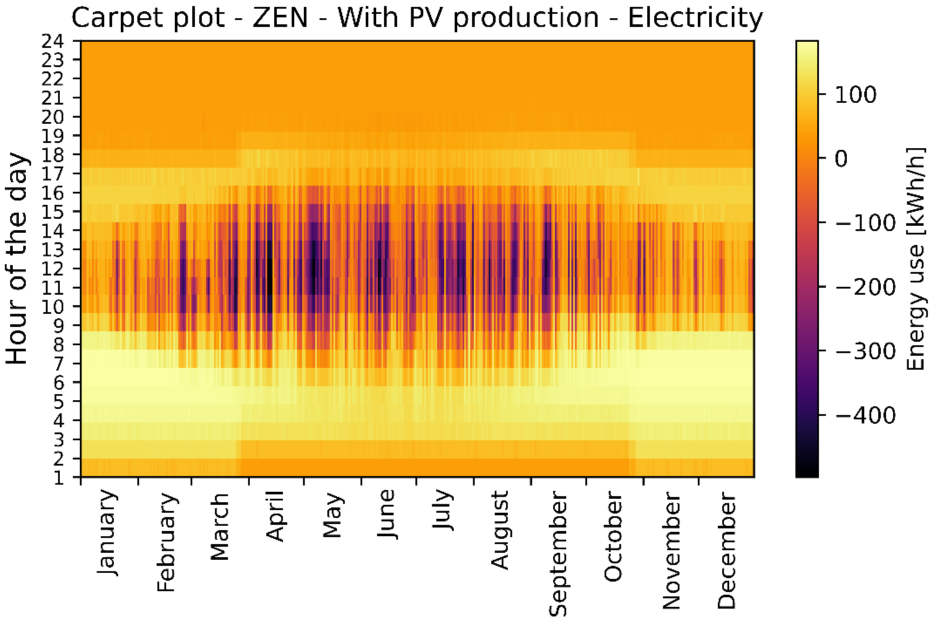

Figure 43. Carpet plot showing the net electricity import [kWh/h] for Dolvik in the ZEN scenario.

Hourly net district heating load (yearly) and load duration

Figure 44 shows the hourly net district heating load and load duration curves for the reference scenario with district heating (REF2) and the ZEN scenario for Dolvik. As one can observe in the figure, the district heating energy use is higher in the reference scenario compared to the ZEN scenario. This is due to more efficient buildings with a lower heating demand in the ZEN scenario. The efficiency of the buildings reduces both the total energy use for heating as well as the peak load.

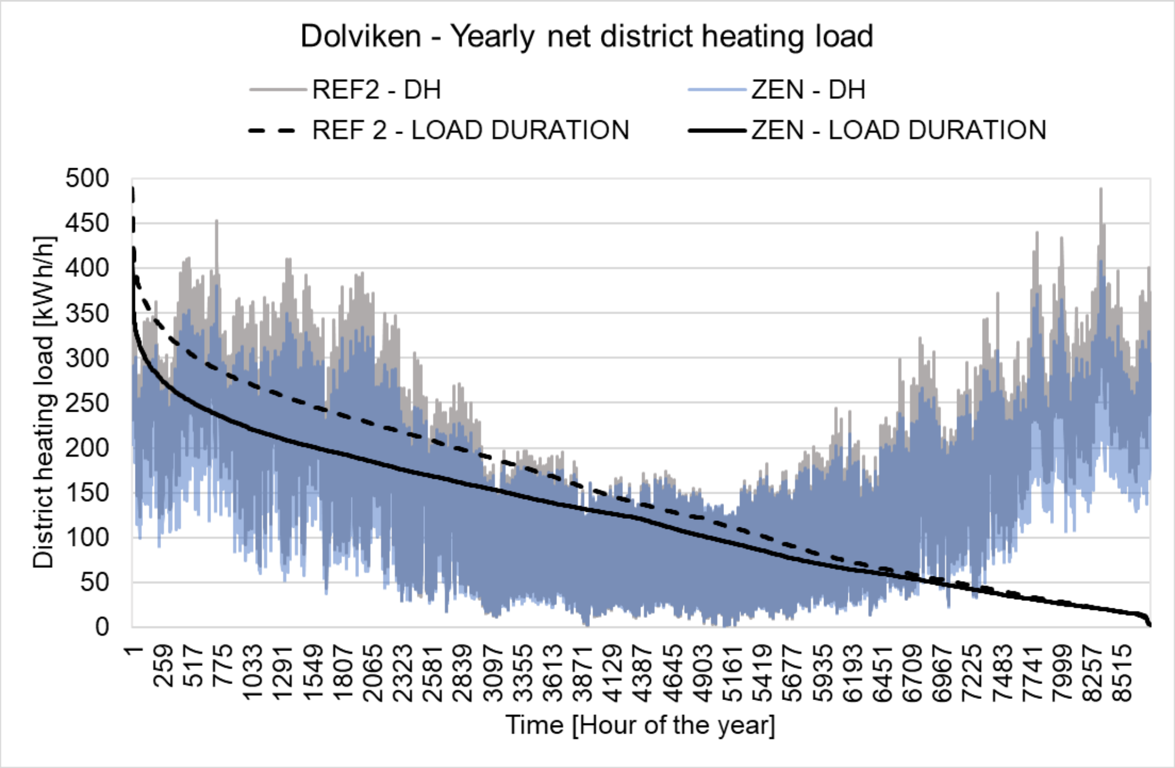

Figure 44. Hourly net district heating load (yearly) and load duration curves for reference 1 and 2, and the ZEN scenario for the Dolvik area.

Annual energy use (both electricity and district heating)

Figure 45 gives an overview of the the annual energy use (both electricity and district heating) for references 1 and 2 and the ZEN scenario for Dolvik. The REF2 is the scenario with the highest energy use in total, both for the net energy demand and energy use. The ZEN scenario has the lowest energy use due to the assumptoin of more efficient buildings with lower heating demand. The ZEN scenario is the only scenario with local energy production (generation).

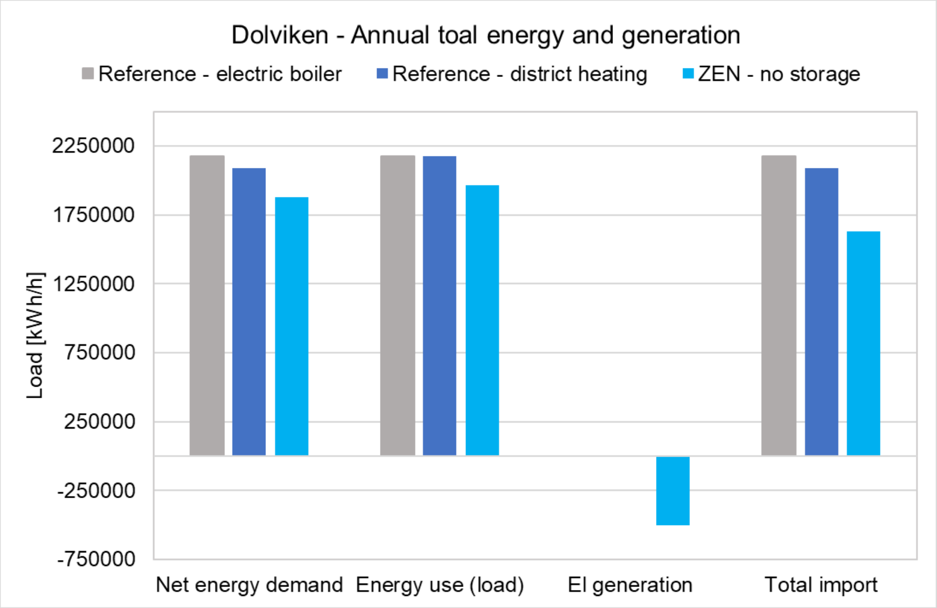

Figure 45. Annual total energy and generation for all scenarios for the Dolvik area.

Peak values all scenarios

Figure 46 gives an overview of the peak loads for all scenarios for Dolvik. As one can observe in the figure below, the highest peak load for electricity occurs in the reference scenario with electric heating (REF1). .

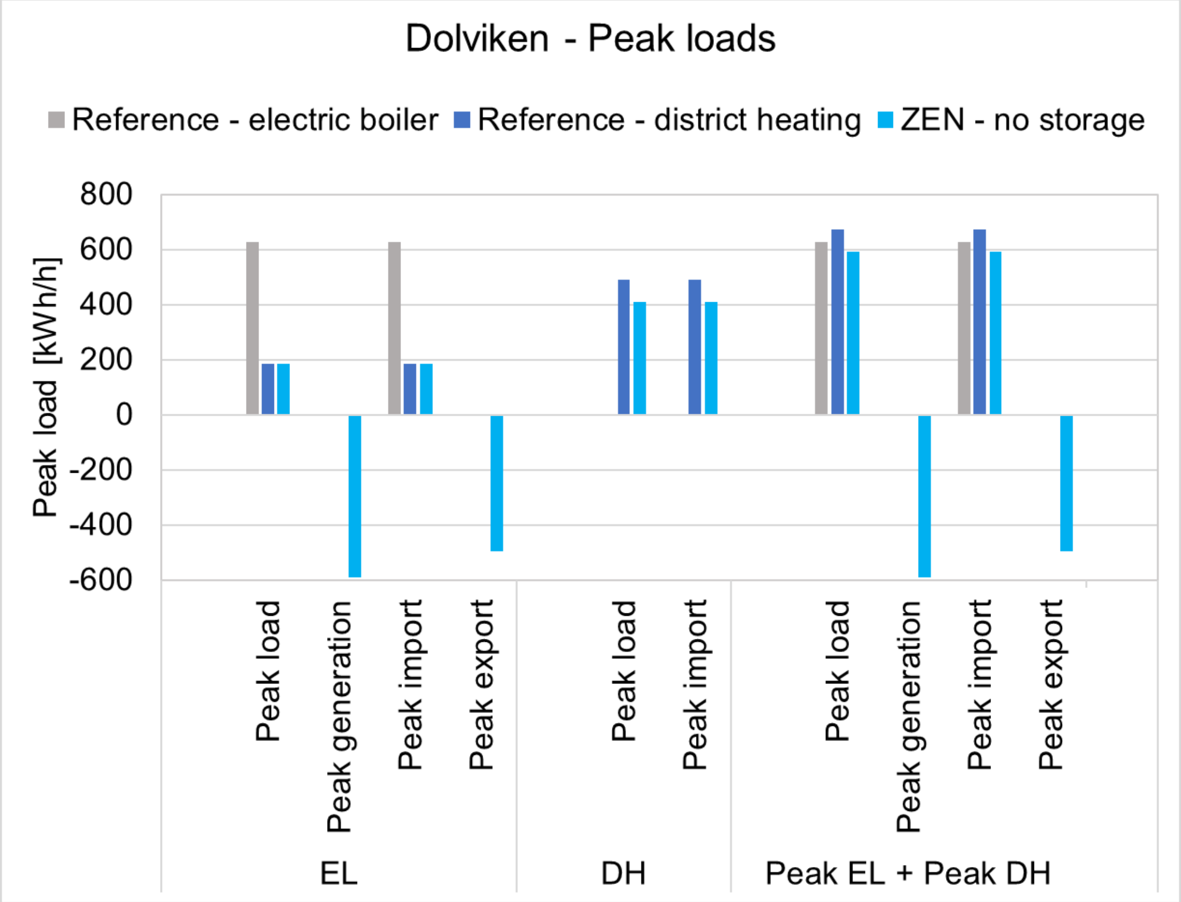

Figure 46. Peak loads for all scenarios for the Dolvik area.

Summary

Table 23 and Table 24 presents the final results of the KPI analysis for the Dolvik.

Table 23. Summary of the KPI scenarios analysis for Dolvik.

		ZEN	**Reference**	
			Reference 1-Electric boiler	**Reference 2 - district heating**
Net energy demand in buildings [kWh/year]	Total	1 881 161	2 175 223	2 088 529
	$/m^2$	71	83	79
Energy use [kWh/year]	EL	880 651	2 176 246	880 851
	DH	1 083 189	-	1 296 785
	Total	1 963 840	2 176 246	2 177 636
Generation [kWh/year]	EL	-501 561	-	-
	EL	587 907	2 176 246	836 298

		ZEN	**Reference**	
			Reference 1-Electric boiler	**Reference 2 - district heating**
Import [kWh/year]	DH	1 041 849	0	1 252 231
	Total	1 629 756	2 176 246	2 088 529
Export [kWh/year]	EL	-208 817	-	-
Peak load [kWh/h]	EL	183	625	184
	DH	410	-	489
	EL+DH	593	625	673
Peak import [kWh/h]	EL	183	625	183
	DH	410	-	489
	EL+DH	593	625	673
Peak export [kWh/h]	EL	-497	-	-
Utilization factor	EL	37 %	30 %	55 %
	DH	16 %	-	19 %
Self-generation	EL	57 %	-	-
Self-consumption	EL	33 %	-	-

Table 24. Summary of all energy and power KPIs for Dolvik in each of the three scenarios per m^2.

Per m^2 (Total area 26340 m^2)		**ZEN**		
			Reference 1 - Electric boiler	**Reference 2 -district heating**
Net energy demand in buildings [kWh/m^{2}year]	Total	71	83	79
Energy use [kWh/m^{2}year]	EL	33	83	33
	DH	41	-	49
	Total	75	83	83
Generation [kWh/m^{2}year]	EL	-19	-	-
Import [kWh/m^{2}year]	EL	22	83	32
	DH	40	0	48
	Total	62	83	79
Export [kWh/m^{2}year]	EL	-8	-	-

The main KPIs for the Energy (ENE) and Power (POW) categories to be used for comparison against target values have been calculated for Dolvik as shown in Table 25. The table shows the indicator value for the ZEN scenario, and the comparison of the ZEN scenario value and the reference scenario values.

Table 25: Final results of the KPI analysis for the Dolvik area.

