Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

CONSEQUENCES OF LOCAL ENERGY SUPPLY IN NORWAY

A case study on the ZEN pilot project Campus Evenstad

ZEN REPORT No. 17 – 2019

S. Backe, Å. L. Sørensen, D. Pinel, J. Clauß, C. Lausselet, R. Woods | NTNU, SINTEF

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Consequences of Local Energy Supply in Norway: A case study on the ZEN pilot project Campus Evenstad

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Preface

Acknowledgements

This report has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). We acknowledge Zdena Cervenka who has initiated and motivated this report on behalf of the Norwegian Directorate for Public Construction and Property Management (Statsbygg). A special thanks goes to Igor Sartori and Karen B. Lindberg for helpful discussions along the way. Additional thanks go to technical staff at Campus Evenstad, Per A. Westgaard and Marius A. Kolby, for providing valuable input. We gratefully acknowledge the support from the Research Council of Norway and the Norwegian Directorate for Public Construction and Property Management (Statsbygg). We also acknowledge the Norwegian University of Science and Technology (NTNU) and SINTEF, as well as the ZEN partners: the municipalities of Oslo, Bærum, Bergen, Trondheim, Bodø, Elverum and Steinkjer, Trøndelag county, 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, 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 to plan, develop, and run neighbourhoods with net zero greenhouse gas emissions over their lifetime. Nine pilot projects are spread over all of Norway that encompass an area of more than 1 million m2 and more than 30 000 inhabitants in total. 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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Norwegian Summary

Konsekvenser og muligheter knyttet til lokal energiforsyning på Campus Evenstad

Denne rapporten vurderer Campus Evenstad på veien mot ZEN. Hensikten med rapporten er å vurdere hvilke tiltak som er relevante fremover for å realisere energimål knyttet til ZEN, og den skal gi en forståelse for potensial, konsekvens, verdi og status knyttet til ulike tiltak relatert til drift og investeringer i energisystemet på Campus Evenstad. Vi trekker blant annet frem konsekvenser av ulik grad av selvforsynt fornybar energi. Fire faktorer vurderes for energisystemet: (1) Verdiskaping og regulatorisk rammeverk, (2) fremtidige investeringer, (3) driftsoptimalisering og styringssystemer og (4) utslippsreduksjoner.

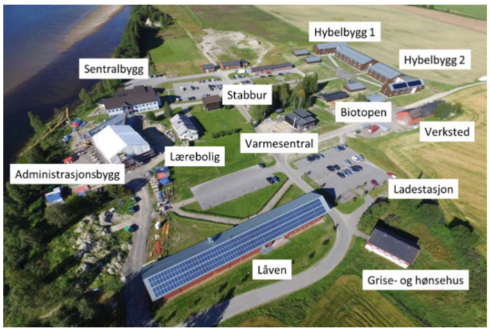
Lokal energiproduksjon er mest verdifull om den brukes innenfor nabolaget

Lokal elektrisitetsforsyning skaper økonomisk verdi hovedsakelig gjennom sparte kostnader som følge av mindre behov for strømimport (i.e. levert elektrisitet til nabolaget). Det skapes verdi både gjennom (1) redusert levert strøm, (2) redusert nettleie og (3) øvrige reduserte elavgifter siden alle disse leddene av strømregningen baseres på netto strømforbruk.

Vi har undersøkt potensielle fremtidige investeringer i energisystemet for Campus Evenstad ved hjelp av en optimeringsmodell. Våre analyser antyder at den mest kostnadseffektive måten å oppnå årlig kompensering av utslipp på er gjennom investeringer i flere solceller. I tillegg bør driftsoptimalisering gjennom planlagt ladning av batteri og elbiler eller foroppvarming av rom og vann for å redusere topplaster og minimere driftskostnader prioriteres fremover.

Campus Evenstad bør i størst mulig grad benytte lokale enheter ved energiforsyning for å minimere utslipp. Denne påstanden kan forsvares ved at de lokale enhetene kun er driftet på fornybare energikilder som erstatter energi produsert med fossile energikilder andre steder i Europa.

Rapporten kan brukes til å støtte videre beslutninger for Statsbygg på Campus Evenstad på veien mot ZEN. Den gir også innsikt i konsekvenser av energivalg generelt i ZEN som er relevant for øvrige ZEN-partnere. Arbeidet spenner på tvers av ulike fagfelt innenfor FME ZEN og binder sammen kunnskap knyttet til økonomiske, driftsmessige og tekniske aspekter ved utviklingen av et nullutslippsnabolag.



Campus Evenstad. Foto: Statsbygg

English Summary

Consequences and opportunities of local energy supply at Campus Evenstad

This report evaluates Campus Evenstad towards becoming a ZEN. The goal is to present which measures are most relevant to realize ZEN goals related to energy and develop an understanding of potential, consequences, value, and status related to operations and investments in the energy system at Campus Evenstad. We evaluate consequences of achieving different degrees of on-site supply of renewable energy. Four aspects are evaluated for the energy system: (1) Value creation and regulatory framework, (2) future investments, (3) operational control and optimization, and (4) emission reductions.

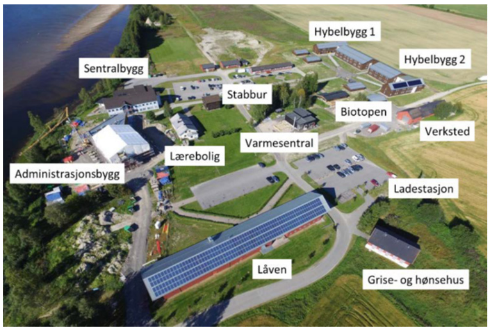
Local energy supply is most valuable when consumed in the neighborhood

Local power supply generates economic value mainly through saved costs of reduced grid import (i.e. delivered electricity to the neighbourhood). Saved costs are achieved due to (1) less delivered electricity, (2) reduced grid tariff, and (3) reduced taxes and levies as the billing is based on net metering of delivered electricity.

We have investigated future investments in the energy system at Campus Evenstad by using a linear programming model. The results show that investments in more PV is the most cost-efficient way of achieving annual compensation of emissions. In addition, operational control through planned charging of battery and electric vehicles or pre-heating space and water to reduce peak loads and minimize operational costs should be prioritized.

Campus Evenstad should aim at self-consuming local energy resources to minimize emissions. This is because the local energy resources are based on renewable resources that replaces energy supply based on fossil fuels other places in Europe.

This report can be used to support decisions for Statsbygg at Campus Evenstad on its way towards ZEN. More general, consequences of energy choices in a ZEN is investigated and will be relevant for other ZEN partners. The report incorporates several work packages in FME ZEN and connects economic, operational, and technical aspects in the development of a Zero Emission Neighbourhood.



Campus Evenstad. Foto: Statsbygg

Utvidet norsk sammendrag

Campus Evenstad består av omtrent 10 000 m^2 gulvareal ment for 250 studenter og 70 ansatte. Byggene eies og driftes av Statsbygg, og består av ulike bygg med varierende energibehov. Det nyeste administrasjonsbygget er klassifisert som et nullutslippsbygg (ZEB-COM). Høgskolen i Innlandet (HINN) er leietaker av samtlige bygg med unntak av to hybelbygg som leies av Samskipnaden i Innlandet (SINN). I tillegg til strømnettet eksisterer det fire kilder til energiforsyning på Campus Evenstad: Solceller, kombinert kraft- og varmeproduksjon (CHP) basert på bioenergi, solfangere og biokjel. Det finnes også en elektrokjel og panelovner som forsynes med strøm fra nettet. Videre er det tre eksisterende kilder til energilagring: akkumulatortanker til varmenett og solfangeranlegg, varmtvannstanker og stasjonært batteri. Det er også én planlagt kilde til energifleksibilitet: Bidireksjonal ladestasjon for elbiler (V2G).

Denne rapporten vurderer Campus Evenstad på veien mot ZEN. Hensikten med rapporten er å vurdere hvilke tiltak som er relevante fremover for å realisere energimål knyttet til ZEN, og den skal gi en forståelse for potensial, konsekvens, verdi og status knyttet til ulike tiltak relatert til drift og investeringer på Campus Evenstad. Vi trekker blant annet frem konsekvenser av ulik grad av selvforsynt fornybar energi på Campus Evenstad.

Analysene presentert i denne rapporten har ført til følgende anbefaling av videre utvikling av energisystemet på Campus Evenstad:

- **Steg 1:** Utvikle og validere et **felles system for datalogging** av import, produksjon og forbruk av energi. Vil gjøre det mulig å få innsikt i konsekvensene av steg 2, 3 og 4.
- **Steg 2:** Kartlegge og realisere potensialet for **økt energieffektivitet** for å redusere forbruk av strøm og varme. Hovedbygget er særlig relevant i denne sammenhengen.
- **Steg 3:** Optimere **nærvarmenettet**. Dette innebærer blant annet: (1) minimere elektrisk varmeforsyning, (2) utvide varmenettet til å levere større deler av varmebehovet på Campus, (3) vurdere temperaturnivå i varmenettet og (4) vurdere å tilknytte solfangere direkte til varmenettet.
- **Steg 4:** Installere øvrig **elektrisitetsproduksjon**. Solceller er mest relevant, men andre alternativer kan også vurderes.

De neste avsnittene oppsummerer funn knyttet til de fire faktorene:

1. Verdiskaping, regulatorisk rammeverk og forretningsmuligheter;
2. Fremtidige investeringer;
3. Driftsoptimalisering og styringssystemer;
4. Utslippsreduksjoner.

Verdiskaping, regulatorisk rammeverk og forretningsmuligheter

De lokale energienhetene på Campus Evenstad er hovedsakelig verdifulle gjennom (1) leveranse av energitjenester med minimale utslipp og (2) leveranse av energitjenester når eksterne kilder er utilgjengelige (e.g. ved strømbrudd). Energikildene med minimal marginalkostnad (solceller og solfangere) bidrar særlig til sparte driftskostnader, altså er kostnaden for disse energikildene hovedsakelig knyttet til investeringene. I 2018 var det inntil 18 års nedbetalingstid på solcelleanlegg for næringsbygg med antakelse om investeringskostnad på 12 NOK/Wp og 2,5 % diskonteringsrente [1], men med dyrere strømpris fra nettet, gunstige rammebetingelser (elsertifikater) og/eller lavere investeringskostnad (oppdaterte tall gir kostnader under 10 NOK/Wp) kan nedbetalingstiden reduseres ned mot 7 år innen 2030 (sammenlignbart med varmepumpe) [2]. Lokal produksjon av elektrisitet leveres i liten grad til det lokale nettet med dagens installerte enheter. Dermed blir det aller meste av produsert strøm brukt på Campus Evenstad. Dette betyr også at det stort sett er noe levert elektrisitet fra det lokale nettet.

Verdien av lokal elektrisitetsforsyning skapes hovedsakelig gjennom sparte kostnader som følge av mindre behov for levert strøm. Det skapes verdi både gjennom (1) redusert levert strøm, (2) redusert nettleie, og (3) øvrige reduserte elavgifter siden alle disse leddene av strømregningen baseres på netto strømforbruk. Dette gjør at spart levert strøm er inntil tre ganger så verdifullt som salg av overskuddstrøm. I tillegg oppnås ekstra inntekt gjennom salg av elsertifikater knyttet til lokalt produsert elektrisitet, og denne inntekten er uavhengig av om den produserte strømmen brukes lokalt eller leveres til nettet. All produsert elektrisitet skaper altså verdi, og lokal produksjon som brukes lokalt gir mest verdi. Det er foreløpig lite potensial for verdiskaping på salg av overskuddsenergi til strømnettet både (1) fordi det er lite kvantum og (2) fordi det er mindre økonomisk verdi enn å bruke energien selv med eksisterende avtaler. Vi estimerer at lokal elektrisitetsforsyning reduserte strømregningen med ca. 16-17 % i løpet av 2016. Campus Evenstad sparer mellom 0.6-0.8 NOK/kWh på lokalt produsert energi som brukes i nabolaget.

Eksisterende strømavtale gjør avregninger hver måned basert på forbruk og den høyeste målte effekttoppen de siste 12 månedene. En slik avtale gjør det vanskelig å selge fleksibilitet (f.eks. flytte forbruk i tid) siden det er krevende å garantere en lav effekttopp over 12 måneder. Dette er (1) fordi en på forhånd ikke vet når effekttoppen inntreffer og (2) fordi en på forhånd ikke vet hvor lav den høyeste effekttoppen kan bli. Alternative avtaler, e.g. kortere effektmålingsperioder eller abonnert effekt, kan gjøre det enklere og mer økonomisk å drifte lagringsenhetene for å redusere topplaster. Energilagringsenhetene skaper dermed foreløpig verdi for Campus Evenstad gjennom (1) energitilgang ved strømbrudd, (2) oppstart av lokale anlegg (gjelder batteri særlig for CHP), (3) økt selvkonsum ved lagring av lokal overskuddsstrøm som brukes senere og evt. (4) reduksjon av høyeste effekttopp over 12 måneder (svært krevende med gjeldene avtaler).

Siden det foreløpig er lite overskuddsstrøm, tillater rammeverket mer lokal fornybar strømproduksjon på Campus Evenstad gjennom eksisterende Plusskundeordning som begrenser maksimal levert effekt til nettet til 100 kW. Elsertifikater og finansieringsstøtte fra Enova gjør det mer attraktivt med slike investeringer. Under dagens rammeverk er det mest verdifullt å investere i enheter som minimerer levert strøm. Ved endring av dagens effekttariffering på Campus Evenstad kan det bli enda mer verdifullt å minimere topplast, men også mer kostbart å utløse høye effekttopper. Minimering av topplast kan utføres gjennom produksjon som sammenfaller med forbruk, lagringsenheter og/eller andre tiltak som bidrar til økt energieffektivisering. De mest relevante forretningsmulighetene fremover innebærer dermed driftsoptimering av energisystemet for å øke selvkonsum, og dette lar seg gjøre gjennom styringssystemer knyttet til målinger av produksjons- og forbruksenheter. Energieffektivisering knyttet til det gamle administrasjonsbygget er særlig relevant.

Fremtidige investeringer

Vi har undersøkt potensielle fremtidige investeringer for Campus Evenstad ved hjelp av en optimeringsmodell. Modellen minimerer kostnader knyttet til investeringer og drift av et energisystem, og er spesielt tilpasset utviklingen av nullutslippsnabolag med innebygde krav om utslippskompensasjon. For Campus Evenstad har vi undersøkt fremtidig utvikling gitt dagens situasjon, samt utvikling av et tilsvarende område uten eksisterende enheter. Dagens situasjon inkluderer alle eksisterende enheter i tillegg til lagringskapasitet tilsvarende det stasjonære batteriet pluss litt ekstra kapasitet fra den fremtidige V2G-løsningen.

Modellen er avhengig av forbruksprofiler med timesoppløsning for elektrisitet og varme for ulike bygg gjennom ett år, samt antakelser rundt kostnader og produksjonspotensialer fra lokale energikilder. Foreløpig er det ikke tilstrekkelig data tilgjengelig fra Campus Evenstad, og våre analyser er derfor basert på et verktøy (utviklet av I. Sartori og K. B. Lindberg) som produserer forbruksprofiler basert på byggets areal og type. Data for temperatur og solinnstråling er hentet fra en målestasjon i nærheten av Evenstad.

To instanser/scenarioer undersøker investeringer for Campus Evenstad gitt dagens situasjon. Den første instansen (ZEN-scenario 1) antar en kompensering av utslipp balansert over et år. Dette betyr at utslipp knyttet til energien som brukes i løpet av ett år blir kompensert for gjennom lokal produksjon av fornybar energi. Utslippskompenseringen betyr i praksis at Campus Evenstad må produsere minst like mye energi fra lokale kilder som det leveres fra strømnettet gjennom ett år. Modellen benyttet i denne rapporten velger investeringer i mer solceller og varmepumpe, og utvider ikke kapasiteten på noen andre energikomponenter. Det første scenariet fører til timer med mye levert strøm til nettet. Eksisterende lagringsteknologi blir brukt, men er ikke tilstrekkelig for å unngå stort overskudd; enkelte effektlaster kommer opp i 400 kW levert til nettet, noe som er omtrent fire ganger høyere enn nærliggende effektlaster for levert strøm fra nettet. Den høyeste effektlasten til nettet overgår den høyeste effektlasten fra nettet. Plusskundeordningen med en 100 kW eksport-grense tillater ikke dette, og det blir dyrt under effekttariffering. Fra 2019 endres vilkår for å bli strømprodusent slik at små produsenter betaler et fastledd per kWh levert til nettet (og unngår et stort fastledd basert på installert kapasitet) [3]. Dette kan være et alternativ til Plusskundeordning som har en øvre grense for levert effekt til nettet og vil gjøre ZEN-scenario 1 gjennomførbart.

Den andre scenariet (ZEN-scenario 2) antar en kompensering av utslipp balansert over hver sesong. Dette betyr at Campus Evenstad produserer like mye energi som det importeres fra strømnettet i løpet av hvert kvartal. Her velger modellen fremdeles solceller og varmepumpe fremfor andre investeringer, og den krever i tillegg tre ganger så mye solcellekapasitet som i ZEN-scenario 1. I ZEN-scenario 2 velger modellen investeringer i mer batterikapasitet. Begrensningen for eksport er satt til 800 kW.
I analysen av området uten eksisterende enheter er fremdeles solceller en dominerende energikilde. Elektrokjel og varmepumper leverer varme til forbruk og lager. I tilfelle med strengere krav for kompensering av utslipp velger modellen store investeringer i batterier. Modellen velger i disse scenariene verken investeringer i CHP, solfangere eller biokjel.

Varmeforsyning basert på elektrisitet (varmepumper eller elektrisk kjel) vil gjøre det vanskeligere for Campus Evenstad å oppnå (1) økt pålitelighet til strømforsyning eller (2) økt selvforsyning av elektrisitet. Varmeforsyning basert i størst mulig grad på biomasse vil altså føre til et lavere behov for solceller til kompensering for utslipp. Varmeforsyning leveres i stor grad av CHP og biokjel under dagens situasjon, så en utvidelse av dette systemet vil være relevant. Anskaffelse av ny og forbedret biokjel, samt forbedringer av biomassen for å sikre god drift av CHP, er allerede igangsatt for å minimere elektrisk varmeforsyning.

Våre analyser antyder altså at den mest kostnadseffektive måten å oppnå årlig kompensering for utslipp for Campus Evenstad er gjennom investeringer i flere solceller. Modellen tar derimot ikke hensyn til investeringer og tiltak relatert til energieffektivisering som også kan øke graden av selvforsynt fornybar energi, og resultatene krever nye rammebetingelser for levert effekt til strømnettet. Videre arbeid kan vurdere energieffektivisering, samt vind, som investeringsalternativer. Strengere/mildere krav til utslippskompensering kan også analyseres med denne modellen.

Driftsoptimalisering og styringssystemer

Det er koblet målere på de fleste lokale energienheter og de fleste lokale forbrukspunkt som logger data inn i et SD-anlegg. Begge hybelbyggene har installert solfangere med målere, men måledataene er i en egen app i stedet for i SD-anlegget. Målet er å logge data med timesoppløsning, fordelt på ulike bygg, enheter og energitjenester.

Datalogging av produksjon og forbruk av energi er foreløpig ikke tilgjengelig i et felles system. Dette gjør det vanskelig å samle og håndtere data til analyser og systemer. Det bør være et mål å samle de mest relevante målingene under ett felles system med timesoppløsning. Relevante data i et slikt system er: netto strømimport, strømproduksjon fra solceller og CHP, varmeproduksjon for ulike enheter i nærvarmenettet og bygningsinndelt energiforbruk (strøm og varme).

Det har frem til nå vært en del problemer med avlesning av flere målere. Begge hybelbyggene er tilkoblet det lokale fjernvarmenettet, men det er uklart om alt forbruk logges. Låven skal være tilkoblet det lokale fjernvarmenettet, men mangler måler (blir installert). Flere mindre bygg mangler målere, blant annet Sveiserbolig, Dølplassen og Settefisk. De to sistnevnte byggene ligger to km unna resten av Campus og er ikke like relevante å måle. Noen målerverdier avviker noe med data fra Eidsiva, og noen energibalanser går ikke opp (i.e. forbruk er ikke balansert med produsert og levert energi).

Med tilstrekkelig og pålitelig data er planen å lage en modell som kan gjøre forbruksprognoser basert på målinger. Et mål er å bruke værprognoser til å produsere forbruksprognoser med modellen. Forbruksprognosene kan brukes til driftsoptimalisering gjennom planlagt ladning av batteri og elbiler eller foroppvarming av rom og vann for å oppnå energimål (e.g. redusere topplaster, minimere driftskostnader osv.). Dette skal gjøres gjennom en MPC-modell som kommuniserer med drifts-kontroller.

Et eksperiment (living lab) knyttet til driftsoptimalisering ble utført gjennom sommeren 2018. Dette gikk ut på å stenge ned deler av ventilasjonssystemet i det gamle administrasjonsbygget på Campus Evenstad. Motivasjonen var å kartlegge potensialet for energisparing samt undersøke tekniske og sosiale konsekvenser av tiltaket. Erfaringer gjennom eksperimentet peker på flere utfordringer: (1) mangel på tid og/eller interesse blant ansatte på Campus Evenstad, (2) motstand blant ansatte til å flytte kontor og dermed konflikt med arbeidsmiljølov og (3) mangel på driftsansatte som kunne være ansvarlig for målinger.

Utslippsreduksjoner

Utslipp knyttet til energibruk av området er komplekst og baserer seg på utslippsfaktorer knyttet til energi. Utslippsfaktoren vil i realiteten avhenge av sesong og tid på døgnet. Dette er fordi spot-prisen i markedet påvirker hvorvidt strøm importeres fra utlandet siden dette påvirker lønnsom drift av nasjonale vannmagasiner. For Norge betyr dette at lav spotpris medfører mye import og dermed høyere utslippsfaktor, mens høy spotpris medfører større andel vannkraft i strømmiksen og lavere utslippsfaktor.

Det er fremdeles diskutert hvilke faktorer som skal benyttes for strøm fra det norske strømnettet (blant annet relatert til markedet for opprinnelsesgarantier) og hvorvidt de bør være marginale (basert på den mest utslippsintensive produsenten) eller gjennomsnittlig (basert på utslippsintensiviteten til alle produsenter). Campus Evenstad kjøper strøm med opprinnelsesgarantier. Dette skaper grunnlag for lav utslippsfaktor på importert strøm, men argumentet er ikke knyttet til 'reell' utslippsfaktor i systemet. Dersom vi benytter ZEB-faktoren som er benyttet tidligere, fører det til at lokal fornybar energiproduksjon har en lavere utslippsfaktor enn elektrisitet fra strømnettet. Lokal fornybar energiproduksjon vil også med argumentet om opprinnelsesgarantier være omtrent likestilt med importert strøm. Det betyr at Campus Evenstad i størst mulig grad bør benytte lokale enheter ved energiforsyning for å minimere utslipp. Denne antakelsen kan forsvares ved at de lokale enhetene kun er driftet på fornybare energikilder som erstatter energi produsert med fossil energikilder andre steder i Europa. Utslippsreduksjon over nabolagets levetid er mest sannsynlig ved fokus på energieffektivisering siden energi som ikke brukes naturligvis har minst utslipp, men dette avhenger av utslipp knyttet til investeringer utover drift (produksjon av materialer osv.) og 'rebound' effekten (tilbakeslag på potensielt spart energi gjennom økt energibruk pga. f.eks. lavere kostnad).

Det har blitt utført omfattende LCA for å kartlegge utslipp relatert til det nyeste administrasjonsbygget på Campus Evenstad. LCA er relevant for (1) å identifisere hvilke løsninger og deler av bygg som er knyttet til utslipp og (2) hvordan tiltak fremover kan påvirke utslippene og energibruken. Det nyeste administrasjonsbygget består av 1141 m^2, altså omtrent 10% av totalt gulvareal på Campus Evenstad. Beregningene er hovedsakelig basert på EPD-dokumentasjon, som også har vært grunnlaget for valg av materialer. Kontordelen krever mindre energi per kvadratmeter enn utdanningsdelen, men kontordelen har større total energibruk. Størst varmetap skjer gjennom vinduer og dører.