KPI	**Indicator**	**ZEN scenario value**	**Reduction in the scenario value in the ZEN-scenario compared to the Reference scenarios**	
			1. Electric boiler	**2. District heating**
ENE2.1 Net energy use	/m^2	71	-14 %	-10 %
ENE2.2 Delivered energy /m^2	EL	22	-73 %	-30 %
	Bio	0	-	-
	DH	41	-	-16 %
	Total	62	-25 %	-22 %
ENE2.3 Self-consumption and self-generation	Self generation	57 %	-	-
	Self consumption	33 %	-	-
POW 3.1 Peak load	EL	183	-71 %	-1 %
	DH	410	-	-16 %
	EL+DH	593	-5 %	-12 %
POW 3.2 Peak export	EL	-497	-	-
POW3.3 Utilization factor	**Indicator**	**ZEN scenario value**	**1. REF electric boiler scenario value**	**2. REF district heating scenario value**
	EL	37 %	30 %	55 %
	DH	16 %	-	19 %

6.5 Flexibility: Typical days

In this chapter, the typical days for winter workdays for electricity and district heating are shown for each scenario. Bottle necks in the electricity and heating grids typically occur during winter workdays. Due to this, studying the typical winter workdays may help give a better understanding of the flexibility potential on winter days aimed at reducing peak loads during peak hours. The typical days are calculated as the average winter workday from November – February with the respective weather file.

Figure 47 presents the typical days for net delivered electricity in Dolvik on winter workdays 5th and 95th percentile. This means that the figure below showes 90 % of the data points; 90 % below and above the median solid line, which are presented with a shaded color. Reference 1 uses direct electricity for heating. This scenario has a clear morning and evening peak for net delivered electricity. This is due to the occupant's behavior and night setback on ventilation and heating. It is also clearly demonstrated that reference 2 and the ZEN scenario have a lower energy use, as electricity is not used for heating in these scenarios. The ZEN scenario has a clear valley from 09 until 15. This is mainly due to solar energy production. A net export of electricity is expected during the middle of the day in Dolvik, with large daily variations. However, it also should be mentioned that this is an average profile over the selected winter month. The results may vary depending on the solar radiation.

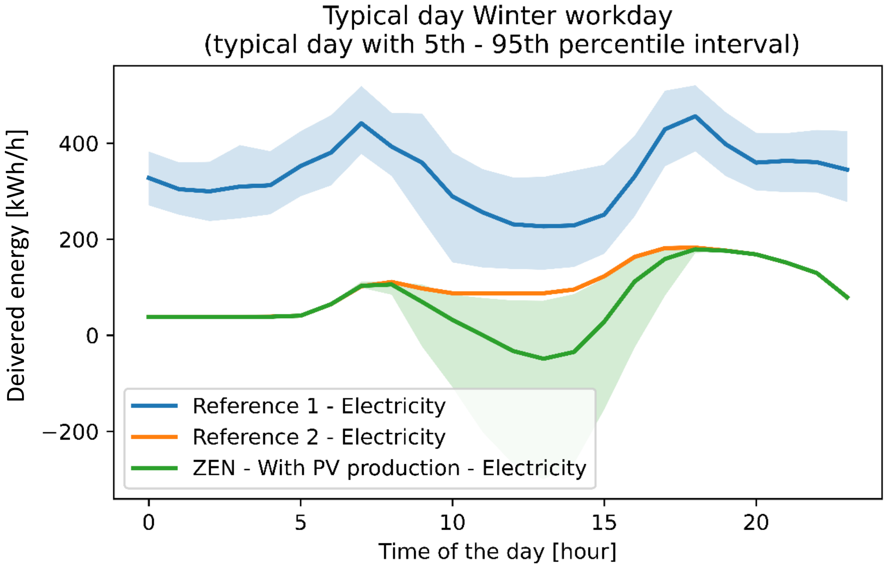

Figure 47. Typical daily net delivered electricity in Dolvik during winter workdays.

The net delivered electricity on summer workdays in Dolvik is shown in Figure 48 The reference scenario with district heating have a somewhat similar net delivered electricity profile during typical summer workdays and winter workdays. The reference scenario with electric heating uses electricity for heating of domestic hot water and have a higher electricity use compared to the other reference scenario as expected. In the ZEN scenario, there is typically net export of electricity during the day during summer workdays (although with large variations) due to a high electricity production from PV during the summer.

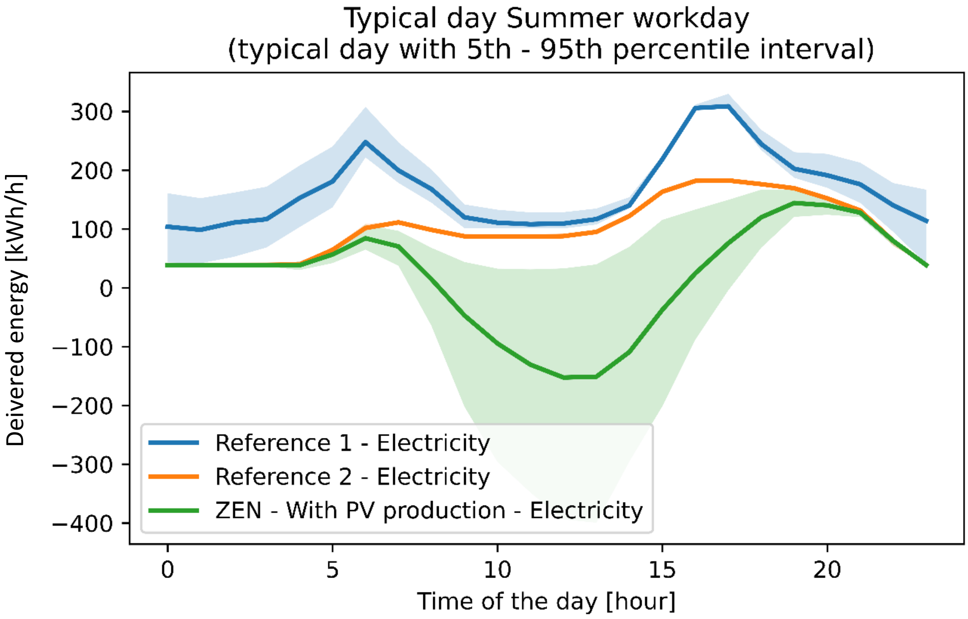

Figure 48. Typical daily net delivered electricity in Dolvik during summer workdays.

The typical daily profile for district heating energy use on winter workdays for the ZEN scenario and the reference scenario with district heating is shown in Figure 49. The typical days have a morning peak due to the demand for heating (both room heating and domestic hot water heating) in the morning. The daily variations are caused by variations in the outdoor temperature.

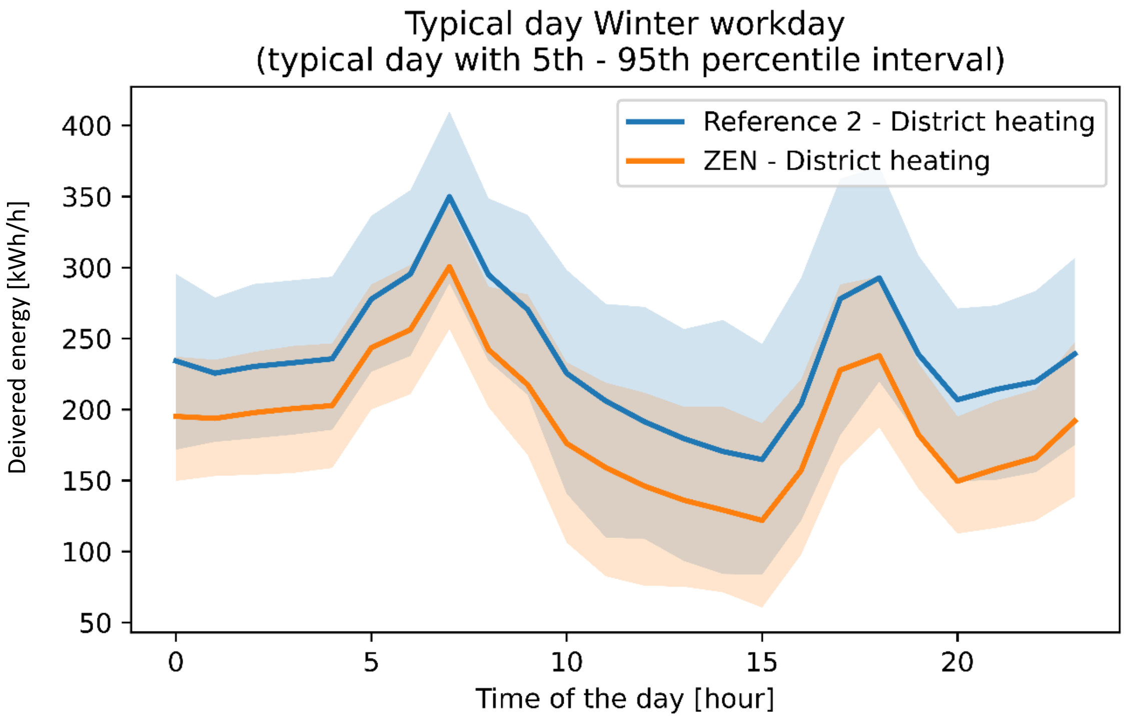

Figure 49. Typical district heating energy use during in Dolvik during winter workdays.

7. Case: Campus Evenstad

7.1 Description of the area

Campus Evenstad is a university campus site in Stor-Elvdal municipality in Norway. There are 20 buildings located at the campus, with a total floor area of approx. 9 000 m^2 , including buildings for administration, education and student housing. Figure 50 gives an overview of the site and buildings. The campus site is owned, developed and operated by Statsbygg while Høgskolen i Innlandet (HINN) rents the site and runs the campus. HINN is a public education institution with eight campuses spread out on the south-eastern part of Norway. The student housing is used by a regulated third party, Studentsamskipnaden i Innlandet (SINN). The end-users at Campus Evenstad include about 70 employees (academic employees, operators, and administrative staff) and about 250 students. Campus Evenstad is being renovated with high ambitions for climate gas emission reductions, and the area is developing towards a ZEN. The campus site was also a pilot project in The Research Centre on Zero Emission Buildings (FME ZEB)[2].

Figure 50. Campus Evenstad

7.2 Scenarios

Campus Evenstad is in the operational phase. In Evenstad, heat is supplied to the buildings via a local heating grid. Heating is generated in a heating central from a bioboiler, an electric boiler and a biobased Combined heat and power (CHP) plant. PV panels have been installed on the building "Låven".

In this case study, the suggested KPIs for energy and power have been tested using historical measurements of energy use and energy production in Evenstad. The measurements were collected from the builing management system (BMS) for the period October 2017 until July 2019. From these measurements, 2018 is the only full-year, and hence, measurements from 2018 were used to calculate the KPIs.

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[2] https://fmezen.no/wp-content/uploads/2019/08/ZEn-Report-no-17-ny.pdf

As all of the three scenarios are based on the same measurements, it's been assumed that there are no differences in the energy demand of the buildings, the differences in the scenarios refer to differences in the heating system and in the local energy production. The following assumptions have been made for each of the three scenarios:

- **Reference 2 with electric and biobased heating (or "As-measured"):** Represents energy use from measurements from 2018 as they are. The measurements have been split into two energy carriers; electricity and bioenergy. This scenario includes electricity generation onsite from CHP and PV. The thermal demand is met by a biomass CHP, biomass boiler and electric boiler. The electric specific loads are covered by generated electricity from PVs and the CHP, and by electricity from the grid.
- **Reference 1 with all-electric heating (or "Baseline"):** Campus Evenstad is considered to be supplied with electricity from the grid only, covering both thermal demand and electric specific demand. No local energy production on site.
- **The ZEN scenario (or "*Biobased heating*"):** This scenario refers to a more optimal heating system for Evenstad. In this scenario, the heating system is assumed to be operated so that all thermal demand is covered by the biomass CHP and the biomass boiler, without any use of the electric boiler. Electric specific loads are covered by electricity generated by PVs and CHP and by electricity from the grid.

Table 26 show a summary of the assumptions made in the three scenarios.

Table 26. Campus Evenstad - Scenarios

	ZEN	**Reference**	
		1. Electric heating	**2. Electric/bio heating**
	Biobased heating (optimal)	***Baseline***	***As-measured***
Energy storage solutions	None.	None.	None.
Local energy production	PV panels – 60 kWp CHP electricity – 40 kW	None.	PV panels – 60 kWp CHP electricity – 40 kW
Heating	Combined heat and power (CHP) – bio based – 100 kW Bioboiler – 300 kW	Local heating system, with electric boiler. Electricity from the grid (efficiency = 1)	Electric boiler – 315 kW Combined heat and power (CHP) – bio based – 100 kW Bioboiler – 300 kW
Cooling	Not included	Not included	Not included
Transport habits [7]	Not included	Not included	Not included
Transport technologies	Not included	Not included	Not included

7.3 Methodology

The KPI calculations are based on available measurements from the energy meters on the site from 2018, shown in Table 27. These energy meters register cumulative values for every hour.

Reconstruction of data

From the cumulative metered values, hourly energy use can be calculated by subtracting the value from one hour with the previous one. This gives the energy use in Wh/h which can also be seen as the average power (W) for that hour, assuming constant power for one hour.

Table 27. Energy meters at Campus Evenstad

Energy meter	Description
Main meter - electricity	Electricity from grid, including electricity to the electric boiler.
PV - electricity	There is a separate meter for PV electricity generation in Evenstad, however, For the PV system, too many datapoints where missing and the measurements have been replaced with simulated values.
Biomass CHP - electricity and heat production	Measurements are available for generated electricity from the CHP. Heat from the CHP is not measured and has been calculated with the assumption that: *Heat_CHP = El_CHP * 2,5*
Bioboiler – heat production	Measurements available.
Electric boiler – heat production	Measurements available, also included in measurements for main meter.
Local heating east – Heat load	These meters measure total heat use on the site delivered from the heating plants.
Local heating west – Heat load	

Following the analysis of the measurements, there were too many missing data points for the year 2018 to be a complete full-year of measurements. As the measurements are cumulative values, it has been possible to calculate a monthly and yearly total of the energy use. This have been calculated based on available measurements for the first day in each month of the year. Due to the missing data points, it has not been possible to generate a complete dataset with hourly values for a full year for Campus Evenstad. Data on hourly loads are only considered to be valid for timesteps where all energy meters have measured values. For evaluation of KPIs for Evenstad the hourly load data have therefore been reconstructed to only contain these timesteps, leading to a dataset with valid datapoints for 3 342 hours.