Det er planlagt å utføre ytterligere analyser for andre bygg på Campus Evenstad med særlig fokus på energibruk. Her vil det være vanskeligere å samle inn data, men det finnes litteratur som vurderer eldre teknikker og andre materialvalg. Beregningene er avhengig av at hvert bygg har definert (1) valg av konstruksjonsmetode, (2) byggår og (3) gulvareal.

Contents

1. Introduction

1.1. Definition of Zero Emission Neighbourhoods (ZEN)

For a neighbourhood aiming to reduce its emissions towards zero, or a Zero Emission Neighbourhood (ZEN), many factors must be taken into consideration. Within FME ZEN, the definition of such a neighbourhood is an ongoing process. The first version of the ZEN definition [4] states the following:

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, building and infrastructure elements to include[4]. The neighbourhood should focus 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 behaviour**.
g) Development of the area is characterised by innovative processes based on new forms of cooperation between the involved partners leading to **innovative solutions**.

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[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 decarbonised 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 decarbonised energy system and reduction of power and heat capacity requirements

This report focuses on points b), c), and e) of the above ZEN definition related to **energy efficiency, renewable energy, flexible operations, and economic sustainability**. Technical and economic aspects of the energy system in a ZEN will be the core topic. Aspects mentioned in the FME ZEN definition also relate to building design, sustainable transport, and spatial qualities, but these aspects are outside the scope of this report. **GHG emissions** are considered related to operations of the energy system.

Increased energy efficiency in buildings combined with a local supply of clean energy is part of the relevant solutions that could reduce emissions in a neighbourhood. Through technological development and decreased costs, local energy supply is becoming feasible and affordable. Local renewable energy sources in a ZEN can decrease the need for external energy and contribute to less outages and efficient land use.

A very relevant development is the drop in cost of PV technologies. This is especially relevant in ZEN since PV modules can be integrated in buildings and utilize area (e.g. roofs) almost anywhere. It is expected that the capital expenditure of PV plants will halve in the next 17 years [5]. PV and batteries can play a major role in ZEN and the power system to ensure clean, cheap, and reliable energy. For a normal household in Norway in 2018, the current payback time of covering the roof with PV was estimated to 19 years if all production was self-consumed [1]. With expected lifetime of the PV panels of 30 years, this is already profitable.

However, the neighbourhood consumption might not always match the supply of the local energy source. Therefore, energy flexibility will be important to ensure that renewable energy is used efficiently with minimized spillage. To enable both renewable generation and flexible operation as part of the energy system, the economic framework must facilitate the integration of these solutions. Operational control (based on e.g. Model Predictive Control (MPC) [6]) is also needed to ensure efficient use of all local units. The control should integrate operation of local energy production, local energy storage, and local energy consumption. The cost of batteries is expected to drop 67 % by 2030 compared to today [5].

There is still uncertainty about the role of distributed energy supply and control in neighbourhoods. With an overall goal of emission reductions related to neighbourhoods, there is a lack of insight into the consequences of approaching energy independence for a neighbourhood. New opportunities arise with new local investments, and it is unclear what value these units could have inside and outside the neighbourhood.

1.2 The new standard for calculating emissions

A method based on different emission compensation ambition levels has been developed in the context of the Norwegian ZEB Centre [7]. The focus was on nZEBs, which are buildings where the required low amount of delivered energy to a significant extent is covered by energy generation from on-site or local renewable sources. This includes electricity and heat produced and delivered inside or nearby the neighbourhood boundary, for example by heat pumps, biomass combined heat and power (CHP), or photovoltaic (PV) technologies.

There are several ambition levels related to becoming a ZEB. Some ambition levels include compensating for emissions from operation of the building (ZEB-O), while other ambition levels include more life cycle modules considering emissions from the production, operation, construction, and end-of-life phases of the building (ZEB-COMPLETE). The goal is to compensate for the total life-cycle GHG emission measured in CO_2 eq. by producing on-site energy. The energy locally produced is based on renewable sources, and the emission credits gained by feeding the grid with this extra produced energy lead to emission credits by using a marginal approach. The method is now used in a new standard NS 3720:2018 [8].

1.3 Regulatory framework in Norway

Norway has committed itself to reducing its greenhouse gas emissions by 40 % by year 2030 with respect to 1990 [9]. The Norwegian power production consists of about 96 % flexible hydro power [10]. The national energy supply, including residential heating, makes up about 2.1 million tons of the annual national greenhouse gas emissions of 53.3 million tons of CO2 equivalents [11]. The greatest contributors to Norwegian emissions are industries, especially oil and gas, followed by transport.

Most residential heat demand is met with electricity in Norway. Because heat is a big part of Norwegian residential energy demand, electric heating can make up 65 % of electricity use [12]. Direct electric heating has been most common, but heat pumps are now becoming more common. Bio energy meets around 7 % of Norwegian heat demand [13].

One of the motivations to develop ZEN in Norway is to increase the national potential of being Europe's green battery, as there is a growing share of intermittent renewable generators on the continent [14]. Since little new hydro power capacity will come online in the next years, local power production in ZEN could provide extra electricity and increase clean Norwegian exports of energy and flexibility services. Flexible resources at the neighbourhood level can also reduce the need for the grid investments that are expected in Norway in the next years [15].

The regulatory framework in Norway makes it possible for end-users to sell locally produced electricity to the grid. End-users producing energy that is mostly self-consumed (not exported) can sign the "plusskunde" agreement[6]. The "plusskunde" agreement was last updated 1. January 2017, and it reduces the costs of consuming electricity based on the energy produced by the end-user. It also provides revenue from selling surplus electricity to the grid. The billing agreement is based on the net load on the connection point of the end-user (net load = consumption - local production). The net electricity exported to the grid is subject only to a feed-in tariff (cost) according to a marginal loss rate. The marginal loss rate depends on the impact the exported electricity has on local grid losses. Since locally exported electricity is likely to contribute to less grid losses, this rate is often negative (income for the local producer). The negative feed-in grid tariff means locally produced electricity is worth more per kWh for the producer selling the surplus electricity. The electricity retailer is obliged to purchase exported electricity under the current "plusskunde" agreement, however, the net export cannot exceed 100 kW. A hearing by the Norwegian Water Resources and Energy Directorate (NVE) [3] has recently been sent out to make provide an alternative to the “plusskunde” agreement for small-

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[6] NVE Plusskunder. URL: https://www.nve.no/reguleringsmyndigheten-for-energi-rme-marked-og-monopol/nettjenester/nettleie/tariffer-for-produksjon/plusskunder/

scale producers. The alternative is to become a producer with no export limit being subject to a feed-in tariff based on energy delivered to the grid (not based on installed capacity).

The regulatory framework can also add value to electricity produced locally by renewable sources (e.g. PVs) through green certificates ("elsertifikater"). This income is independent of whether the produced electricity is self-consumed or delivered to the grid. Certificates are assigned to producers upon application, and retailers are obliged to provide a certain share of electricity with green certificates to end-users. The certificate cost is passed on to end-users through retailers by being incorporated into the energy part of the bill.

Financial barriers for ZEN investments are reduced in Norway through the public institution Enova, which is owned by the Ministry of Climate and Environment. Investments in technologies that can contribute to energy efficiency, reduced greenhouse gas emissions, and innovation can be partly supported by Enova upon application. Statsbygg received financial support from Enova for installation of the CHP at Evenstad [16].

1.4 Aim and structure of the report

This report presents a case study of the ZEN pilot project Campus Evenstad in rural Norway. This campus site consists of several buildings and has already implemented local energy production and storage. We investigate the following questions:

- How much energy is produced and consumed at Campus Evenstad?
- What economic value does the local energy production and storage represent at Campus Evenstad?
- How does the local energy system at Campus Evenstad contribute to the reduction of GHG emissions?
- How can local control systems contribute to efficient operation at Campus Evenstad?
- What is the potential for energy savings at Campus Evenstad related to partially closing a building in summer?
- What kind of local energy production and storage is required to produce 100 % of the energy consumed at Campus Evenstad cost-efficiently?

The structure of the report is as follows: Chapter 2 describes Campus Evenstad and updated energy demand, supply, and storage components of the energy system. Chapter 3 contains evaluation of technical, monetary, and environmental value of these energy components under current and emerging business models. Chapter 4 presents an analysis of how to achieve 100 % self-supply at Campus Evenstad as well as energy saving measures. Considering the above chapters, Chapter 5 discusses which measures and goals are most relevant for Campus Evenstad on its way towards becoming a ZEN.

2 Campus Evenstad

2.1 General

As one of the pilot projects in FME ZEN, Campus Evenstad is developing towards a ZEN. The campus site was also a pilot project in The Research Centre on Zero Emission Buildings (FME ZEB), which resulted in the development of Norway's most ambitious ZEB, classified as ZEB-COM [16]. The site is in Stor-Elvdal municipality in Norway, and it has about 10 000 m^2 of total floor area in 22 buildings (see Figure 1). The campus site is owned, developed and operated by Statsbygg. The institution using the buildings, Høgskolen i Innlandet (HINN), rents the site to run 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 of the campus.

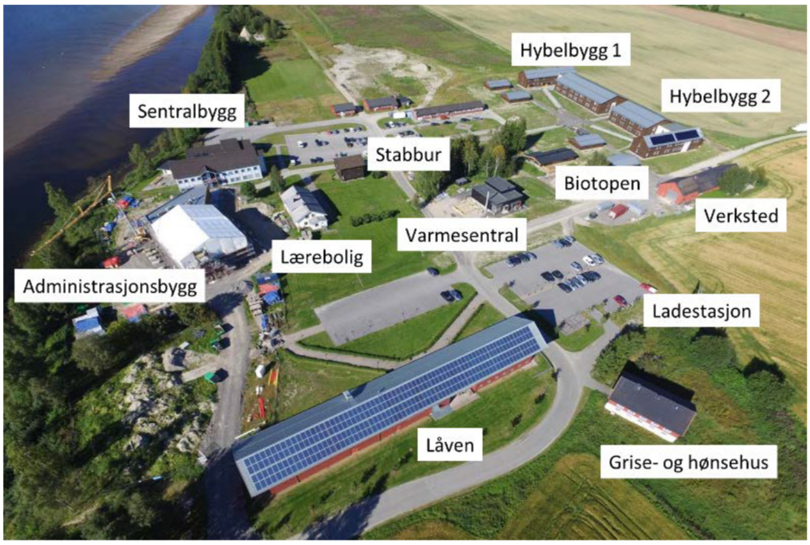

Figure 1 Overview of Campus Evenstad. Photo by Statsbygg

The ambitious development of the energy system has been motivated by Statsbygg's strategy for development of public buildings [17] stating that "Statsbygg shall contribute to the development of areas towards zero emissions". The development has also been in line with Campus Evenstad's profile of being innovative and original. Statsbygg also highlights the importance of having motivated and skilled people in the development of new technical solutions, and they emphasize the high value of testing innovative solutions at a real site.

2.2 Energy at Campus Evenstad

In one year, Campus Evenstad consumes about 1 000 000 kWh of electrical energy. Electricity is today mainly provided by the grid and partly provided by local units, including a combined heat and power (CHP) plant and solar PV panels. Figure 2 shows electricity imported from the grid from 2015 to May 2018 (excluding January 2017). The grid operator is Eidsiva Nett, which has plans of grid upgrade in the area[7].

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[7] Eidsiva Nett. URL: https://www.eidsivanett.no/aktuelt/kartlegger-losninger/

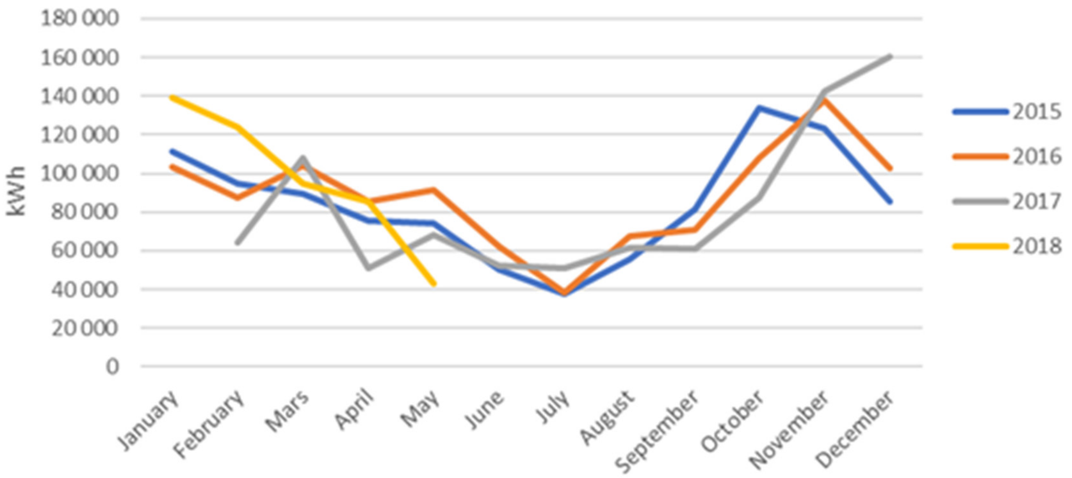

Figure 2 Electricity imported from the grid to Campus Evenstad

Table 1 shows more detail about the connection with grid electricity from 2015 to 2017. The utilisation factor is the annual average load divided by the annual peak load, self-consumption is the share of locally produced energy that is consumed on-site and self-generation is the share of total consumption that is produced on-site [18].

Table 1 KPIs for electricity at Campus Evenstad. Estimates are marked with *

	2015	2016	2017 (ex. Jan)
Grid electricity (net) [kWh]	1,012,941	1,058,962	906,955
Max import [kWh/h]	436	479	468
Utilisation factor [%]	27	25	24
Average [kWh/h]	116	121	104
Export [kWh]	0	158	70
Delivered electricity PV [kWh]	62,454	61,960	62,000*
Delivered electricity CHP [kWh]	-	160,000*	160,000*
Self-consumption [%]	100	99.93	99.97
Self-generation [%]	6*	17*	20*

The PV system at Campus Evenstad produces around 62 000 kWh annually. This electricity is (mainly) used directly on Campus. Figure 3 shows monthly PV production from December 2013 to September 2017 compared to values simulated by PVsyst.

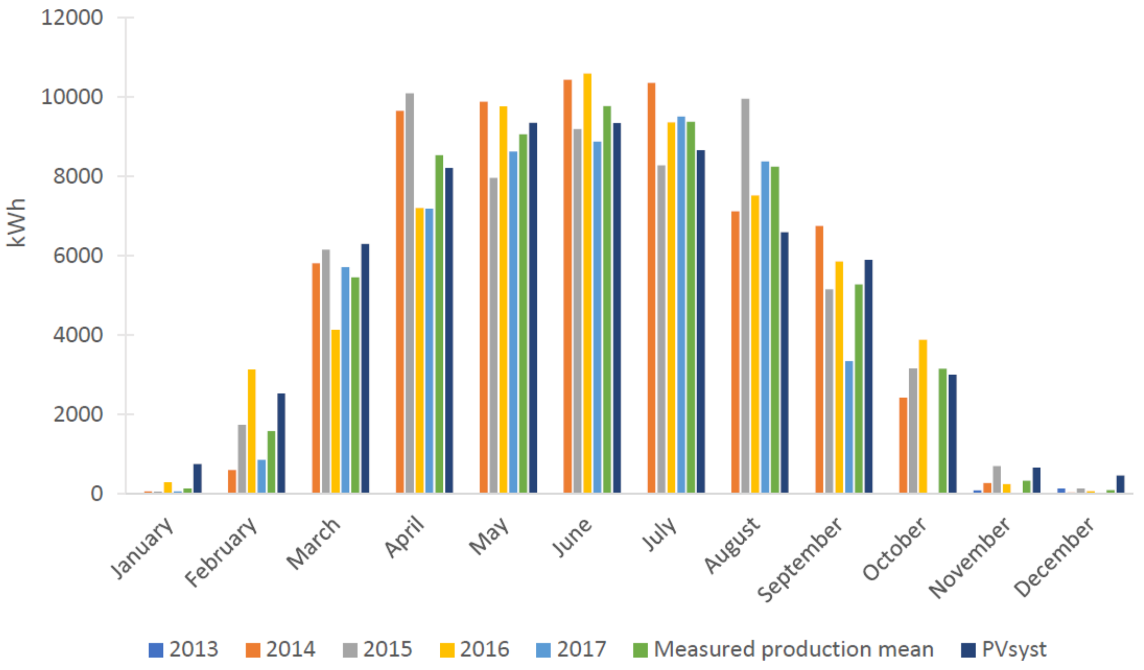

Figure 3 Electricity produced by PV at Campus Evenstad from December 2013 to September 2017, measured production mean, and simulated monthly production for a typical year (by PVsyst). Reference: [19].

Figure 4 shows the monthly distribution of delivered electricity to four buildings measured in 2016: Stabburet, Verksted, Hovedbygget, and Hybelbygget 1&2.

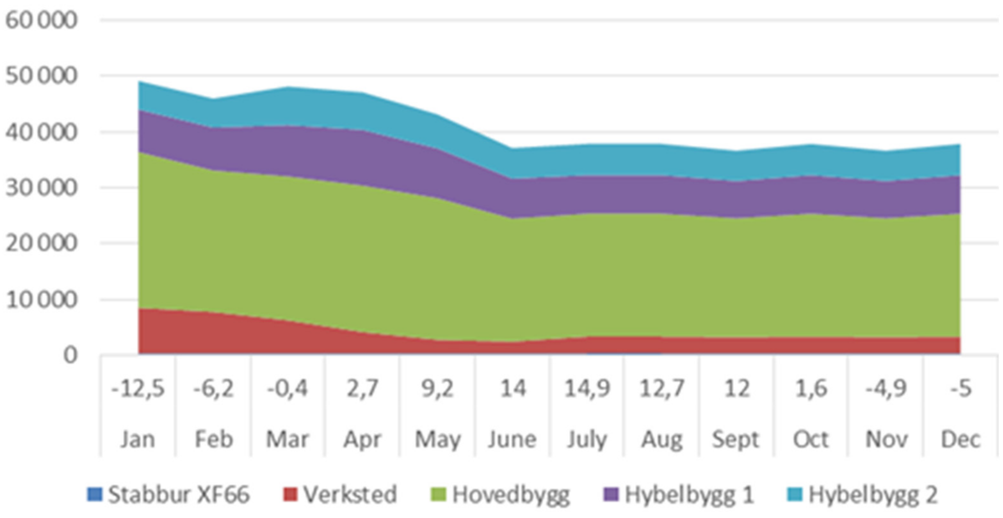

Figure 4 Delivered electricity (kWh) to Stabburet, Verksted, Hovedbygget and Hybelbygget at Evenstad in 2016, as well as the average outdoor temperatures each month. Reference: [20].

The total energy consumed for heating purposes adds up to about 620 000 kWh. Figure 5 shows delivered heating in 2016. Most demand is served by local heat sources, including the CHP plant, a bio boiler, and solar collectors. The remaining heat is provided by an electric boiler and direct electric heating. The CHP plant and the bio boiler are both fueled by wood chips and distribute heat through a local heating grid. An electric boiler also supplies heat to the heating grid. Six of the buildings, as well as a snow melting unit, were connected to the local heating grid by 2017.

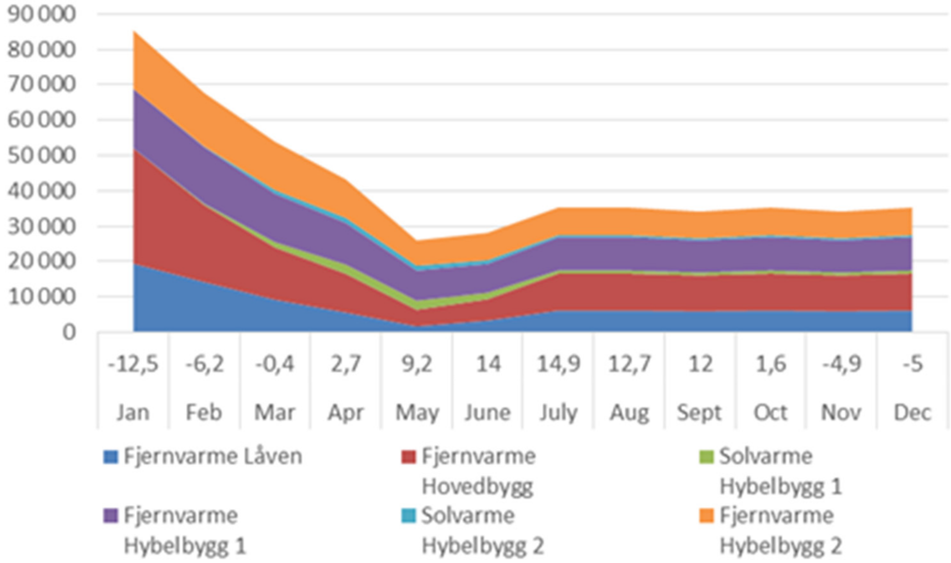

Figure 5 Delivered heating (kWh) to Låven, Hovedbygget, and Hybelbygget 1&2 at Evenstad in 2016, as well as the average outdoor temperature each month. Reference: [20]

The local heating grid is mainly providing space heating demand on campus, not domestic hot water (DHW). The solar collectors are placed on Hybelbygg 1&2 and provide DHW to these buildings. However, Hybelbygg 1&2 also gets DHW from the local heating grid. For one other building (the new adm. building), DHW is preheated by the local heating grid. For the remaining four buildings (Hovedbygget, Låven, Lærerbolig, Sveiserbolig), DHW is delivered by electric water heaters placed locally. The other three buildings only cover space heating demand from the local heating grid.

Table 2 presents an overview of the most relevant existing generators, the installed capacity, and the annual energy production. The annual production is estimated for the CHP-unit and the solar collectors and based on 2016-measurements for the bio boiler, the electric boiler, and the solar cells (PV). The numbers are only preliminary since there have been changes since 2016, with more buildings connected to the local heating grid.

The CHP unit is a Volter 40 Indoor[8] that produces both thermal and electric energy from biomass. It produces about 0.4 kWh of electricity per kWh of thermal energy. The fuel consists of wood chips that are bought on contract from a local supplier at a fixed price per cubic meter and delivery. The wood chips must be of high quality in terms of humidity content and size. It has been estimated that the CHP unit needs between 800 and 1000 m^3 of wood chips annually spread out on about 25 deliveries. The heat produced is distributed through a thermal grid. In addition to the CHP unit, a bio- and electric boiler can supply heat to the grid. In 2017, there were six buildings and a snow melting unit connected to the grid. The estimated operation time for the CHP-unit is 4000 hours of operation per year, which is quite high. The CHP-unit has first priority, but does not have high enough heating capacity to deliver all the needed heat. The bio-boiler is second priority and deliver most of the heat demand. The electrical boiler is third priority/backup, and its use should be minimized when possible.

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[8] Volter – Power from wood: Volter 40 Indoor (100 kW_{th}/40 kW_{el}). https://volter.fi/products/volter-40-indoor/

Table 2 Generation of heat and electricity from local units at Campus Evenstad in 2016. Estimates are marked with *. Reference: [20].

Generator	Capacity, thermal	Capacity, electricity	Annual generation
CHP, Thermal	100 kW_{th}	-	400,000 kWh_{th} *
CHP, Electricity	-	40 kW_{el}	160,000 kWh_{el} *
Boiler, Bio	350 kW_{th}	-	300,000 kWh_{th}
Boiler, Electric	315 kW_{th}	-	275,000 kWh_{th}
Solar collectors	100 m^2	-	40,000 kWh_{th} *
PV	-	60 kW_{el}	62,000 kWh_{el}

In addition to the generation units in Table 2, there are 11 hot water storage tanks of varying size and temperature dependent storage capacity. The total volume of the storage tanks is 21 600 liters.