Further, by comparing the metered values for heat production from the biomass CHP, bioboiler and electric boiler with sum of metered values from the two local heating meters, the total heat load for the local heating system was higher than measured produced heat. The total heat use on site should have been lower than the heat productions, and this indicates that the measurements from the local heating meters might not have correct values. In the following, the KPI calculations are based on the metered values for the CHP, bioboiler, electric boiler and the main meter, and simulated values for the PV electricity production.

For the all-electric baseline scenario ("reference 1") both heat and electric specific energy use is considered to be covered by electricity from the grid with an energy efficiency of 1.

In the as-measured scenario ("reference 2") the annual energy demand and energy use are split in the two energy carriers; electricity and bioenergy according to the 2018-measurements. Electricity includes both electric specific energy use and the electric boiler (with an efficiency of 1). This is covered by electricity from the grid and generated energy from PVs and the CHP. Bioenergy is calculated from the heat production from the biomass CHP with an thermal efficiency of 0,50 and the bioboiler with an efficiency of 0,90.

For the final scenario ("biobased heating" or "ZEN-scenario"), all thermal demand is considered to be covered by the biomass CHP and the bioboiler. The biomass CHP is the base load with a capacity of 100 kW, while the bioboiler covers all themal demand above 100 kW. Based on the heat total the biomass CHP can cover 79 % of the annual energy use, and the bioboiler covers the last 21 %. The efficiencies are the same as for the as-measured scenario. Electricity from the grid and generated electricity from PVs and the CHP cover only the electric specific load on the campus.

Annual net energy demand and annual energy use of the buildings (kWh/m^2)

Annual net energy demand has not been calculated for Campus Evenstad in this report. The KPI evaluation is based on historical measurements from 2018. The gross energy demand for heating on campus is calculated by summarizing metered values for heat from the CHP, bioboiler and electric boiler. The annual energy use is split in the two energy carriers; electricity and bioenergy, and is calculated from the cumulative monthly values from the energy meters, including efficiencies of the heating units.

Annual and hourly energy use for infrastructure

Energy use for infrastructure (outdoor lighting, elevators and snow melting systems etc.) at Campus Evenstad has not been separately evaluated in this report.

Hourly profile for charging of electric vehicles

There are charging points for elecric vehicles at Campus Evenstad, but energy use for electric vehicles are not separately evaluated in this report.

Hourly profile for electric generation

At Campus Evenstad electricity is generated from both PV and from the CHP. The measurements from the local PV system had too many missing data points, and instead simulated values have been used for PV. The values were simulated using a method developed by Rognan (2018), based on 2018-climate data from nearby weather station[22]. For electricity from the CHP the measured values have been used.

Hourly profiles for building energy demand and energy use in buildings

The hourly profiles for energy use at Campus Evenstad is based on the dataset containing only valid datapoints covering 3 342 hours of the year. This impacts both the hourly load profiles and the load duration curves.

7.4 Results

Figure 51 shows the load profile and load duration curve for net delivered electricity in all of the scenarios in Evenstad. As shown in this figure, one can observe the missing datapoints which occur on several periods throughout the year. In the biobased heating ("ZEN") scenario it's assumed that electricity is not used for heating purposes. In this scenario, there is little seasonal variation in the electricity use. This scenario is the only scenario where there is export of surplus electricity to the grid. In the reference scenarios, there is a larger seasonal variation in net delivered electricity due to electricity being used for heating purposes in the heating central.

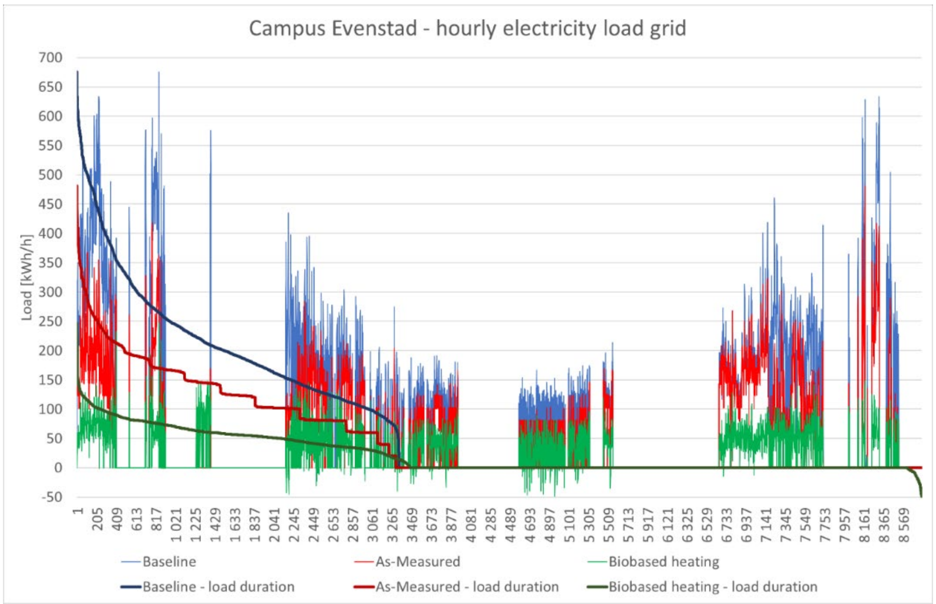

Figure 51. Campus Evenstad – hourly electricity load grid

Figure 52 shows the load profile and load duration curve for the local heating system at Campus Evenstad. The figure shows the total heat energy use delivered from the heating central, which is assumed to be the same for all of the scenarios.

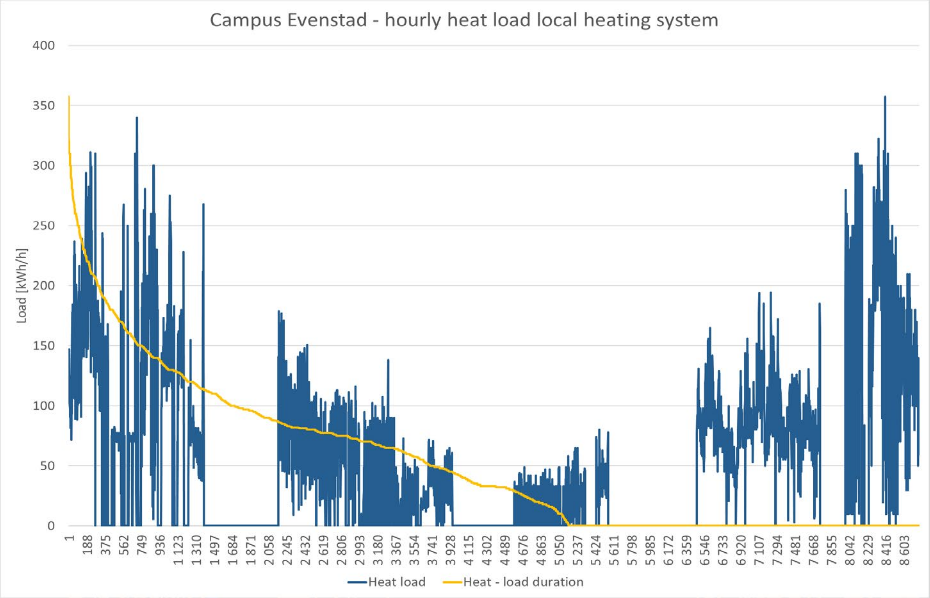

Figure 52. Campus Evenstad – hourly load bioenergy

Due to the large number of missing values, colour coded carpet plots of the net delivered electricity have not been included.

Figure 53 presents the annual energy use of electricity and bioenergy, total generated electricity and electricity imported from the grid at Campus Evenstad for the three scenarios.The totalt annual electricity use in the as-measured scenario ("reference 2") and in the biobased heating scenario ("ZEN-scenario") include imported electricity from the grid and generated electricity on site from PV and the CHP (excluding export). For the baseline scenario ("reference 1") all electricity is imported from the grid. Compared to the baseline ("reference 1"), both as-measured ("reference 2") and biobased heating

("ZEN") have a significant reduction in electric energy use and in imported electricity as the thermal energy use is moved towards a biobased heating system.

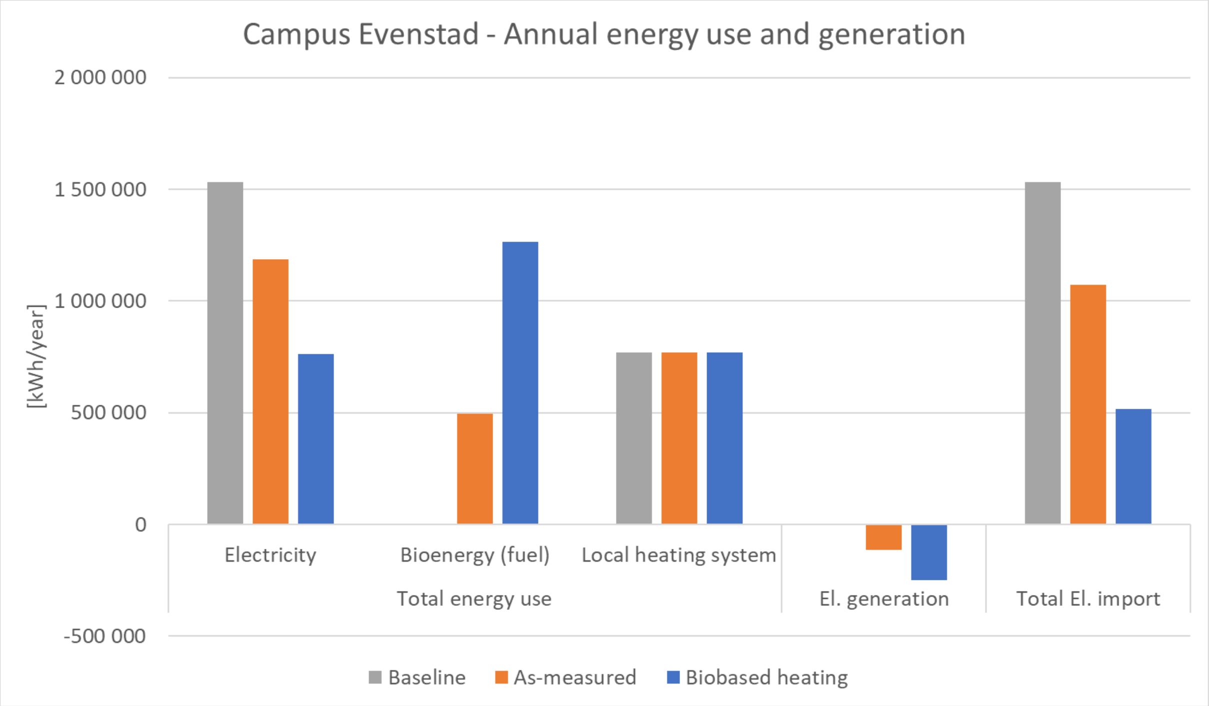

Figure 53. Campus Evenstad – Annual energy use

Figure 54 presents the peak loads for the three scenarios. The peak load is calculated as an average power peak for one hour, and is the highest metered value from the reconstructed hourly dataset with valid datapoints. The missing hourly values leads to incomplete hourly load profiles and load duration curves for all three scenarios.

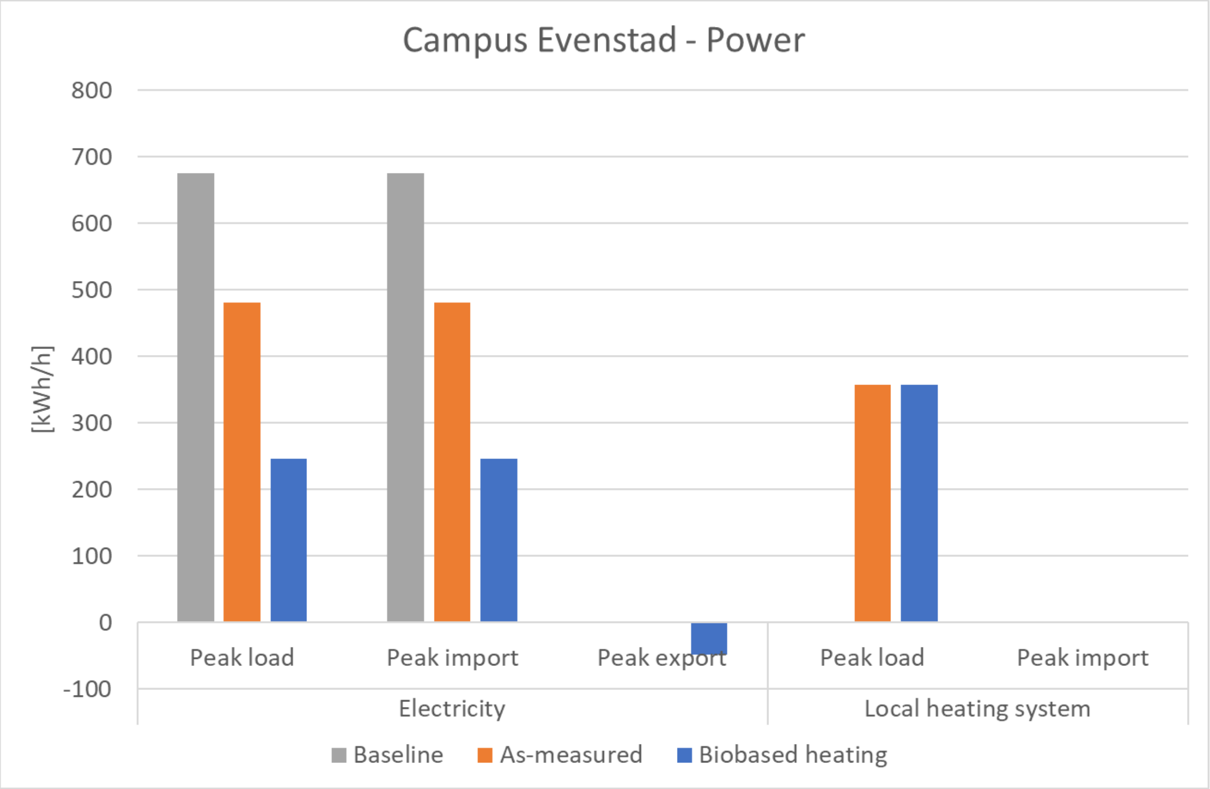

Figure 54. Campus Evenstad - Power

Due to the missing datapoints and incomplete hourly datasets, the KPIs based on hourly values, such as peak load, import and export, can involve some uncertainties. Regardless of this, the available measurements have still been used to test the KPIs as they represents the actual measurements at Campus Evenstad in 2018. In addition, the coldest months, January and February, contain many datapoints. It is reasonable to assume that that the peak load would occur during one of these months, and that the actual peak loads therefore may be represented in the data set.