Electric vehicle (EV) charging stations are also installed. One fast charger from Fortum can deliver 50 kW_{el}, one E-route71 charging point deliver 20 kW_{el}, and the three remaining E-route71 charging points deliver 10 kW_{el}. There are also plans for a new charging station which can take energy from the EVs (vehicle-to-grid, V2G), turning them into mobile batteries.

A stationary li-ion battery was installed in 2018. It is used primarily as a back-up power source but can also be integrated with the energy management system to shave peaks and store locally produced electricity. The battery can store 204 kWh_{el} and charge/discharge at 120 kW_{el}. It is dimensioned to be able to perform approx. 2 hours of "island operation" in winter times (i.e. operation of critical systems without any electricity delivered from the grid).

The thermal demand varies between 250-350 kW_{th} throughout the year, with a difference between space heating and DHW. Electric demand is more volatile and can at times reach beyond 400 kWh/h_{el} (see Figure 6).

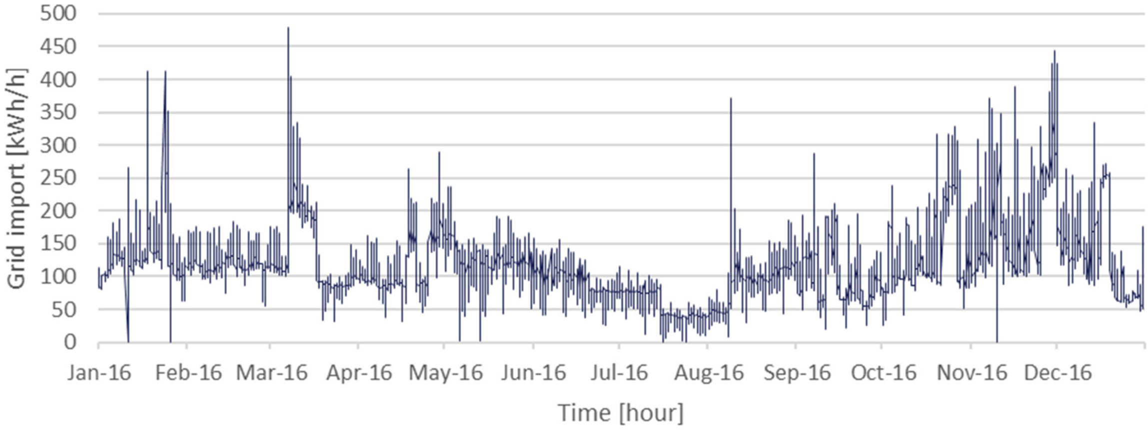

Figure 6 Hourly electricity import from the grid (kWh/h) at Campus Evenstad in 2016. Reference: [20].

The monitoring of the energy use and production is currently not available in a single system. This makes it challenging to get access to relevant data. Ideally, it should be possible to follow the most important energy data in one system, with up to an hourly resolution. Such energy data is for example:

- Electricity imported and exported from the Campus to the grid (today available from Eidsiva)

- Electricity and heat generated from the CHP unit (today not available)
- Electricity generated from the solar cells (today available from another energy company)
- Heat delivered from the bio boiler and electric boiler (today available from SD-system)
- Heat delivered from the solar collectors (today not available)
- Electricity and heat delivered to each of the buildings and infrastructure (today partly available from SD-system). Ideally the domestic hot water should also be measured (today not available)

2.3 ZEB-COM administration and educational building at Campus Evenstad

An exhaustive LCA has been conducted on the latest built pilot administration and education building. The construction of this pilot building lasted from 2015 to 2016 and is the first ZEB-COM building designed and constructed in Norway. The ZEB-COM ambition level means that all emissions from construction (C), operational energy (O), and materials (M) are compensated for through on-site, renewable energy production.

The inventory as well as the results are well described in two reports by Selvig, Wiik [16] and Wiik, Sørensen [21]. In addition to the detailed building material inventory, a special focus was given on the calculation of CO_2eq emissions during the construction phase. The pilot building has a total heated floor area (BRA) of 1141 m2. The life-cycle inventory is mainly based on environmental product declarations (EPD), and the material phase is responsible for 572 087 kgCO_2eq or 8.4 kgCO_2eq/m^2/yr embodied emissions, for a total of 23.9 kgCO_2eq/m^2/yr over the life-cycle. In comparison, [22] have reported embodied emissions in the range of 3.8-14.1 kgCO_2eq/m^2/yr for different building types of the passive standard in Norway.

The overall GHG emissions have been shown to be compensated for through on-site renewable energy generation from a combined heat and power plant, and the ZEB-COM ambition level was achieved.

3 Value of local energy supply

3.1 Comparison of local and external electricity installations at Campus Evenstad

The energy supply chain can be categorized in two main categories: (1) production of energy and (2) transport of energy. The first category relates to converting an energy source into usable power or heat. In Norway, each installed kW of hydropower produces about 4000 kWh$_{el}$ annually[9]. The investment cost of hydropower is estimated to be 10 000-15 000 NOK/kW$_{el}$ [23]. This means the annual value of electricity production installations for a consumer like Campus Evenstad (if only supplied by hydropower) is 2.5-3.75 MNOK (see Table 3).

The installed PV panels at Campus Evenstad produces about 62 000 kWh$_{el}$ per year with an installed capacity of 60 kWp$_{el}$, which means Campus Evenstad would need about 1000 kWp$_{el}$ installed (17 times the current installed capacity) to produce the current electricity volume with PV only. Large PV installations (>100 kW) cost about 10 000 NOK/kWp$_{el}$ [1], which means 1000 kWp installed would cost about 10 MNOK (see Table 3). This is not considering the additional need for installations to

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

balance supply and demand (e.g. on dark winter days). These installations include the grid for import and export, batteries for storage, or a combination of both.

Table 3 Calculation of the value of electricity installations for Campus Evenstad in Norway assuming an annual demand of 1 000 000 kWh$_{el}$.

Supply	Installed capacity need	Value of installations
Hydropower	1 000 000 kWh / 4 000 kWh/inst-kW = 250 inst-kW	(250 inst-kW)(10-15 kNOK/inst-kW) = 2 500 000 – 3 750 000 NOK
PV	1 000 000 kWh / 1 000 kWh/inst-kWp = 1 000 inst-kWp	(1000 inst-kWp)(10 kNOK/inst-kW) = 10 000 000 NOK

PV in Norway is, according to these estimates, 3-4 times costlier than using hydropower. This does not mean that PV is not profitable; the installations have a lifetime of 25-30 years and a payback time of 18 years for commercial buildings in 2018 [1].

The second supply chain category relates to transporting energy. However, transport does not need to be in *space*; energy can also be transported in *time* with storage technology. Thus, grids and batteries in power systems serve similar purposes: Moving energy to *where* and *when* it is needed. With more variations and uncertainty related to supply (e.g. PV) and demand (e.g. EV charging), moving energy in time is increasingly relevant.

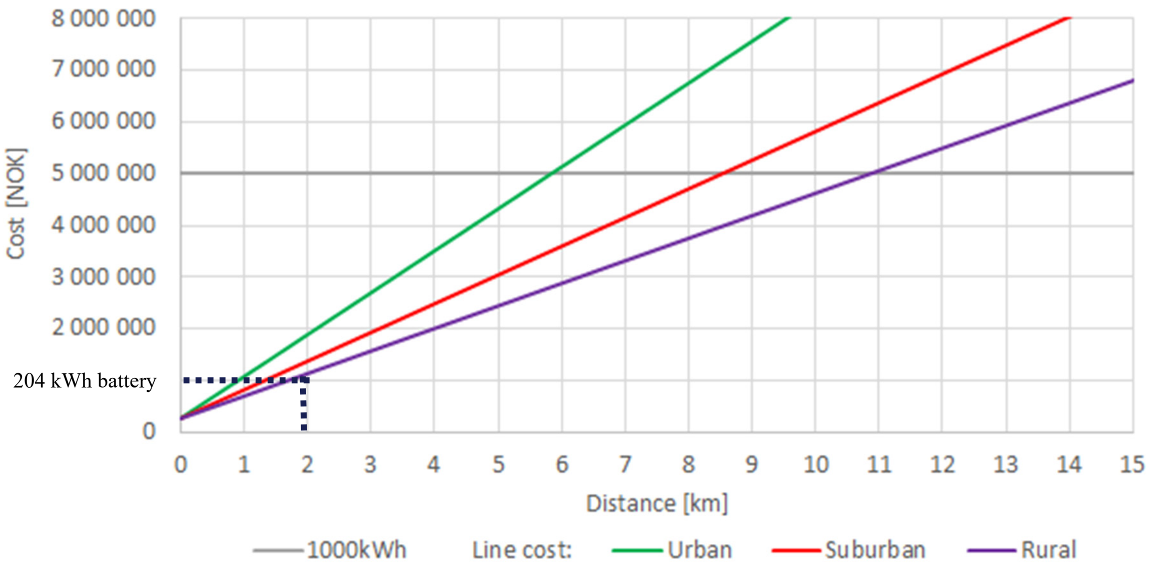

Figure 7 The cost of batteries compared to the cost of transmission lines in Norway. Source: SINTEF IntegER (2017)

Figure 7, from the Norwegian SINTEF project IntegER, illustrates the substitution between battery storage and traditional grid infrastructure in the power system. The grey line represents the cost of a 1000 kWh battery. The green, red, and purple lines represent the cost of a 315 kVA line in an urban, suburban, and rural environment depending on the length of the line. Given a need for grid reinforcement and more varying load in time and space (higher peak) one can either replace or upgrade a high voltage line or install 1000 kWh of battery storage at a cost of 5 000 000 NOK. If it is a rural environment like Campus Evenstad (purple line in Figure 7) and the line is shorter than 11 km, it will be cheaper to replace the line. If it is longer, the battery will be the cheaper alternative. The stationary battery installed at Campus Evenstad is 204 kWh and has a cost of about 1 020 000 NOK (linearly scaled from Figure 7).

A nearby hydropower plant (Storfallet, annual production 8,4 GWh[10]) is approx. 10 km away connected by a 22-kV airborne distribution line with a value of 0.8 MNOK/km [23] (see Figure 8). With other consumers also using the line, we can assume Campus Evenstad uses 10 % of this line, making it worth 0.8 MNOK. This means the value of installations for production and transport of hydropower to Campus Evenstad can be estimated at 3.3-4.55 MNOK.

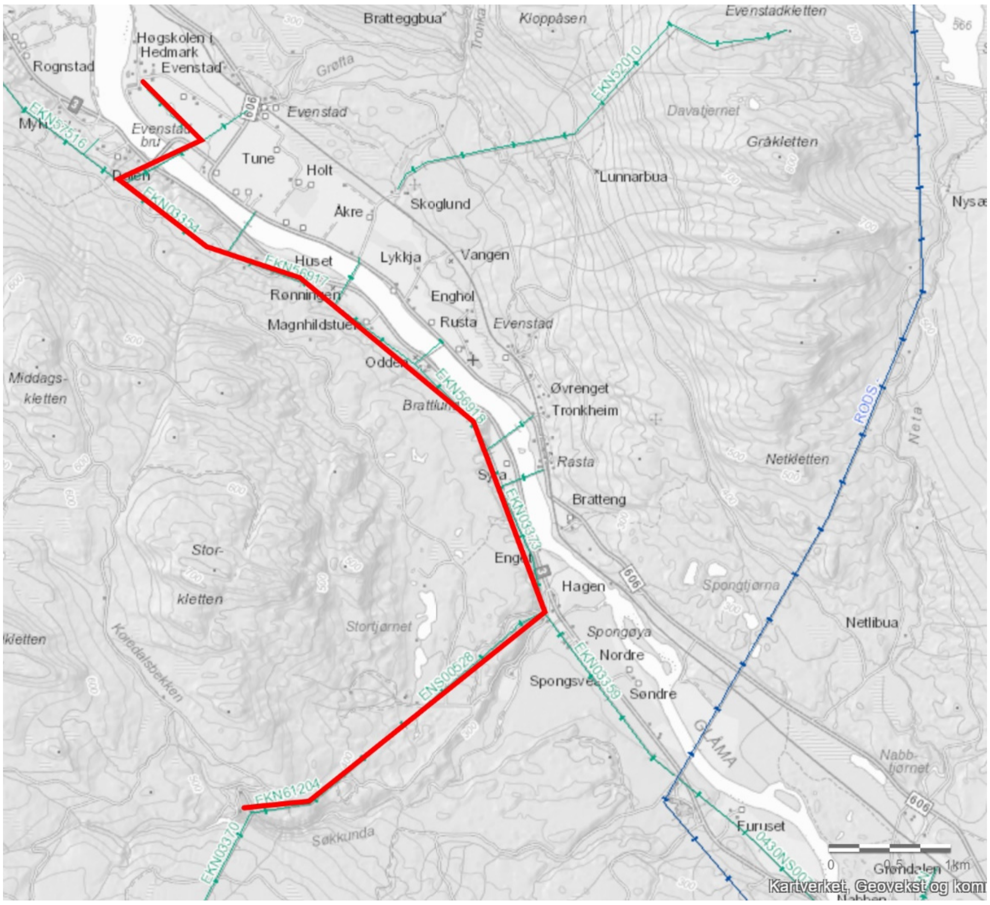

Figure 8 Link between Campus Evenstad and the hydropower plant 'Storfallet' (~10 km). Source: NVE Vannkraftkonsesjoner i kart. URL: https://gis3.nve.no/link/?link=vannkraft

Even if the battery (and operational control of energy units) was enough to balance supply from 1000 kWp PV, the estimated cost of a local PV+battery supply system (10+1.02 MNOK) would still be *more than double* the current cost of the hydropower supply and distribution lines (3+0.8 MNOK).