Table 28 and Table 29 summarize all the KPIs (annual totals, peaks and factors) for the three scenarios for Campus Evenstad. The total building area is assumed to be approx. 9 000 m^2. Local heating is marked in gray, as this is the same for all scenarios, and refer to the heat delivered from the local heating central (not energy purchased from a district heating network).

Table 28. Campus Evenstad - Summary of all documentational KPIs and main KPIs (annual values, peaks and factor) for the three scenarios.

		ZEN	Reference	
			2. Electric/bio heating	1. Electric heating
		Biobased heating	*As-measured*	*Baseline*
Net energy demand in buildings [kWh/year]	Total	-	-	-
	/m^2	-	-	-
Energy use [kWh/year]	EL	764 000	1 188 000	1 533 000
	Bio *	1 265 000	495 000	0
	LH	769 000	769 000	769 000
	Total	2 029 000	1 683 000	1 533 000
Generation [kWh/year]	EL. PV	64 000	64 000	0
	EL. CHP	184 000	50 000	0
Import [kWh/year]	EL	516 000	1 074 000	1 533 000
	Bio	1 265 000	495 000	0
	LH	-	-	-
	Total	1 781 000	1 569 000	1 533 000
Export [kWh/year]	EL	-2 000	0	0
Peak load [kWh/h]	EL	247	481	675
	LH	358	358	358
	EL+DH	605	839	1033
Peak import [kWh/h]	EL	247	481	675
	LH	0	0	0
	EL+DH	247	481	675
Peak export [kWh/h]	EL	-49	0	0
Utilization factor	EL	23 %	28 %	32 %
	LH	25 %	25 %	25 %
Self-generation	EL	32.4 %	9.6 %	-
Self-consumption	EL	99 %	100	-

* Energy content in bio chips.

Table 29. Summary of all energy and power KPIs for Evenstad in each of the three scenarios per m^2.

Per m^2 (total area 9000 m^2)		ZEN	Reference	
			2. Electric/bio heating	1. Electric heating
		Biobased heating	*As-measured*	*Baseline*
Net energy demand in buildings [kWh/m^2year]	Total	-	-	-
Energy use [kWh/m^2year]	EL	85	132	170
	Bio *	141	55	0
	LH	85	85	85
	Total	225	187	170
Generation [kWh/m^2year]	EL	7	7	0
Import [kWh/m^2year]	EL	57	119	170
	Bio	141	55	0
	DH	0	0	0
	Total	198	174	170
Export [kWh/m^2year]	EL	0	0	0

* Energy content in bio chips.

The main KPIs for the Energy (ENE) and Power (POW) categories for the biobased heating scenario ("ZEN" scenario) have been calculated for Campus Evenstad as shown in Table 30. The table shows the indicator value for the biobased heating scenario, and the percentage difference between this scenario and the reference scenarios (the "baseline" and "as-measured" scenario). Negative values for the comparison indicates a reduction for the biobased heating scenario ("ZEN") compared to the reference scenarios. As the biobased heating scenario ("ZEN") is considered to only use bioenergy though the CHP and bioboiler to cover the heat demand, the peak load for bioenergy is higher in this scenario, while the peak import for electricity is reduced.

Table 30. Campus Evenstad - The main KPIs for the Energy (ENE) and Power (POW) categories for comparison against all biobased heating.

		ZEN scenario value	**Reduction in the scenario value in the ZEN-scenario compared to the Reference scenarios**	
			1. Electric heating	2. Electric/bio heating
KPI	**Indicator**	*Biobased heating*	*Baseline*	*As-measured*
ENE2.1 Net energy use	/m^2	-	-	-
ENE2.2 Delivered energy / m^2	EL	57	-52 %	-66 %
	Bio	141	-	+156 %
	Local heating	85	0 %	0 %
	Total	198	+14 %	+16 %
POW 3.1 Peak load	EL	247	-63 %	-49 %
	Local heating	358	0 %	0 %
POW 3.2 Peak export	EL	-49	-	-
KPI	**Indicator**	**ZEN scenario value**	**1. REF electric boiler scenario value**	**2. REF district heating scenario value**
ENE2.3 Self-consumption and self-generation	Self generation	32 %	-	10 %
	Self consumption	99 %	-	100 %
POW3.3 Utilization factor	EL	23 %	32 %	28 %
	Local heating	25 %	25 %	25 %

7.5 Flexibility: Typical days

Studying the typical hourly energy use on winter and summer workdays may give a better understanding of the flexibility potential and the potential for reducing peak loads during peak hours. Studying the typical winter workdays may help give a better understanding of the flexibility potential on winter days aimed at reducing peak loads during peak hours. The peak export of electricity in areas with PV typically occur during the summer. In this chapter the typical electricity use on winter and summer workdays are shown for each scenario in Campus Evenstad.

The typical daily profile for net delivered electricity (electricity use – electricity production) in the different scenarios for Evenstad on winter workdays is shown in Figure 55. The lines show the average winter workday net electricity profile, while the shaded area around these lines show the variation in electricity use (on winter workdays) from the 5th-95th percentile interval.

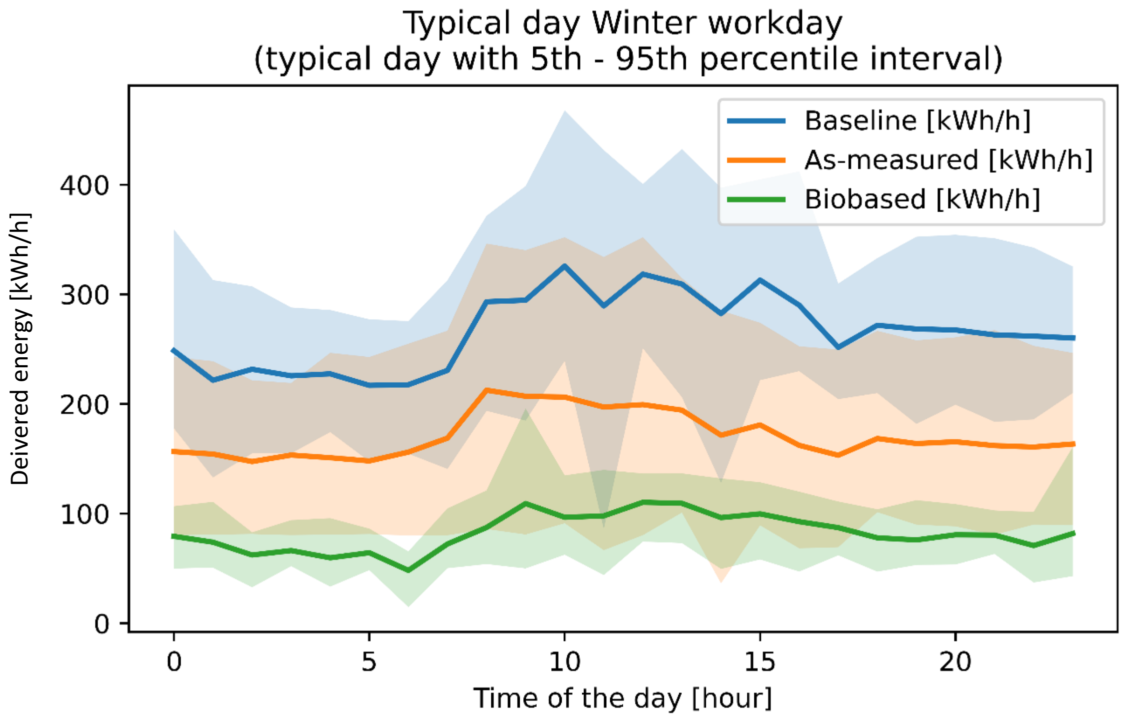

Figure 55. Typical net delivered electricity on winter workdays in Campus Evenstad.

The figure shows that the typical net delivered electricity on winter workdays have a peak during the middle of the day. This is typical for areas with service buildings, as the activity in these buildings is highest during the day. The baseline scenario (Reference scenario with all-electric heating) shows a much higher electricity use during winter workdays compared to the other scenarios. This is due to the electricity being the only heat source in this scenario, and that there is no generation of electricity from PV. There is also a larger variation in daily electricity use in this scenario due to the link between electricity used for heating and the outdoor temperature. Electricity is also used for heating in the second reference scenario, "As-measured", but in this scenario, the electricity for heating has been reduced, due to biofuels being used in addition to cover parts of the heating demand. This reduces both the total electricity use throughout the day, as well as the peaks in electricity use. In this scenario, there is also generation of electricity from PV which reduces the need for import of electricity from the grid. In the biobased scenario ("ZEN"-scenario) electricity is not used for heating, only for electric specific loads. In this scenario there is a low demand for electricity during the day.

The typical daily profile for net delivered electricity (electricity use – electricity production) on summer workdays for each of the scenarios in Evenstad is shown in Figure 56.

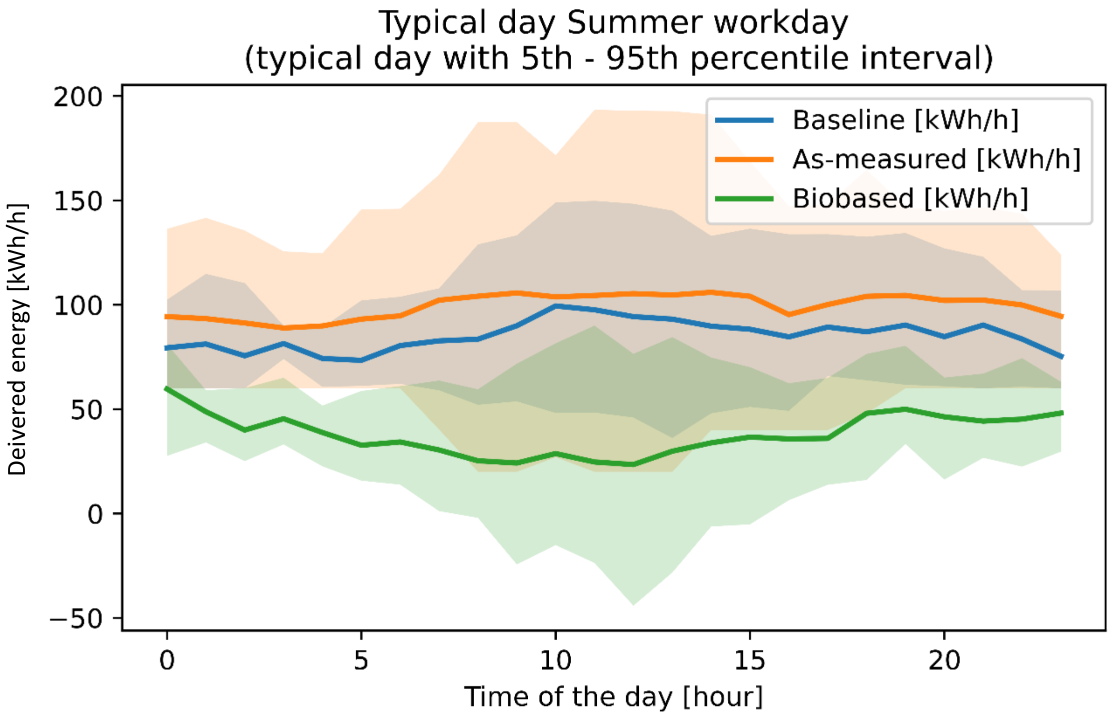

Figure 56. Typical net delivered electricity on summer workdays in Campus Evenstad.

The reference scenarios show a low, somewhat flat curve for electricity use during the summer days, similar to the net electricity curve of the biobased (ZEN scenario) during the winter workdays which is as expected as the electricity use during the summer is mostly for electric specific purposes. In the biobased (ZEN scenario), there is local production of electricity from PV during the middle of the day.. There is also local electricity production from the CHP throughout the entire day, even during the night, which affects the import of electricity. There are a few days during the summer when there is net export of electricity from Evenstad in this scenario.

8. Case: Mære

8.1 Description of the area

Mære is an agricultural school in Steinkjer municipality which is owned by Trøndelag County Municipality (TRFK). The school has 70 employees and 200 students who are trained in agriculture, forestry, local food production and climate/energy initiatives in agriculture. The farm operates about 1050 decares (daa) of arable land, about 300 daa for grazing and 528 daa of forest. Livestock farming includes 50 yearlings and 30 cows, 20 lambs and 55 piglets. In the greenhouse there is the production of tomato, flowers and a fruit garden. Mære has a total building area of 23 190 m^2 consisting of farm buildings, greenhouses, apartment housing, administration buildings and educational buildings. In recent years, a wooden dairy barn, a nursing cow barn (with a roof-integrated solar farm) and a residential building (constructed as a passive house with PV) have been built in Mære. In addition, a new stable is now being built as a zero emission building (ZEB-O). Mære has a local heating grid which is connected to a heating central with a ground source heat pump (GSHP). Some of the school buildings are connected to the heating grid, while the remaining are unheated or use direct electricity for heating. Two of the farm buildings have local energy production from PV-panels. A complete list of the different buildings in Mære is shown in Figure 57 and Table 31.

Figure 57. Overview of Mære Landsbrukskole. Source: Arne Nyaas, Fjellfolk Media.

Table 31. List of buildings in Mære Landsbrukskole, their usable area (BRA) and installed energy systems.

Building name	Building type	BRA (m^2)	Energy systems
Mære A, B, C	School, administration, conference room (ZEN)	3421	LH (GSHP)
Mære D, H	Office, museum	1198	LH (GSHP)
Mære F	Diary barn (ZEN)	1700	Direct electricity (no heating)
Mære G	Stable	506	LH (GSHP)
Mære I	Dormitory (ZEN)	1634	LH (GSHP), PV
Mære J	Cafeteria	1154	LH (GSHP)
Mære L	Old farm building	1675	Direct electricity
Mære M	Greenhouse (ZEN)	2870	LH (GSHP)
Mære N	Pig barn (ZEN)	1800	LH (GSHP)
Mære O	Sheep barn	400	Direct electricity (no heating)
Mære Q	Garage, gardening shed	1000	Direct electricity
Mære R	Workshop	442	Direct electricity
Mære S	Forest centre	959	Direct electricity
Mære W, X	Old horticulture building and storage	1700	Direct electricity
Mære Y	Storage	2100	Direct electricity (no heating)
Mære Z	Calf barn (ZEN)	1300	Direct electricity (no heating), PV
Mære Kåret og Rabben	Unknown	290	Direct electricity
Total		**23 190**	

Local heating grid and GSHP

Mære has a local heating grid which is connected to a heating central with a ground source heat pump (GSHP), and a LPG boiler used for top heating. Several of the buildings in Mære are connected to this grid, as given in Table 31. The GSHP is located close to the horticultural buildings of the school. The remaining buildings are unheated/or use direct electricity for heating.

Solar thermal heat collectors at the roof of the greenhouse collect heat from solar radiation, which is stored in a waterbased heat storage tank underground (short-term storage), and can be led further down into deep boreholes, 150-250 m in the bedrock outside the greenhouse (long-term storage). The temperature in the bedrock below the deep boreholes rises when heat is conducted down in the summer. The energy transport in and out of the boreholes takes place by means of a liquid medium which is led in plastic pipes inside the boreholes. The temperatures in the short-term and long-term storage are relatively low, 0-15 ° and the GSHP is used to raise the temperature further. The Greenhouse building uses free cooling via so-called aerotempers on the roof which conveys additional heat to the GSHP.

The heat is transferred from the boreholes to the greenhouse and most of the other buildings (classrooms, offices, canteens and dormitories) during the cold season, where a low/medium temperature floor heating system is installed. An overview of the local heating grid is shown in Figure 58.

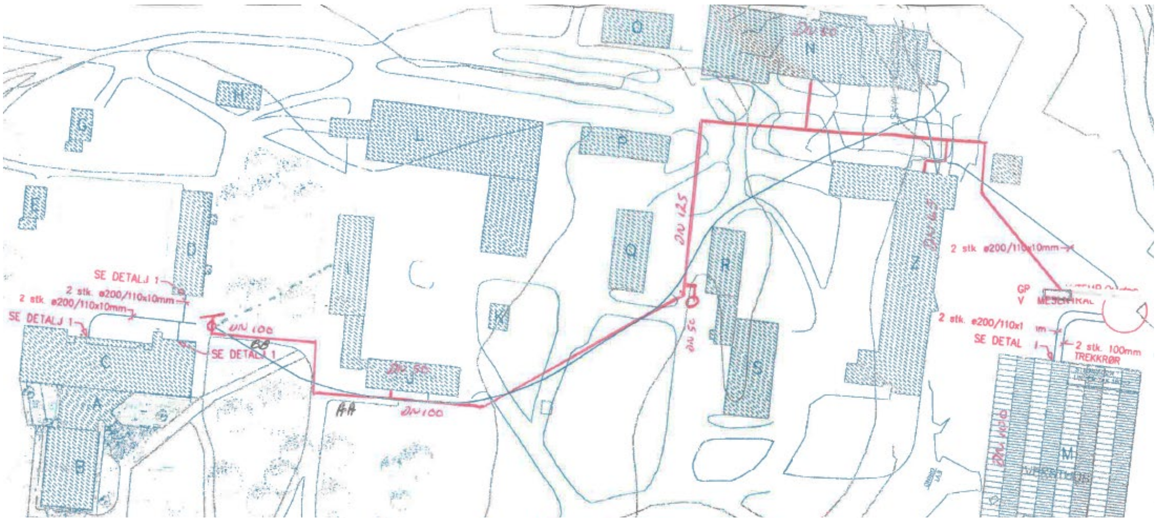

Figure 58. Scheme of the District Heating system in Mære Landsbrukskole. Courtesy of Mære Agricultural School.

PV systems

PV-systems have been installed on two of the buildings in Mære.

The first building is the calf barn (building Z, Figure 59 - left). Here, a total of 120 PV panels cover an area of 192 m^2. The peak output of the solar system is 34.8 kWp.

The second is the dormitory (building I, Figure 59 - right). Here, a total of 216 PV panels cover an area of 300 m^2, providing a peak power output of 58 kWp.

The two PV systems are estimated to have delivered an annual electricity production of approximately 75 000 kWh in 2020.

Figure 59. Left: PV system on the Building Z (calf barn). Right: PV system on the Building I (dormitory). Photos courtesy of Mære Landsbrukskole.

8.1 Scenarios

Mære Landsbrukskole is composed of a variety of buildings with different uses. Several of the buildings do not have a heating demand, and some of the energy used on-site is used for the operation of agricultural/industrial machines. This makes Mære stand out from other ZEN pilots, which are composed of mostly residential and service buildings.

The electricity use is measured in each of the different buildings separately with a weekly resolution. In some of the buildings, measurements of the electricity use is available at a hourly resolution, however, a full year of measurements of electricity use from most of the buildings is not available. For some of the buildings, hourly measurements of electricity use has only been available since march 2021, as shown in Table 33.

There is a separate electricity meter for electricity used in the GSHP, but there are not separate electricity meters for the different energy purposes in the buildings. Some of the buildings use direct electricity for heating and it is not possible to distinguish between electricity used for heating purposes and other end-uses in these buildings.

Given these factors, it was not possible to derive a meaningful reference scenario for Mære Landbrukskole (such as in Evenstad), to analyze the effect of the renovation of the buildings and the installation of the new heating system. However, it was still decided to collect and present the available data on energy use in Mære, to enlighten the demand for data and the challenges linked to calculating the energy and power KPIs when using measurement data.

As an alternative to creating a reference scenario, the energy and power KPIs have been collected for the following scenarios (Table 32):

Table 32. Summary of scenarios analyzed in the Mære case study.

Scenario 1	**Scenario 2**
Measured data/ actual scenario	**Comparative analysis between different PV scenarios**
1: Measured energy use data retrieved from the Optima Energy data center (more details in chapter 8.2 Methodology) with simulated PV production of the currently installed area of PV modules (492 m^2).	2A: The scenario "Extended PV system – S) is built by using the scenario 1 in addition to simulating the potential PV production by installing PV panels on all the South facing roof areas (4122 m^2). Roof areas are measured from a general plan of the area. For simplicity, shading between building elements and trees are not taken into account.
	2B: A scenario called " Extended PV system – S – E-W) is built by using the scenario 1 in addition to simulating the PV production given by PV panels installed on all the South, East, and West facing roof areas (8268 m^2). East and West facing roof areas are multiplied by a 0.5 factor to consider the time they are exposed to direct sunlight. For simplicity, shading between building elements and trees are not taken into account.

The objective of scenario 1 is to show the actual energy use measurements and estimated electricity production, separated into net delivered electricity, use of gas, and heat generation from the GSHP. The objective of scenario 2 is to evaluate to what extent the roof in Mære Landsbukskole can be utilized further to increase the local energy generation.

In addition to this, an attempt to estimate the energy demand for Mære before the renovation using the PI-SEC tool[8] was carried out, by making assumption about the buildings and construction year of the administration buildings (Building A,B,C,D) and dormitory building (Building I). In this scenario, it is assumed that heating was supplied to Mære from existing fossile fuel boilers and not local heating with GSHP. However, this comparative study was discarded in the report, as separate heating measurements for the selected buildings were not available, and it was not possible to create a meaningful estimation of the energy use for the entire Mære area due to the composition of buildings in the area (both residential, service and industrial/agricultural). Hence, a comparison of results from the two scenarios was not possible.

8.2 Methodology

Collection of Energy use measuremtents

Energy measurements from Mære are collected in the Optima Energi data centre from Entro AS (www.optima.entro.no), which holds data measurements of most of the different meters (for energy use, energy production and flow) which are installed in Mære. Measurements with weekly resolution is available for all meters in the Optima Energi data centre. Hourly resolution is only available for some of the meters, with measurements starting from different dates (Table 33).

The electricity use is measured in each of the different buildings separately with weekly and annual resolution. For some of the buildings there are measurements available with hourly resolution, however, at the start of this case study, a full year of hourly measurements was only available for some of the buildings, as shown in Table 33. There is a single electricity meter in each building, and not separate electricity meters for the different energy porpuses in the buildings. The electricity meters installed in the buildings measure the electricity use only (and not the net delivered electricity) as the PV-systems are connected to separate meters.
Electricity used by the GSHP is measured separately with hourly resolution (since 2020).
To get the total annual electricity use for Mære, the electricity use from each building was added together with the annual electricity used in the GSHP.

Thermal heat production from the GSHP is measured separately with hourly resolution.
Energy use produced from the gas boiler (top heater) is measured separately with a weekly resolution.
The buildings do not have separate meters for thermal energy use.

Table 33. List of buildings in Mære Landsbrukskole and the availability of hourly measurements of electricity use in each building.

Building name	Availablity of hourly measurements of electricity Optima Energi data centre
Mære A, B, C	08.03.2021
Mære D, H	08.03.2021
Mære F	From 27.04.2016
Mære G	From 07.02.2020
Mære I	Not reported
Mære J	Not reported
Mære L	Not reported
Mære M	From 01.01.2015
Mære N	From 20.11.2018
Mære O	From 22.12.2020
Mære Q	From 22.12.2020
Mære R	From 22.12.2020
Mære S	From 22.12.2020
Mære W, X	From 01.04.2019
Mære Y	From 08.03.2021
Mære Z	From 01.01.2015
Mære Kåret og Rabben	From 16.05.2019

PV production

The electricity production from the PV system in Building I (dormitory) is measured at a separate meter, and reported in the Optima Energi data centre at hourly resolution (from May 9th, 2020 with several hours missing). There is no separate meter installed for the PV system on Building Z (calf barn). Due to this, the electricity production of both meters have been estimated through the means of simulations.

The calculation of PV production scenarios 1, 2a and 2b was performed using the PVGIS webtool (https://ec.europa.eu/jrc/en/pvgis). Hourly timeseries of solar radiation was downloaded from PVGIS for the years 2005 until 2016 at the location of Mære landbruksskole. The solar radiation profiles were averaged to produce a typical solar radiation year for Mære. PV production was then calculated by multiplying the hourly solar radiation data with efficiency of the PV system and overall system losses. The efficiency of the PV system installed in Mære was then adjusted in the simulation to match the simulated result with the actual measurement of PV production for 2020 from the panels in building I. The PV modules were estimated to have an efficiency of 18% while the system efficiency was estimated to have an efficiency of 83 %, and scaled according to the total PV area (in building I and Z).

Scenario 2a was then derived from the above-mentioned simulated PV system by adding and estimating the effect of extending the PV area to include all the south facing roof areas (4122 m2). Scenario 2b was simulated by adding and estimating the effect of extending the PV area to include all the installed on all the South, East, and West facing roof areas (8268 m^2).

8.3 Results

Measured weekly energy use

Figure 60 (left) shows the weekly electricity use (sum of all electricity meters and GSHP meter) and gas energy use (for the top heating) of the Mære pilot.

The profile indicates seasonal variations due to increased heating demand during the winter, which increase the electricity use for the GSHP.

The values given in the duration curve in Figure 60 (right) are obtained by dividing the total weekly energy demand by the hours for each week, giving weekly averaged hourly values, before sorting the values in decending order of magnitude. This gives a load duration curve with artificially low peaks and troughs.

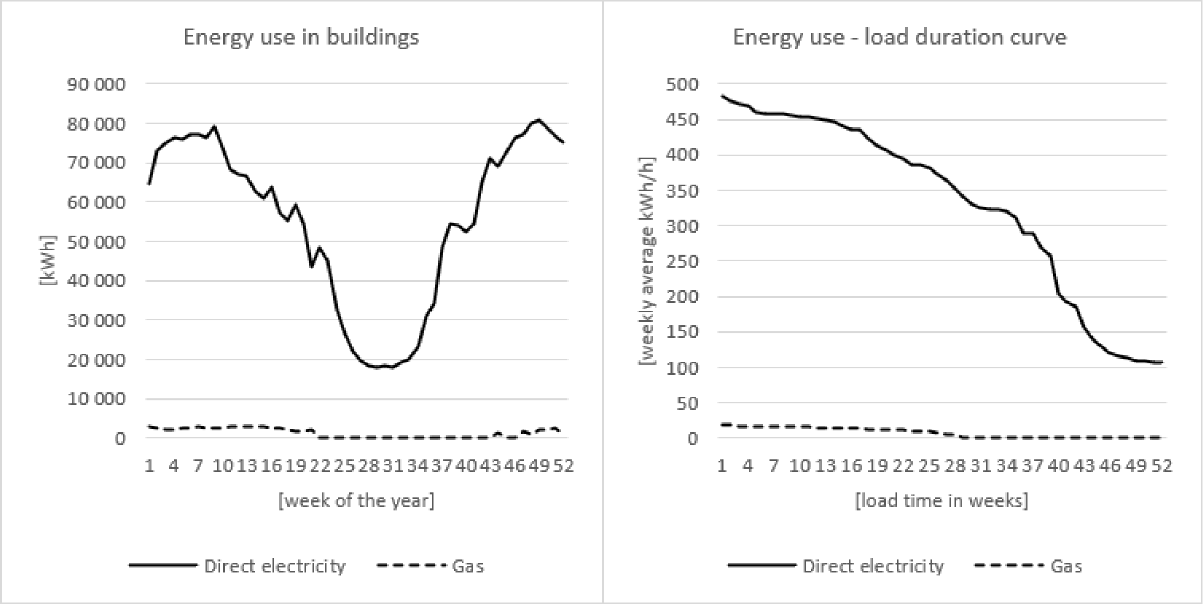

Figure 60. Energy use in all Mære buildings. Left measured weekly energy need over one year. Right: estimated duration curve of the energy load expressed as a weekly averaged hourly load.