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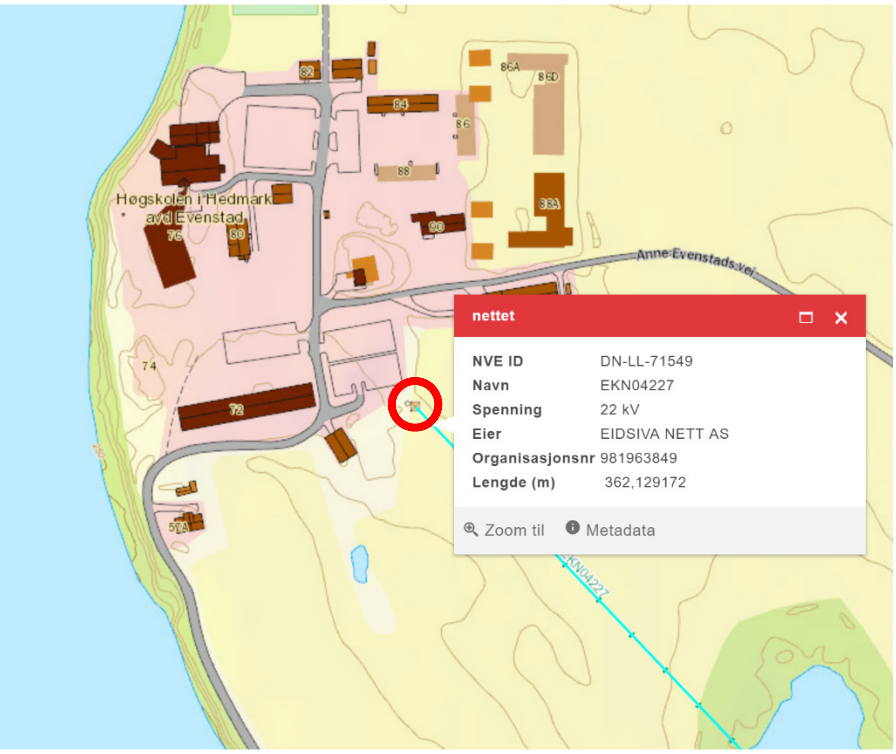
[10] NVE Vannkraftverkdatabase.
URL: https://www.nve.no/energiforsyning-og-konsesjon/vannkraft/vannkraftdatabase/vannkraftverk/?id=738
https://www.nve.no/energiforsyning-og-konsesjon/vannkraft/vannkraftdatabase/vannkraftverk/?id=738

3.2 Electricity trading at Campus Evenstad

HINN has common contracts for power purchases with the retailer (Ishavskraft) and the grid company (Eidsiva Nett) for all its eight campuses in the region (including Campus Evenstad). The contract with the retailer follows the daily varying spot price of the power market in addition to a fixed monthly price. The contract with the grid company has three parts: one fixed annual part, one energy part (related to transportation losses), and one power part (related to maximum load). The power part is based on the highest measured power from the last 12 months averaged over an hour (maximum annual measured power [kWh/h]). Norway also has an excise tax on all electricity consumption except power intensive industry. Campus Evenstad has a connection to the primary (medium voltage) distribution grid (22 kV, see Figure 9). Based on available online cost data from Ishavskraft, Eidsiva Nett, and other public sources, we present estimates of the power purchase rates in Table 4.



NVE ID	DN-LL-71549
Navn	EKN04227
Spenning	22 kV
Eier	EIDSIVA NETT AS
Organisasjonsnr	981963849
Lengde (m)	362,129172

Figure 9 Grid connection (red) at Campus Evenstad is from the primary distribution grid at a voltage of 22 kV. Source: NVE Nettanlegg (map: https://gis3.nve.no/link/?link=nettanlegg)

Table 4 Estimate of power purchase rates for Campus Evenstad based on open sources.

	Fixed part	Energy part	Power part
Energy rates (ex. VAT)	49 NOK/month[1]	0.06 – 2.07 NOK/kWh[2]	-
Grid tariff (ex. VAT)	13,200 NOK/yr[3]	0.04 NOK/kWh[3]	432[3] NOK/kWh/h
Tax charges (ex. VAT)	800[3] NOK/yr	0.1658[4]+0.02[5] NOK/kWh[3]	-

[1] *Ishavskraft. Fixed monthly fee.*

[2] *Nord Pool Historical Market Data 2018. Wholesale spot price.*

[3] *Eidsiva Nett (22 kV, max power <500 kW).*

[4] *Norway state budget 2018. Consumer excise tax*

[5] *The Norwegian Water Resources and Energy Directorate. Electricity certificates*

Campus Evenstad used 1 058 647 kWh through 2016 with the peak load on 7. March at 13:00 (479 kWh/h). Through 2017, 1 079 125 kWh was used, and the peak load was on 22. November at 13:00 (468 kWh/h). With these assumptions, we can make an estimation of annual electricity costs at Campus Evenstad in 2016 and 2017 (see Table 5). Costs related to taxes make up the highest share of the electricity bill.

Table 5 Annual electricity cost estimation based on energy consumption and peak load for 2016 and 2017 (plus January 2018).

Period	Calculation	Total cost
Jan. 2016 – Jan. 2017	Energy (31% of total):	
	(49)(12) + (spot price)(hourly demand)	= 273 375 NOK
	Grid (39% of total):	
	13 200 + (0.04)(1 058 647) + (432)(479)	= 262 474 NOK
	Tax (40% of total):	
	Excise tax: (0.1658)(1 058 647)	175 524 NOK
	25% VAT: (0.25)(273 375 + 262 474 + 175 524 + 800)	+ 178 043 NOK
	Sum tax: Excise tax + VAT + 800	= 354 367 NOK
	Total	= 890 216 NOK
Feb. 2017 – Feb. 2018	Energy (33 % of total):	
	(49)(12) + (spot price)(hourly demand)	= 313 621 NOK
	Grid (28 % of total):	
	13 200 + (0.04)(1 079 125) + (432)(468)	= 258 541 NOK
	Tax (39 % of total):	
	Excise tax: (0.1658)(1 079 125)	178 919 NOK
	25% VAT: (0.25)(313 621 + 258 541 + 178 919 + 800)	+ 187 970 NOK
	Sum tax: Excise tax + VAT + 800	= 367 689 NOK
	Total	= 939 851 NOK

Table 6 Estimation of the monetary value associated with energy savings, export and peak shaving.

Saving measure	Calculation	Monetary saving
Energy savings	(0.39[a] + 0.02 + 0.04 + 0.1658 + 0.02)(1.25)	0.79 NOK/kWh
Energy export	(0.39[a] + 0.02 + 0.04)	0.45 NOK/kWh
Annual highest peak shaving	(432)(1.25)	540 NOK/kWh/h

[a] *SSB (avg. spot price 1st quarter 2018). URL: https://www.ssb.no/elkraftpris/*

For local power production, Campus Evenstad has a "plusskunde" agreement for the PVs and the CHP unit, which means they can legally deliver up to 100 kW to the grid. Estimates of monetary value related to energy savings, export, and peak shaving are presented in Table 6. Note that Campus Evenstad gets money on green certificates both from savings and from earnings when they are both producing and using electricity. HINN does not yet have a contract with the retailer to earn revenue on the exported electricity. If the retailer purchases electricity exported to the grid, the normal contract is spot price plus a rate to compensate for local grid losses. Export from Campus Evenstad in 2016 was approx. 158 kWh, so the lost revenue from not having a contract with the retailer was approx. (0.45)(158) = 71 NOK (€ 7).

The additional value of electricity produced by the PVs is captured through green certificates (approx. 0.02 NOK/kWh, see Table 4). The income through green certificates is independent of whether the produced electricity is self-consumed or exported. There is an ongoing application process to realize higher value through green certificates for the energy produced by the CHP plant. Since the PVs and the CHP produce rather small quantities of electricity, the revenue from green certificates is also rather small. With green certificates on both CHP and PV, the annual revenue from the certificates alone is approx. (0.02)(162 000+62 000) = 4 480 NOK (€ 500)**.**

The savings from 2016 due to the local PV generation amounted to (0.79 + 0.02)(62 000) = 50 000 NOK (€ 5 200). Savings from the CHP in 2016 (with green certificates and estimating 4 000 hours of operation) was (0.79 + 0.02)(162 000) = 131 000 NOK (€ 13 600). Note that (in contrast to the PV) the CHP has significant operational cost. In total, the local electricity production contributed to 16-17 % savings on the energy bill in 2016 ([50 000+131 000]/[890 216+50 000+131 000]).

Moving energy in time with batteries and operational control is a cost saving measure for the local distribution system operator (Eidsiva Nett). This is independent of whether the stored energy is produced at Campus Evenstad or imported from the grid. Eidsiva Nett has an ongoing research project where they are mapping flexibility potential and needs in the regional gird [24] that will be relevant for Campus Evenstad and other neighborhoods in the distribution system.

If we compare the savings of the PV with savings related to peak shaving, we find that the same saving through annual peak load shaving valued at 540 NOK/kWh/h require the highest peak to be reduced by (47 000)/(540) = 93 kWh/h. This would mean that the maximum annual load peak cannot exceed 386 kWh/h (peak load in 2016 was 479 kWh/h). In 2016, there were a total of 24 hours spread over 7 different days with a load above 386 kWh/h. Two days in November (29.nov and 30.nov) had 7 consecutive hours of loads higher than 386 kWh/h. The battery, with a potential to deliver 120 kW for 2 hours, could contribute to this peak shaving. Other flexible resources, like operational control of thermal demand and V2G, could also contribute to reducing the maximum peak load. The challenge is to ensure reliability of the flexible resources so that they are prepared to respond when the load is peaking.

The current regulatory framework encourages as little delivery to and from the grid as possible to maximize the value of the investments that have been made. Further investments in energy installations are most valuable if they increase self-consumption, i.e. generation capacity that could meet demand in hours where there is delivery from the grid. Storing surplus generation that is not immediately self-consumed to be used later requires storage capacity or operational control. Additional storage capacity is cost-efficient if the storage costs (investment and operation) are lower than the saved costs of not importing electricity from the grid and reducing high loads.

3.3 Value of local energy supply and storage at Campus Evenstad

This section presents the local supply- and storage units at Campus Evenstad, their costs, and how they create value for the neighbourhood. The current business model for the energy supply- and storage units creates monetary value for stakeholders at Campus Evenstad in mainly five ways:

1. Saved costs from less electricity delivery from the grid,
2. Saved costs through lowering annual peak load (selling of flexibility services),
3. Power during outages,
4. Saved fuel costs related to the CHP unit, and
5. Revenue from selling electricity to the grid (still small and unrealized).