Estimated thermal energy production of the GSHP

Figure 61 shows the estimated hourly thermal energy produced by the Ground Source Heat Pump which is connected to the local heating grid. The measurements are from 2020. The 1-year profile given on a hourly resolution is shown on the left and the duration curve is shown on the right.

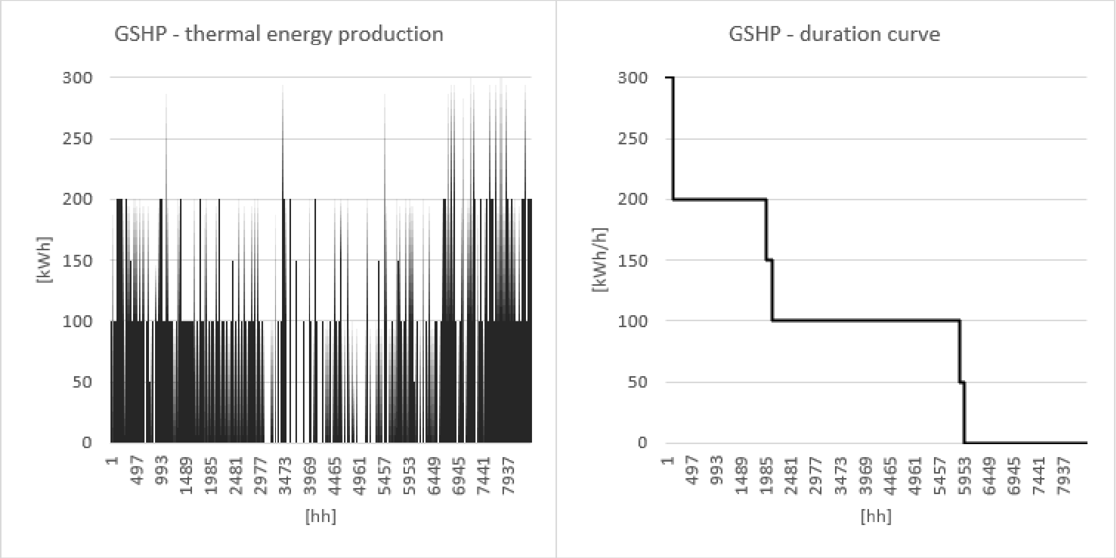

Figure 61. Thermal energy produced by the GSHP. Left: hourly production over one year. Right: duration curve 1-hour resolution).

Measurement of PV electricity production in building I

Figure 62 shows the hourly electricity production from the PV system installed on the Building I (apartment building) in the period 09.05.2020-08.05.2021, as hourly measurements of PV production dating prior to this period is unavialble. The right figure shows the load duration curve of the PV energy production. Surplus/exported electricity from the PV system in building I shown in yellow

PV electricity production from Building Z is not shown, as this PV system does not have a separate energy meter.

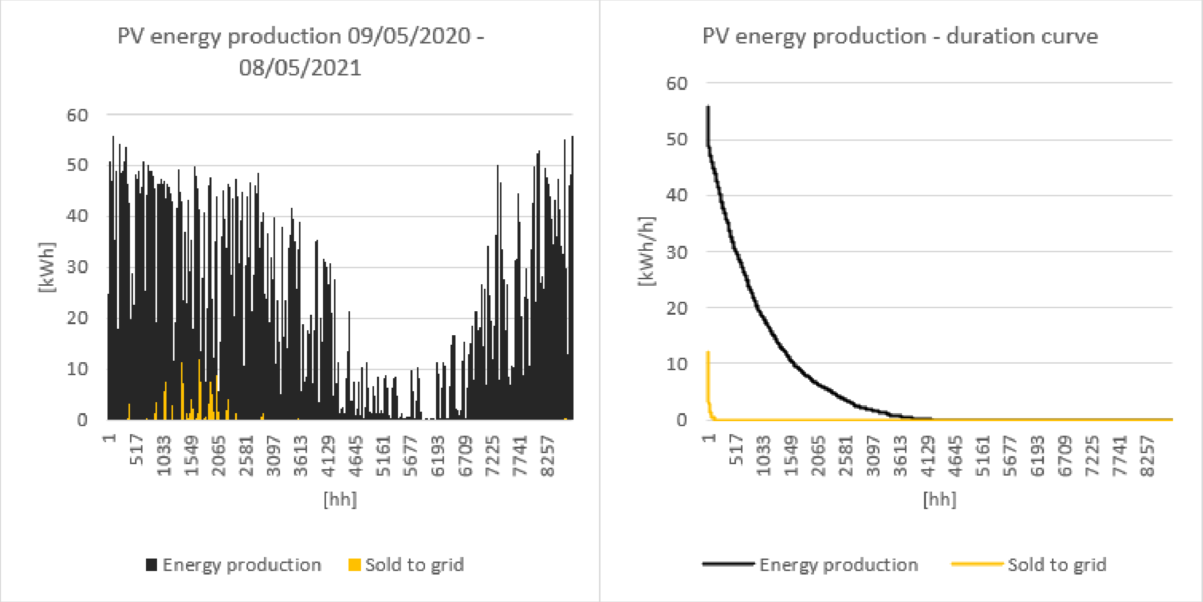

Figure 62. PV production and excess sold to grid of Building I. Left: hourly production over one year. Right: duration curve (1-hour resolution).

Estimated PV electricity production

Figure 63 shows the energy balance of annual electricity use (calculated as weekly averaged hourly loads as given in Figure 60) and electricity production from PV at Mære estimated for the scenarios 1, 2a and 2b using PVGIS.

The Scenario 1 represents the existing situation in all buildings of Mære Landsbrukskole (measurements of 2020), whereas Scenarios 2a and 2b (increased area of PV production) represent the energy use measured for Scenario 1 plus the simulated electricity production from additional PV areas. The area covered by PVs in Scenario 1 is 492 m^2, given by two PV systems. The areas covered by PVs in Scenario 2a and 2b are 4 122 m^2 and 8 286 m^2, respectively. Overshading between buildings and from trees was not accounted for, nor different roof inclinations, as such information was unavailable.

The annual electricity production from PVs is simulated to be 75 011 kWh, 628 447 kWh, and 1 605 822 kWh for Scenario 1, 2a and 2b, respectively. Scenario 2c has the potential to compensate for 54% of the Mære electricity use on the annual level.

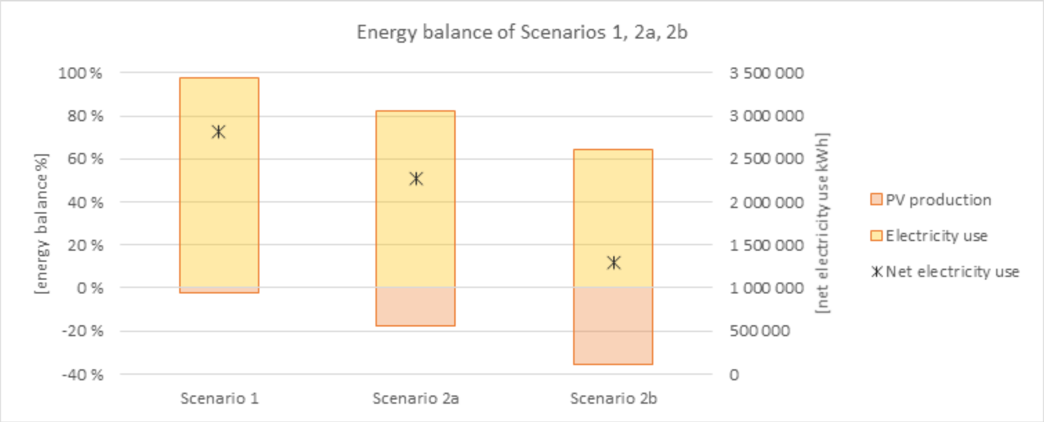

Figure 63. Energy balance of Scenarios 1, 2a and 2b

Figure 64 compares the hourly estimation of electricity production in scenarios 1, 2a and 2b against the electricity use (expressed as a weekly averaged hourly load from Figure 60). The self-consumption and self-generation have been calculated from these plots. Self-consumption is defined as the proportion of on-site generation consumed by building, and self-generation is defined as the proportion of electrical demand met by on-site generation. Given that the hourly electricity use is calculated from averaging weekly values, this may affect the self-consumption and self-generation values (which is supposed to be calculated from hourly values).

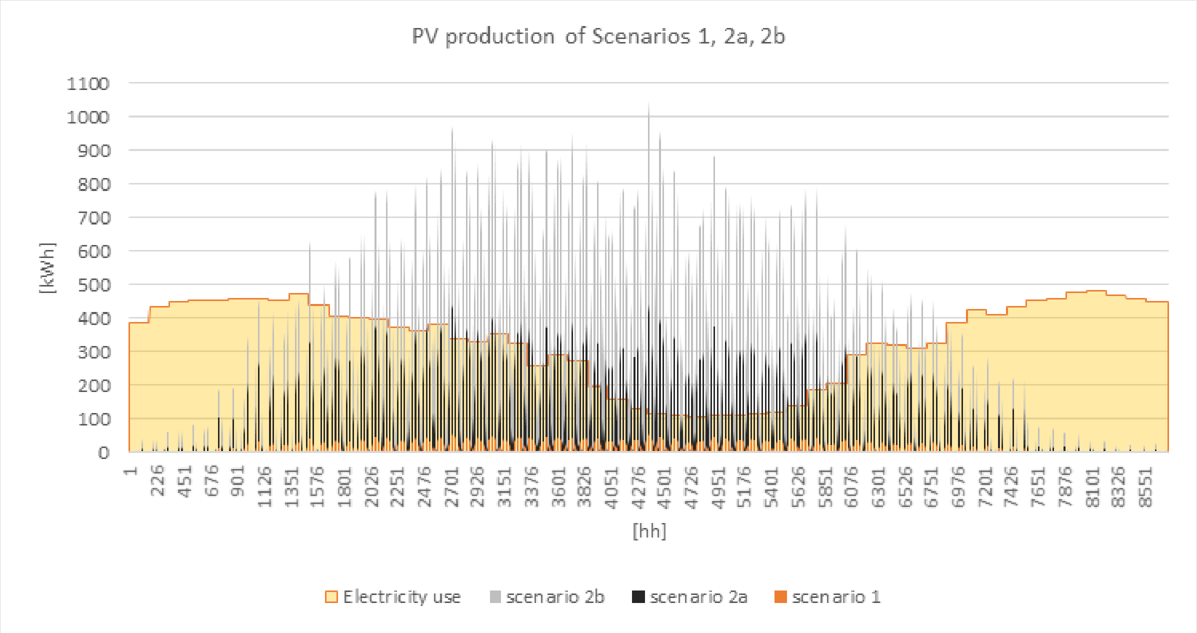

Figure 64. Results of scenario 1, 2a and 2b. Measured electricity use (weekly average) and PV production (hourly data).

Figure 65 shows the load duration curve of electricity use (weekly averaged hourly values) and net delivered electricity in scenario 1, 2a and 2b. The figure shows that little export of electricity occurs in scenario 1, with increasing hours of export in scenarios 2a and 2b. In reality, the mismatch between export and import is likely to be bigger, as the hourly electricity use is based on weekly averages, and there would in reality be a larger variation in the electricity use from one hour to another.

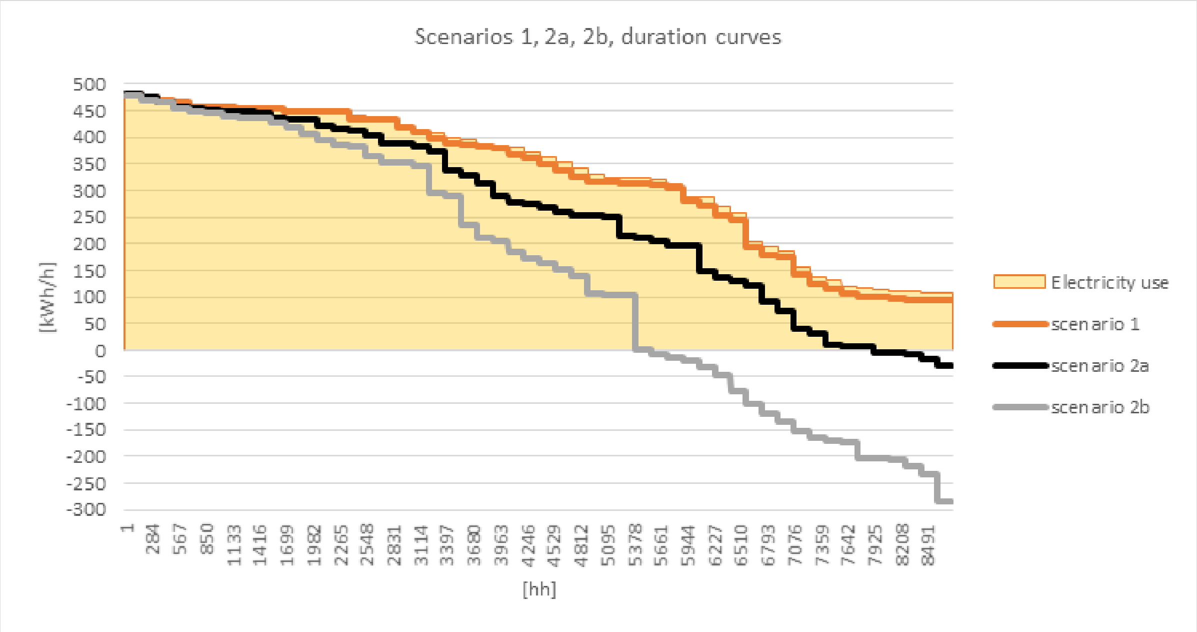

Figure 65. Load duration curve of electricity use (weekly averaged hourly values) and net delivered electricity in scenario 1, 2a and 2b.