Reduced peak load can potentially save costs but is challenging under current contracts. Campus Evenstad does not have a contract to sell exported electricity yet, but this is anyway a small quantity (68 NOK in 2016). Below is an elaboration on the different energy resources and their value at Campus Evenstad:

The PV installations produce electricity depending on the solar irradiation which is highest during the summer. Most of the electricity produced by the PVs in 2016 was consumed locally, and export happened only a few hours in the summer month of July (see Figure 10). With a low degree of electricity export, the value of the PV capacity is through saved import from the grid. The PVs have close to zero operational costs. The return on investment is therefore almost entirely dependent on the saved costs related to self-consumption of the electricity from the PVs, i.e. the price of electricity from the grid. Thus, the risk related to payback time is linked to the variations in the spot price in the power market. The cheaper the electricity from the grid, the longer it takes to get a return on investment.

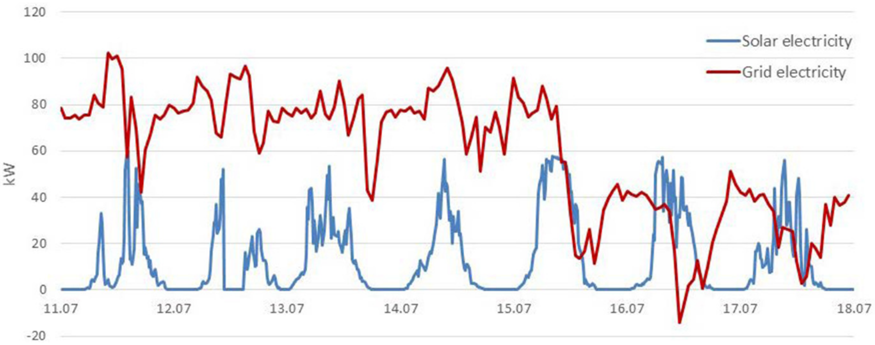


Figure 10 Load (red) and solar production (blue) profile for a week in July 2016 at Campus Evenstad.

The CHP unit creates value by serving thermal and electric demand at the connected points, i.e. by delivering space heating, domestic hot water (DHW) heating, and electricity. The operation of the CHP is dependent on heat demand, so the electricity produced is a by-product of producing heat. The electricity produced by the CHP is almost entirely self-consumed. Thus, like the PVs, the value of electricity produced by the CHP is created mostly through saved import of electricity from the grid. Providing electricity during outages is also a source of value, and the CHP can supply more stable and reliable electricity than the PVs. There are operational costs related to fuel (import of wood chips) and start-up of the CHP plant. The start-up is currently done with the electric battery, alternatively using electricity from the grid.

The solar thermal collectors create value by saving fuel costs of the other heating sources in the heating grid. Like the PVs, the solar thermal collectors have minimal operational costs. There are fundamental issues related to solar thermal collectors at a university campus: the production is highest during summer when there is little demand (few students). Significant heat spillage is hard to avoid unless long-term seasonal storage of surplus heat can be realized.

The bio boiler is used to meet heating demand on second priority after the CHP. It therefore creates value by saving import of electricity to the electric boiler (which is third priority). The bio boiler serves as a back-up and an additional source of heat. The CHP unit cannot alone supply all heat demand and can neither ensure a fully reliable heat supply. The bio boiler has similar operational costs as the CHP unit. It does not require the same quality of fuel as the CHP, but the same wood chips are used for both units. Naturally, it does not require the same amount of wood chips per unit of thermal energy as the CHP since it does not produce electricity in addition to heat.

Electric sources of heat are direct electric space heating (building connected) and the electric boiler (connected to the heating network). The electric boiler is valuable if the CHP or the bio boiler are unavailable for heat supply. If the fuel cost of the bio boiler and the CHP is higher than the cost of electricity, monetary value is created by using the electric boiler for heating. On the other hand, if heating demand can be met by the CHP, electricity is produced (CHP produces 0,4 kWh of electricity per kWh of thermal energy). Avoiding use of an electric boiler can create value through (1) saved imports from the grid and (2) produced electricity by the CHP.

The hot water storage tanks some buffer capacity, so the operation has some flexibility in terms of matching the heating of water and serving hot water demand. Value is thus related to allowing more efficient operation of the heat supply units and serving as a back-up heat supply. The heating system operation (and the value of the tanks) is highly dependent on (a) the dimensioning of the heat supply system, (b) the volume of the water storage tank, (c) the placement of the temperature sensors in the water tank, (d) the hysteresis set-points, and (e) the layout of the storage tank in combination with the heat distribution system.

The battery is valuable as back-up during outages. The battery is also valuable to start the CHP and serve electric demand from locally stored energy. The most valuable electricity is stored from the PVs since they have the lowest marginal cost. Utilizing stored electricity during periods of high demand could be extra valuable and lower the delivered electricity from the grid.

The bi-directional EV charging stations (V2G) will be able to transfer electricity from connected vehicles to the grid. Depending on the number of EVs and agreement with the EV owners, this will create a big or small flexibility potential. Most likely, there is decreasing availability for flexibility towards the afternoon when people leave campus. How the EVs are being charged will affect the lifetime of their battery [25]. This will affect the value of charging operation in providing flexibility services and must be considered when evaluating the flexibility cost and potential. The EVs can be valuable by supplying energy during outages. Controlled operation of the charging could also contribute to lowering the load on the connection point at Campus Evenstad. Smart charging can also be valuable through price arbitrage of grid electricity (buying cheap and selling expensive).

3.4 New power grid tariffs

There could be great value of reducing peak load through saved infrastructural costs in the power system [26]. In Norway, there is a suggestion to change the tariff structure to incentivize lower load on delivered electricity from the grid for all customers (not just for non-residential customers) [27]. The changed tariff structure will affect the attractiveness of local installations in a ZEN. Note that these suggestions only relate to changing the power part of the grid tariff.

The motivation behind revised grid tariffs is to make the grid part of the electricity bill more dependent on the power flow, not just energy. With value assigned to flexibility, there is an incentive to import from the grid before expected peak periods. It is therefore more attractive to invest in storage capacity regardless of whether it stores energy from the grid or from local units. Self-consuming locally produced energy will still be more valuable than selling it to the grid with a power-based grid tariff.

The monetary value of reducing peak load will have consequences for several energy installations, especially variable generation units (e.g. PV) and flexible storage units (e.g. battery). In [28], they explain how the value of reduced peak load will make PVs potentially less valuable. This happens if the peak load is unchanged regardless of whether there is PV or not. Therefore, an incentive is created to produce energy at the right time. This can be partly controlled by optimally placing the PVs to produce during expected peak hours. However, peak demand in Norway happens mainly during winter when production from PV is low due to little sun.

For flexible storage units, the fact that an incentive is created to reduce peak load could change the cost-optimal operation of them. By scheduling charging before expected peaks, storage units can reduce peak load by partly supplying energy from a local source (as opposed to delivering everything from the grid during the peak period). This potential can be realized through optimized charging operation of stationary batteries and EVs based on forecasts and control. The cost of fast charging EVs will become more volatile and expensive with a power-based part on the grid tariff. The tariff scheme should reflect that it is more expensive to charge when the grid load is high and less expensive to charge when the grid load is low. In [29] they look at operational control of EV charging under different grid tariffs with PV installed. They find that operational control of EV charging can save 12-19 % of the electricity costs. Compared to a stationary home battery, the EV battery could achieve higher savings due to capacity and power capabilities. The economic potential of achieving savings through operational control depends on future power prices, battery technology costs, grid tariff design, power demand profiles, and consequences for degradation of batteries.

With the current agreements at Campus Evenstad, using the storage units for peak shaving or demand response could theoretically be used to achieve cost savings. Note that the current regime only incentivizes peak shaving of electricity consumption during the highest peak of the year (not within each month or day). There is therefore no incentive to reduce the highest load during a month if the peak is not expected to go above the highest annual value. Alternative contracts for power-based grid tariffs (like the ones suggested by NVE [27]) might therefore be beneficial for Campus Evenstad and the local grid operator because they might provide more savings for both parties related to peak shaving.

3.5 Emission reductions

Campus Evenstad has its own local energy system for electricity generation but is also connected to the power grid. Regarding the operational phase of the campus, it is possible to distinguish between emissions related to the electricity from the grid and emissions related to the local energy system. Furthermore, it is possible to find the emission-optimal operation for Campus Evenstad, using electricity either from the grid or from the local energy system depending on what leads to the lowest overall emissions.

Generally, the average $CO_{2eq.}$ intensity of the electricity mix can be used as an indicator for the fraction of renewable energies in the electricity mix[11]. The ZEB Centre has established a constant $CO_{2eq.}$ factor to calculate emissions related to a building assuming a 60 years lifetime for this building. To determine this $CO_{2eq.}$ factor, an average $CO_{2eq.}$ intensity for the electricity mix in Europe has been assumed for the year 2010 and with a linear decrease of the $CO_{2eq.}$ intensity to 0 $gCO_{2eq.}$/kWh towards year 2054. An average $CO_{2eq.}$ factor of 132 $gCO_{2eq.}$/kWh has been determined. This value is, however, a rough estimation. The use of a yearly average electricity mix leads to errors, and accounting for temporal variation of electricity would greatly improve the reliability and comprehensiveness of LCA of electricity related impact. According to [30], the use of a yearly average electricity mix as opposed to an hourly electricity mix in the context of energy-efficient buildings can lead to errors above 30%.

The time perspective of a ZEN is assumed to be the same as the building lifetime of 60 years. The decarbonization level of the electricity mix over the years is by definition uncertain in such a long time perspective. In Europe, from a current value of 300-350 g $CO_{2eq.}$/kWh, the deployment of a different set of technologies can lead to values in the range of 19-250 g $CO_{2eq.}$/kWh [31]. Emission levels are affected by many factors, and one way to cope with this embedded uncertainty is to create a set of sub-scenarios defined for each main electricity scenario [32].

A detailed calculation of hourly average $CO_{2eq.}$ intensities of the electricity mix is not trivial. The average $CO_{2eq.}$ intensity of a country or bidding zone depends strongly on the power plant fleet, their fuel type used, and their efficiency. As bidding zones are physically connected via electricity transmission lines, electricity imports from other bidding zones can impact the average $CO_{2eq.}$ intensity of the local electricity mix as well.

In Norway, electricity is mainly generated from hydropower, which has a low average $CO_{2eq.}$ intensity. The $CO_{2eq.}$ intensity in the Norwegian grid is strongly dependent on electricity exchanges with neighboring countries, because countries like Denmark and the Netherlands rely to a larger extent on more carbon intensive fuels for electricity generation, such as gas or coal. Figure 11 presents the hourly average $CO_{2eq.}$ intensity in the Norwegian bidding zone NO1 for the year 2015. Campus Evenstad is in this zone. Fluctuations in the average $CO_{2eq.}$ intensity are obvious and give the possibility to minimize $CO_{2eq.}$ emissions during operation by dedicated controls. The annual average hourly $CO_{2eq.}$ intensity in Figure 11 can be estimated to 18 $gCO_{2eq.}$/kWh in the Norwegian bidding zone NO1.

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[11] Nuclear power plants are not carbon intense either. To say for sure that a low carbon intensity is only due to renewables, knowledge about installed power plant capacities of a country should be known.