Summary

A summary of the results and the energy and power KPIs calculated for Mære is shown in Table 34 (total values) and Table 35 (per m^2). Grey marked values indicate values which are not required, but give more detailed information about the energy use in Mære. Values in grey cursive letters indicate values which must be collected from hourly data, but where weekly average hourly data has been used instead. These values hold high uncertainty.

Import and export of energy has not been calculated.

Table 34. Summary of the energy and power KPIs calculated for Mære in each of the three scenarios.

		Scenario 1	Scenario 2a	Scenario 2b
Net energy demand in buildings [kWh/year]	**Total**	-	-	-
Energy use [kWh/year]	EL	2 889 474	2 889 474	2 889 474
	Electricity for GSHP	380 586	380 586	380 586
	Gas	67 251	67 251	67 251
	Local heating	1 318 727	1 318 727	1 318 727
Generation [kWh/year]	EL. PV	-74 208	-628 449	-1 604 748
	Heat from GSHP	1 251 476	1 251 476	1 251 476
Peak load [kWh/h]	*EL*	*385.7*	*385.7*	*385.7*
	EL GSHP	100	100	100
	Heat generation GSHP	300	300	300
Peak export [kWh/h]	*EL*	*0*	*33*	*421*
Utilization factor	*EL*	*68 %*	*69 %*	*79 %*
Self-generation	*EL*	*3 %*	*18 %*	*29 %*
Self-consumption	*EL*	*100 %*	*81 %*	*51 %*

Table 35. Summary of the energy and power KPIs calculated for Mære in each of the three scenarios per m^2.

Per m^2 (total area 23 190 m^2)		Scenario 1	Scenario 2a	Scenario 2b
Net energy demand in buildings[kWh/m^{2}year]	Total	-	-	-
Energy use [kWh/m^{2}year]	EL	124.6	124.6	124.6
	Electricity for GSHP	16.4	16.4	16.4
	Gas	2.9	2.9	2.9
	Local heating	56.9	56.9	56.9
Generation [kWh/m^{2}year]	EL. PV	-3.2	-27.1	-69.2
	Heat from GSHP	54.0	54.0	54.0

8.4 Flexibility: Typical days

Studying the typical hourly energy use on winter and summer workdays may give a better understanding of the flexibility potential and the potential for reducing peak loads during peak hours. Studying the typical winter workdays may help give a better understanding of the flexibility potential on winter days aimed at reducing peak loads during peak hours. The peak export of electricity in areas with PV typically occur during the summer.

As a reference scenario study has not been conducted in this case, a comparison of the typical daily profiles for electricity and heating in Mære in the ZEN-scenario and reference scenario can not be presented in this chapter. However, typical daily profiles of electricity from each of the buildings in Mære, as well as Mære in total (over one year) created from available data is shown in this chapter. Studying these typical daily profiles can show what time of the day the different buildings in Mære experienced peaks of electricity use, and to what extent different buildings contribute to the overall electricity use of Mære

As mentioned previously, although hourly electricity use measurements are available for the buildings in Mære, many have hourly data available for less than one year (as detailed in Table 33)
Figure 66 shows the daily profiles for each months of the buildings in Mære for which hourly measurements are available. Yellow, green and blue lines represent summer, spring/autumn, and winter months, respectively. The figure clearly shows how different buildings in Mære have largely different profiles of electricity use, in relation to both the total electricity use (kWh/h) and the daily variation. This is because farm-related activities are different from building to building and few of them host residential- and/or office-related activities (see Table 33 for details).

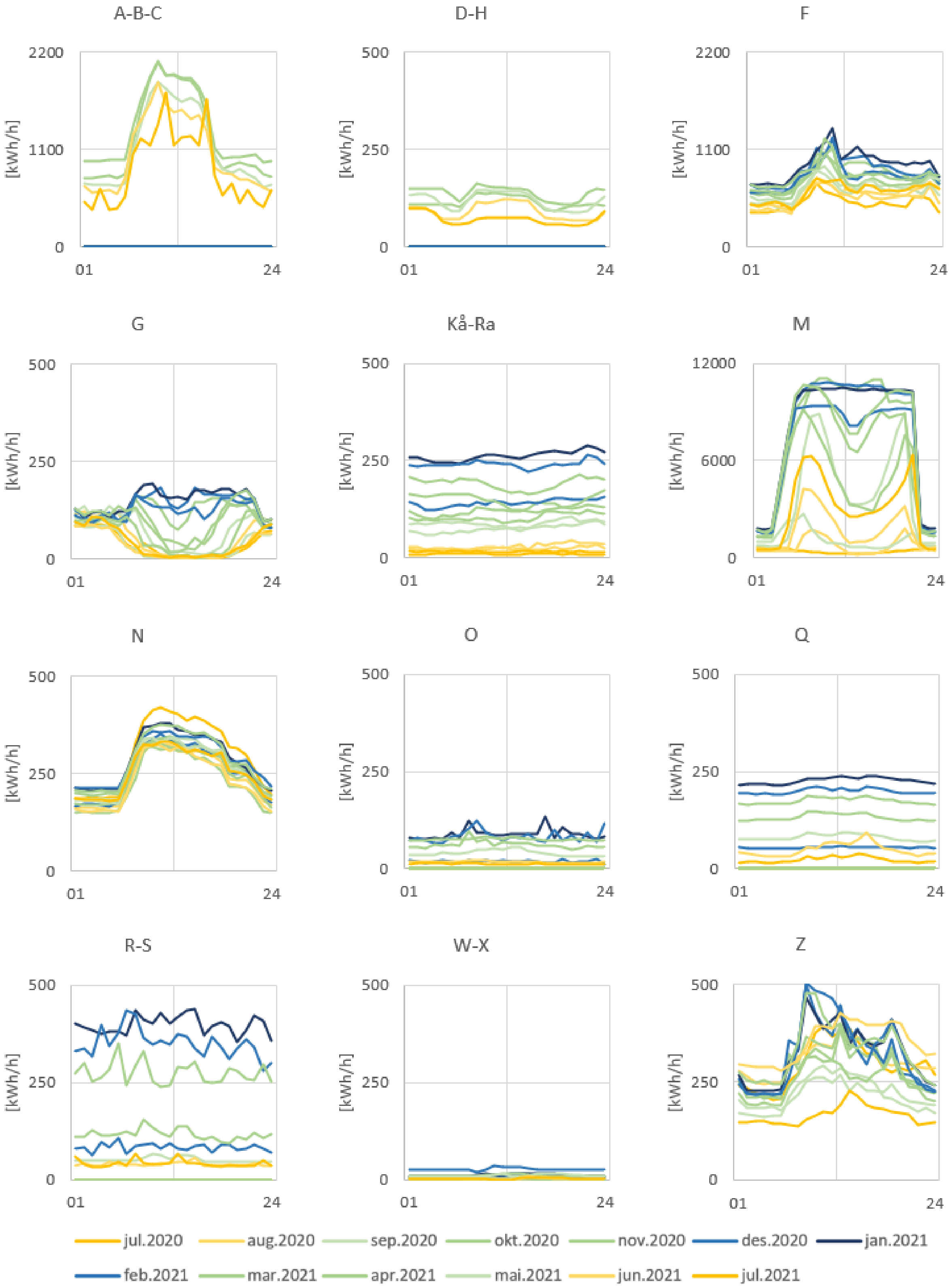

Figure 66. Typical daily electricity use for each month and each building in Mære (some months are missing for some of the buildings).

A typical day for a total year for all of the buildings which hourly data could be obtained (see Table 33 for details on period of available data) is shown in Figure 67. The typical daily profile has been plotted by summing the measured electricity use for the same hours of the day for all the days in the period between 01.07.2020 at 00:00 and 30.06.2021 at 23:59. The figure also shows the superimposed typical daily profiles for the three PV production scenarios (1, 2a and 2b).

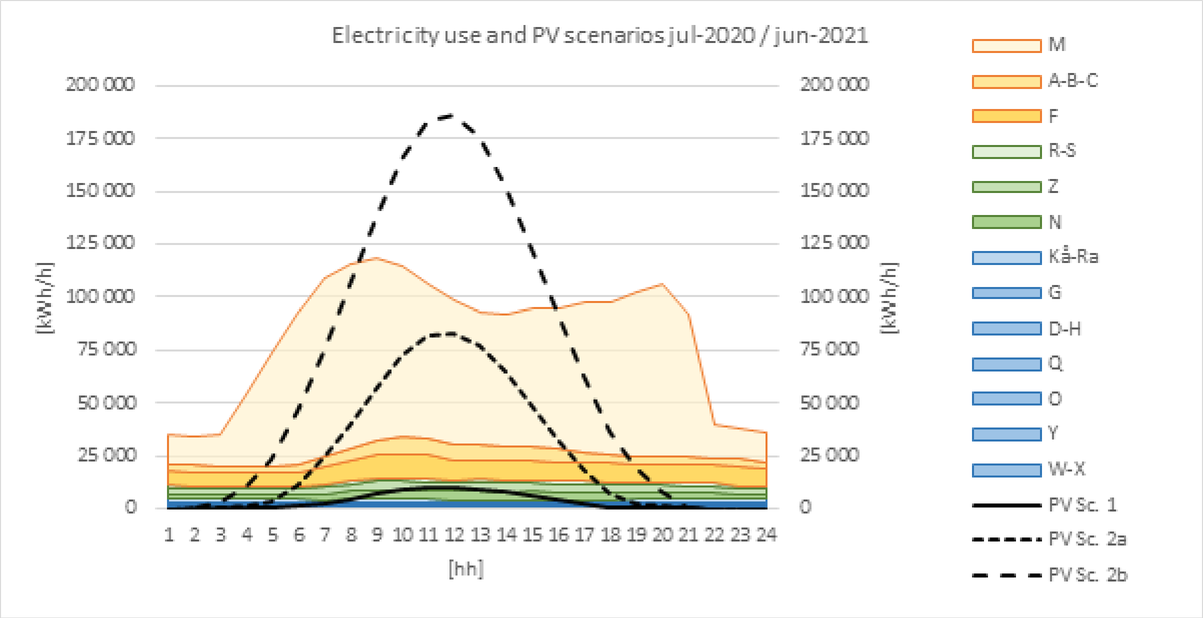

Figure 67. Typical daily profile of electricity use over one year for all buildings in Mære (based on available data).

9. KPI evaluation and summary of the results

This chapter show a summary of results for the main energy and power KPIs suggested in the first chapter for 5 different cases studies. The results from the case study of Mære have not been included in the comparative study in this chapter due to the lack of hourly data, and because it was not possible to derive a meaningful reference scenario for Mære.
The main KPIs for energy and power were calculated based on estimated values from simulations in 4 of the cases (Ydalir, Oksenøya, ZVB and Dolvik), and from measurements in the last case (Campus Evenstad).

ENE2.1 Energy need in buildings

ENE2.1 shows the total simulated energy need of all the buildings in a pilot area per m^2. The net energy need in buildings is an indicator which must be simulated as it shows the energy need of the building envelope when the losses in the buildings' heating system is not accounted for. Due to this, the energy need has not been calculated for Evenstad, as Evenstad is in the operational phase and the KPI calculations from Evenstad is based on energy use measurements.

The reduction in net energy demand calculated for the pilots is between 8 and 32 %. Note that the areas are all new settlements. Areas with more existing buildings and different compositions of building categories might get different results. The cases where the net energy demand has been calculated assuming minimum requirements in from the TEK/the passive house standard in the PI-SEC tool (Ydalir and Oksenøya) seem to suggest a larger difference in the net energy demand compared to the cases where the energy demand has been calculated using IDA ICE archetypes.

Table 36. Summary of ENE2.1 (net energy use in buildings) calculated for the five different cases.

ENE2.1 Net energy use					
Case	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad
Difference	**-27 %**	**-32 %**	**-8 %**	**-12 %**	Not calculated
Scenario ZEN	75	113	78	71	
Scenario REFERENCE	104	165	85*	81*	

*Average of the two slightly different reference case models.

ENE2.2 Delivered (imported) energy

ENE2.2 evaluates the delivered energy on the neighbourhood assessment level for all energy carriers individually. The delivered energy should be calculated as the hourly mismatch between energy use and energy generation. The purpose of ENE2.2 is to reduce the delivered energy to the area, and hence reduce climate gas emissions to the area.

When the results for ENE2.2 in the ZEN areas are compared to a reference case with electric heating, the delivered electricity is reduced by 66 % - 78 %. When compared against a reference case with non-electric heating, the delivered electricity is reduced between 28 % and 58 % in the ZEN-scenarios.

The district heating energy use is reduced by 9 % - 33 % in the ZEN scenarios compared to the reference cases with district heating. Overall delivered energy (sum of all carriers) is reduced by 14 % - 35 % in the ZEN scenarios compared to the references.

Table 37. Summary of ENE2.2 (delivered energy) calculated for the five different cases.

ENE2.2 Delivered energy						
Electricity	Case	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad
	Difference	**-28% ; -78%**	**-51% ; -71%**	**-58% ; -74%**	**-30% ; -73%**	**-52% ; -66%**
	ZEN	30	56	22	22	57
	REFERENCE DH	42	115	53	32	119
	REFERENCE EL	134	194	85	83	170
Bio	Case	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad
	Difference	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**156% ; n.a**
	ZEN	0	0	0	0	141
	REFERENCE DH	0	0	0	0	55
	REFERENCE EL	0	0	0	0	0
District heating	Case	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad
	Difference	**-33% ; n.a**	**-9% ; n.a**	**0% ; n.a**	**-17% ; n.a**	**n.a.% ; n.a**
	ZEN	63	70	35	41	85
	REFERENCE DH	94	77	35	49	85
	REFERENCE EL	0	0	0	0	85
Total	Case	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad
	Difference	-31% ; -30%	-34% ; -35%	-35% ; -32%	-22% ; -25%	14% ; 16%
	ZEN	93	126	58	63	283
	REFERENCE DH	135	192	88	81	260
	REFERENCE EL	134	194	85	83	256

ENE2.3 Self-consumption and self-generation

Self-consumption is and indicator that tells us to what degree the electricity that is produced in an area is used directly in that area (and that does not need to be exported to the energy-grid). Self-generation tells what share of the energy use in an area which is covered by self-generated energy. The purpose of ENE2.3 is to increase the degree of self-consumption and self-generation in an area.

Areas with low self-generation tend to have a high self-consumption.
The factors also seem to reflect the composition of building types in the area. Ydalir, ZVB and Dolvik have a high share of residential buildings, which tend to have a "dip" in energy use during the middle of the day, which is during the same time which the generation from PV is at its highest, causing a reduced self-consumption. In Oksenøya and Evenstad, which consist of mostly service buildings, the daily peaks occur during the middle of the day and coincides with the daily PV production, hence increasing the self-consumption.

Table 38. Summary of ENE2.3 (self-consumption and self-generation) calculated for the five different cases.

ENE2.3 Self-consumption and self-generation (ZEN-scenario)					
Case	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad*
Self-generation	20 %	17 %	46 %	57 %	32 %
Self-consumption	76 %	96 %	51 %	33 %	99 %

*Biobased heating

POW3.1 Peak load

The peak load indicator refers to the maximum positive hourly import load of electricity/district heating to the neighbourhood during an operational year.

The peak electricity load is reduced by 63 % - 84 % in the ZEN scenarios when compared to reference cases with electric heating. When compared to references with no/low electric heating, the reduction in peak load of electricity is between 1 % and 49 %, the highest being Evenstad. The low reduction in the other cases can likely be explained as the little difference in electric specific energy use in the ZEN case and reference case (pretty similar building standards) and little to no electricity production in the peak hour.

The reduction in the peak use of district heating energy use in the ZEN scenarios compared to the reference case with district heating is calculated to be between 14 % to 35 % which can be explained by the improved building envelopes.

Again, we can observe that the method used in the estimation (PI-SEC vs. IDA ICE) seems to affect the results of the KPIs.

Table 39. Summary of POW3.1 (peak load) calculated for the five different cases.

POW3.1 Peak load						
Electricity	Case	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad
	Difference	**-11% ; -84%**	**-12% ; -83%**	**-2% ; -72%**	**-1% ; -71%**	**-49% ; -63%**
	Scenario ZEN	534	397	629	183	247
	Scenario REFERENCE 2	599	451	644	184	481
	Scenario REFERENCE 1 EL	3 285	2 337	2 252	625	675
District heating	Case	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad
	Difference	**-33% ; n.a.**	**-35% ; n.a.**	**-14% ; n.a.**	**-16% ; n.a.**	0 %
	Scenario ZEN	1953	1234	1641	410	358
	Scenario REFERENCE 2	2934	1912	1903	489	358
	Scenario REFERENCE 1 EL	0	0	-	-	358

POW3.2 Peak export

The peak export indicator refers to the maximum net hourly export load of electricity (when the electricity production is higher than the electricity use) from the neighbourhood during an operational year. If there is no net export, then the peak export is equal to zero.

The absolute in Table 40 shows the relationship between the peak export and the peak import. When the absolute is higher than 100 %, the peak export is larger than the peak import. When the absolute is lower than 100 %, the peak import is higher than the peak export.

In Ydalir, ZVB and Dolvik, the peak export is estimated to become larger than the peak import in the ZEN-scenario. In Oksenøya, and Evenstad the peak export is lower than the peak import.

Table 40 Summary of POW3.2 (peak export) calculated for the five different cases.

POW3.2 Peak export of electricity					
	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad (Biobased heating)
Abs(Pexport/Pimport)	**107 %**	**55 %**	**303 %**	**272 %**	**20 %**
Peak export	-573	- 217	- 1 909	- 497	- 49
Peak import	534	398	629	183	247

POW3.3 Utilization factor

The utilization factor shows how much of the maximum grid connection capacity is required by the neighbourhood and is calculated for electricity and district heating. The maximum value for the utilization factor is 1. A high utilization factor reflect high utilization of the grid.

The utilization factor is affected by whether the the energy carrier is used for space heating. Generally, if electricity is used only for electric specific purposes, the load duration curve will become less steep, and more "flat", and hence increase the utilization factor. If electricity is used for space heating, the load duration curve becomes more steep, with high peak loads, thus decreasing the utilization factor.

For campus Evenstad, the utilization factor for electricity has been calculated based on approximately 3000 hourly values (as opposed to 8760 hours in a year for the other scenarios). This causes some strange behaviour for the utilization factor where the ZEN scenario and the reference scenario with bio heating receives a lower utilization factor for electricity compared to the reference scenario with electric heating.

The ZEN scenario seem to have a reduced utilization factor for electricity use compared to the reference case without electric heating (reference 2) and a higher utilization factor compared to the reference case with electric heating. The reduced utilization factor would indicate that the relationship between the total net delivered electricity and the peak electricity use is worsened. This could point to a challenge in utilizing the grid connection, but, as we know, the peak load of electricity is reduced in the ZEN scenarios when compared to the reference cases. The results of this could indicate that the utilization factor works poorly for expressing the grid utilization and how well the pilots facilitates the transition towards a decarbonised energy system.

Table 41 Summary of POW3.3 (utilization factor) calculated for the five different cases.

POW3.3 Utilizaton factor						
Electricity	Case	Ydalir	Oksenøya	ZVB	Dolvik	Evenstad
	Scenario ZEN	0.50	0.47	0.37	0.37	0.23
	Scenario REFERENCE 2	0.61	0.57	0.57	0.55	0.28
	Scenario REFERENCE 1 EL	0.37	0.30	0.40	0.30	0.32
District heating	Scenario ZEN	0.28	0.19	0.30	0.16	0.25
	Scenario REFERENCE 2	0.28	0.20	0.30	0.19	0.25
	Scenario REFERENCE 1 EL	n.a.	n.a.	n.a.	n.a.	0.25

POW3.4 Load flexibiliy

The load flexibility indicator(s) will reflect how well the neighborhood exchanges energy with the surrounding energy system (electric and district heating) in a **flexible** way. These KPI will be developed in subsequent versions of the ZEN definition and will likely be calculated at either the neighborhood assessment level or building assessment level, with an hourly or sub-hourly resolution. Since the coordination of energy flows with smart grids (both electric and thermal) occurs at an hourly or sub-hourly level, the focus is on the optimisation of the net load profiles on typical days, distinguishing between seasons (e.g. winter, summer) and weekdays (e.g. weekday, weekend). The load flexibility indicators will reflect the difference in load profiles in a reference scenario, where there is limited control and demand response.

The report has presented typical days (winter and summer) for the pilots. The effects of control strategies and energy storage have not been investigated. Nonetheless, the typical daily profiles show clear differences in typical daily profiles for net delivered electricity. The use of electricity for heating (reference 1) will greatly affect the typical profiles in the winter. PV electricity production will create a large difference in net delivered electricity during the middle of the day, often with a net export of electricity. The typical profiles for district heating energy use show that the ZEN scenario have typically the same shape as the reference scenario, but shifted down, with lower peaks.

10. Discussion

The scope of this report has been to test the FME ZEN KPIs for Energy and Power on 6 different pilot areas and evaluate the KPIs. The KPIs were calculated for the pilot areasYdalir, Oksenøya (Fornebu), Zero Village Bergen, Dolvik, Campus Evenstad and Mære landbruksskole. The testing shows that the cases get different results for the ZEN scenarios compared to the reference scenarios.

The main KPIs evaluate the difference between the optimal "as-planned" ZEN-scenario and one or more reference scenarios. When the pilot is in the operational phase, measurements should be used for KPI calculations as far as possible. There are several challenges linked to using measurements for the KPI calculations. Obtaining measurement data is often time consuming, and there is usually missing data points and few, disorganized meters available. Hourly measurements are not always available, and measurements may be missing for periods of the year. This can affect the results of the KPIs, and/or make it impossible to calculate the KPIs. In order to derive a meaningful reference scenario, one could either compare against a simulated reference case or manipulate the measurements to create more scenarios, as done in the case for Evenstad. There is a need for a strict guideline on how the reference case should be formed for the pilots in the operational phase.

When the KPIs are estimated throught the means of simulations (for pilots in the planning phase), the results of this case study indicate that the methodology and simulation program used may affect the results. The difference can be spotted both for the existing KPIs, but also for typical daily profiles. There appears to be larger variations in the daily profiles when PROFet, which is based on measurements, is used to generate the load profile, compared to when IDA ICE, which is based in SN-NSPEK 3031[23] is used. Updated guidelines for calculating the KPIs for energy and power should take this into account.

The impact of electric vehicle charging and other forms of mobility have not been fully investigated for all of the cases. The load curve for charging of electric cars was only estimated for Ydalir and Oksenøya, but based on methods which are not standardized. There is a need for standardized methods for estimation of vehicle charging loads, and to establish system boundaries for energy use for mobility/chargers for the energy and power kpi calculations.

The effects of energy storage solutions and control systems/strategies have not been investigated in this report. Several of the pilots plan on using smart control systems and storage solutions, but the effects of this has not been evaluated in this report. There is still a need for standardized methods for estimation of the load curves for areas with smart controls and storage solutions.

The case study has shown that the utilization factor may not be working as intended. The ZEN scenario seem to have a reduced utilization factor for electricity use compared to the reference case without electric heating (reference 2). The reduced utilization factor would indicate that the relationship between the total net delivered electricity and the peak electricity use is worsened. This could point to a challenge in utilizing the grid connection, but, as we know, the peak load of electricity is reduced in the ZEN scenarios when compared to the reference cases. The results of this could indicate that the utilization factor works poorly for expressing the grid utilization and how well the pilots facilitates the transition towards a decarbonised energy system.

The process of working with the KPI calculations show that a professional with high competence in energy use measurements and calculations is needed to calculate the documentational KPIs (hourly load profiles for energy use) and to generate reference scenarios. To overcome this, there is a need for a standardiced tool with a simple interface and standardized methods.

The aim of this report has been to calculate the energy and power KPIs for several cases and evaluate the KPIs based on the results. At the end of FME ZEN, the KPI results will be used to evaluate the performance of each pilot against the ZEN definition and award the pilots according to a points system. The points and threshold values are still undecided and must be evaluated in further work. The results of the study will be used in further work to establish threshold values for evaluating the pilots against the ZEN definition.

11. Conclusion

The scope of this report has been to test the suggested FME ZEN KPIs for Energy and Power on 6 different pilot areas.The KPIs were calculated for the pilot areas are Ydalir, Oksenøya (Fornebu), Zero Village Bergen, Dolvik, Campus Evenstad and Mære landbruksskole.

The testing of the KPIs for Energy and Power shows that the pilots get different results in the ZEN scenarios compared to the reference scenarios.

- The energy savings in net energy demand is only estimated to be between 8-32 %. This KPI has only been estimated for new areas, and the reduction in net energy demand is small in the ZEN scenario, due to the reference buildings already being rather efficient.
- The electricity savings is estimated to be a lot higher. The net delivered electricity is expected to be reduced between 28 – 58 % in the ZEN scenario (compared to the reference case with district heating) due to efficiency measures and local electricity production. When compared to a reference case with electric heating, the reduction becomes 66 % - 78 %, due to efficiency, local electricity production and the transition from electric heating to non-electric heating (district heating and bio based local heating).
- The testing also shows some potential for large reduction in the peak load (peak import), as a consequence of both more energy efficiency and reduced net delivered electricity. The peak export of electricity may however become large, up to 3 times (300%) of the peak import in the pilots where large areas of PV panels are planned (ZVB and Dolviken). In the latter case, better Energy KPIs (and GHG KPIs during the user phase) come into conflict with worse Power KPIs. This may also cause worse results for the economy KPIS, since the investment in grid capacity depends on the highest peak, regardless of it being import or export. It is also difficult to gauge the effect on the power system of an "overdimensioned" PV systems that cause large export of energy (with large peaks) in the summer without contributing to reduce the electricity import (nor the peak load) in the winter.

The case studies suggest that when the KPIs are estimated through the means of simulations (for pilots in the planning phase), the methodology and simulation programs used may have an effect on the results. When a pilot is in the operational phase, measurements should be used for KPI calculations as far as possible. Using measurements for the KPI calculations are linked to several challenges as obtaining measurement data is often time consuming, and there is usually missing data points and few, disorganized meters available.

The reality is complex, and a collection of of KPIs should reflect the differenct aspects of the effects of the measures taken in the different pilots. The KPIs seem to perform their main role of providing a way to quantify and grasp the main features of a complex reality where different solutions/technologies might have conflicting effects. The process of working with the KPI calculations show that a professional with competence in energy use measurements and calculations is needed to calculate the KPIs for the pilots, and that there is a need for a standardized tool with a simple interface and standardized methods to simplify this process. There is still a need for further work on system boundaries, definition of the reference scenario, and finding standard methodologies. The results of the study will be used in further work to establish threshold values for evaluating the pilots against the ZEN definition.

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