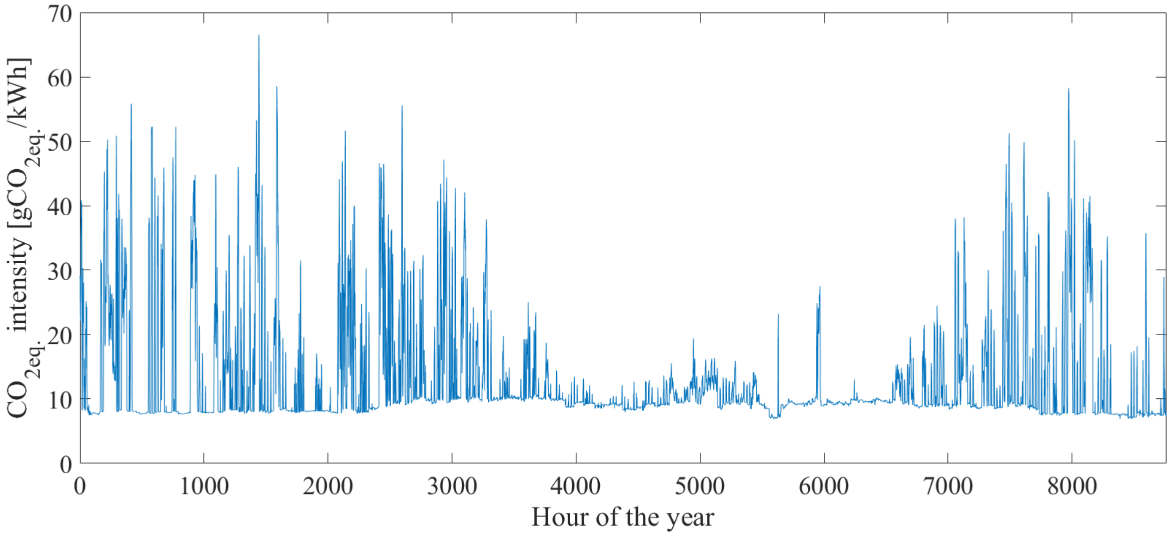


Figure 11 Hourly average $CO_{2eq.}$ intensity of the electricity mix in the Norwegian bidding zone NO1 in 2015 [33].

Figure 12 illustrates the electricity spot price and hourly average $CO_{2eq.}$ intensity in NO1 for an exemplary 5-day period in 2015. Norway usually imports electricity during the night when electricity is cheap and exports during the day when electricity is expensive. This leads to higher average $CO_{2eq.}$ intensities during the nights and lower average $CO_{2eq.}$ intensities during the day.

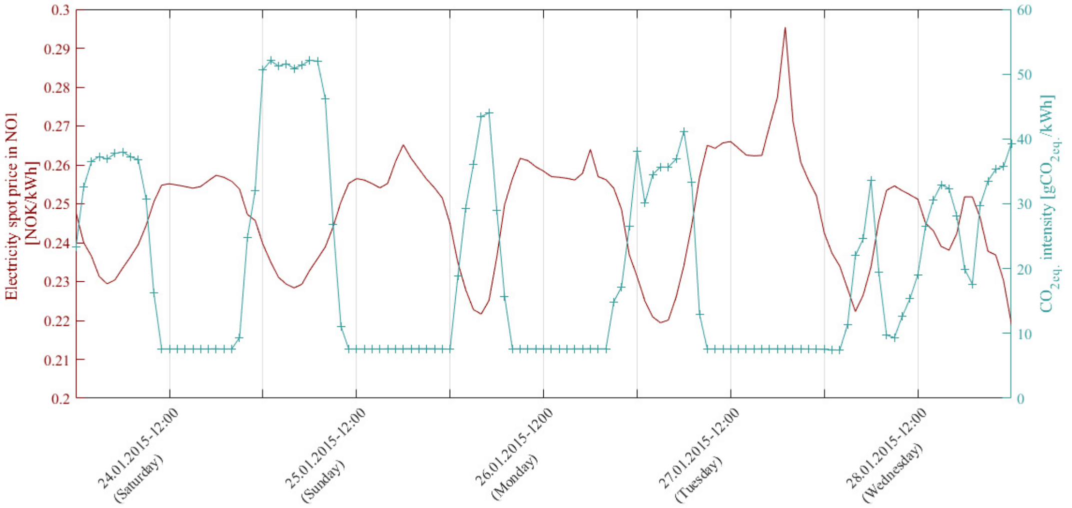


Figure 12 Electricity spot price and $CO_{2eq.}$ intensity in NO1 during 5 days in January 2015 [33].

Advanced controls, such as model-predictive control, can be used to schedule the operation of the energy system and to take decisions on when to import electricity or when to use on-site produced electricity from CHP or PV. The basic idea of the control principle is to avoid using electricity during hours with high $CO_{2eq.}$ intensities in the electricity mix. For Campus Evenstad, it is possible to import electricity from the grid at hours with low carbon intensity by making use of thermal storage such as the building thermal mass and DHW storage tanks. This load shifting is also referred to as a demand response measure.

Using the average $CO_{2eq.}$ intensity as a control signal has its limitations. In general, the average $CO_{2eq.}$ intensity of the electricity mix can be evaluated based on the forecast of the electricity generation. The signal can be used in a decoupled approach, meaning that the interaction between the supply side and the demand side is not considered. However, if this signal is applied for many buildings, the resulting electric load can be affected so that the forecasted generation would not be optimized for the occurring load anymore. Further, if a significant number of buildings take part in demand response, there may be an imbalance between the forecasted and the real electricity consumption. Therefore, in the best case, an approach considering the interaction between the supply and demand side is required, so that the demand response control is considered in the planning of the electricity generation (not just the other way around).

For Norway, if controlling the electricity of buildings according to an average $CO_{2eq.}$ intensity, electricity use will increase during peak hours, causing more stress on the grid. Already existing peak loads may be amplified, potentially leading to higher electricity prices (see Figure 12) and grid congestions. Furthermore, Figure 12 shows that a price-based control and a CO_2-based control would lead to contradictory operation periods, meaning that minimizing CO_2 emissions at the same time as minimizing costs would not be possible.

A control based on marginal emissions would also be possible, but a more advanced methodology is required to evaluate marginal emissions. The marginal approach means identifying the marginal (most expensive) generator of the system and assume additional generation (or reduced demand) will reduce emissions depending on the emission intensity of this marginal generator. In general, the emission savings are higher for a marginal approach compared to the hourly average approach described above. Variability of emission intensity is also generally higher with the marginal approach (higher difference between emission intense and non-intense hours).

3.6 Flexibility and operational control

According to the ZEN definition [4], a ZEN must manage energy flows in the built environment and with the surrounding energy system in a flexible way to facilitate the transition towards a decarbonised energy system. Examples of benefits of an energy flexible neighbourhood are:

- The possibility to avoid energy peaks, by reducing energy use or increasing energy production when needed,
- Maximising self-consumption of locally produced electricity, to avoid delivering electricity to the grid,
- Providing flexibility services to the grid owner, so that the neighbourhood uses less/more energy when this is beneficial for the grid owner.

Expected energy use can be forecasted in a “grey-box model”, using weather forecast as input. The forecasts can be used to control the energy demand in an optimal way (e.g. preheating buildings, modulating electric vehicle charging), for example using day-ahead price forecast to minimize operational cost. In ZEN WP4, such models are developed, and the plan is to test the “Model Predictive Control” (MPC) at Campus Evenstad.

As the EU aims at reducing GHG emissions, applying the $CO_{2eq.}$ intensity as a control signal for the building energy system operation aims at supporting these goals, but reducing peak load is also a relevant goal at the neighborhood level in Norway.

4 Measures to approach 100 % self-supply of renewable energy

4.1 Definition of 100 % self-supply

Different ambition levels can be set for neighborhoods motivated by different objectives. The minimum is barely meeting the standards requirements, which often leads to the lowest cost. Going beyond those regulations can be motivated by for example an objective of increased sustainability or increased reliability. Becoming a Zero Emission Neighborhood (ZEN) is a good choice for the ambition level if the main driver is increasing sustainability. Becoming 100% self-supplied is an objective of reliability, which may also imply increasing the sustainability.

A Zero Emission Neighborhood (ZEN) does not necessarily have all its electricity coming from on-site production. The ZEN framework used for the investment analysis presented in the next section states that the emissions of CO2 should be compensated for in the lifetime of the neighborhood. The compensation is based on the assumption that when clean electricity is exported from the neighborhood, some of the more carbon intensive production is reduced in other parts of the grid. Thus, a connection to the national grid is intrinsic to this framework. This relation of equality between the emission and compensation is called the *zero-emission balance*. It should be met over the lifetime of the neighborhood to be a ZEN, but one could also define the same balance over shorter periods of time to be even more ambitious.

The objective of being 100% self-supplied in terms of energy is different from being a ZEN but also different from having a zero-emission balance at each hour or each day. Being 100% self-supplied means that all the energy used in the neighborhood comes from on-site sources. This implies that no electricity from the grid is imported and that the neighborhood can only export excess electricity. A 100% self-supplied neighborhood can be a ZEN if it compensates for its emissions by exporting electricity to the grid. However, for this to remain possible both the sustainability and the reliability objective should be kept in mind and fuels such as coal or gas avoided. It is therefore impossible to be completely islanded from the national grid if the neighborhood also aims at being a ZEN, and the grid connection remains necessary. In addition, if the objective is purely being 100% self-supplied, and no goal is set on emissions, a larger number of technologies and fuel can be considered.

Another ambition level that can be set is to fulfill the zero-emission balance on various time scales, for example every hour, every day, every month, every season, or every year, as it is the case in the analysis presented in the following section. The smaller the scale at which the balance must be met, the harder it becomes to fulfill it. Moving from an annual balance to a seasonal balance is already a big step as the system can no longer rely on the PV production from the summer to compensate for the emissions from the winter. However, those even more ambitious targets usually have the benefits of bringing higher levels of self-supply.

4.2 Investment analysis for Campus Evenstad using the ZENIT tool

In this part, a brief description of the tool called ZENIT will precede an overview of some results of an analysis conducted with it. ZENIT (Zero Emission Neighborhood Investment Tool) is a tool to help stakeholders in taking decisions when planning a Zero Emission Neighborhood (ZEN). It is an optimization program that minimizes the cost of investing and operating the energy system of a ZEN during its lifetime.

The main purpose is to design the energy system of ZENs, but it also can be used with varying levels of the zero-emission balance. A detailed description of the model and its implementation in the case of Evenstad can be found in [34]. The objective function, which is the function that we aim at minimizing, gathers the cost of investing in each technology for the lifetime of the neighborhood, and the cost of the operation and maintenance discounted to the present time. The ambition level for the neighborhood is set through the zero-emission balance. In the ZEN framework, this balance is met for the lifetime of the buildings [4]. In ZENIT, we assume that each year in the lifetime can be represented by one average year, and we want to fulfill this balance over one year. Other ambition levels can be set by reducing the timeframe (to seasons, months, or days for example) or by having partial ZEN (compensating only a percentage of the emissions).

Other equations are used to model physical constraints, such as the operation of the different technologies or the electricity and heat balances (production, consumption, export, import). The input data necessary to run ZENIT are the electric and heating loads (ideally separated between domestic hot water and space heating), the outside and ground temperatures, the solar insolation, and the electricity prices. These data need to be available for every hour for the representative year chosen. In addition, information about the buildings in the neighborhood needs to be available, such as the floor area and the roof area. A heating grid can be included or not in the analysis. If it is included, the user can define its characteristics (layout, losses, and cost) or use a module that provides an estimate for all those parameters based on the layout of the neighborhood.

The analysis for Evenstad was performed with estimates of the loads, since no sufficient data was available at the time. The estimates were obtained by specifying different group of buildings and based on [35] and [36]. Unless otherwise specified, the CO_2 factors used were 17 gCO_2/kWh for electricity (inspired by average hourly marginal emission factor in price zone NO1, see Figure 11 [33]), 277 gCO_2/kWh for gas [37], and 7 gCO_2/kWh for wood chips [38]. The electricity produced via PV panels or solar thermal collectors on-site does not have CO_2 associated with it. Embodied emissions were not included in this study. The revenue from export of electricity was based on the spot price for all cases.

The optimization in ZENIT was run for four different cases:

1. Annual zero-emission balance w/ asymmetric emission factors (800 kW export limit),
2. Annual zero-emission balance w/ symmetric emission factors (800 kW export limit),
3. Annual zero-emission balance w/ symmetric emission factors and 100 kW export limit, and
4. Quarterly zero-emission balance w/ symmetric emission factors (800 kW export limit).

The symmetry of emission factors refers to the difference between emission credits gained from exporting and emission credits paid for importing. With asymmetric factors, the credits are not necessarily the same for import and export (can be based on an hourly average or a marginal approach, see Section 3.5). The results appear on the Figure 13. The dashed part of each bar represents the energy system that is already installed at Evenstad.

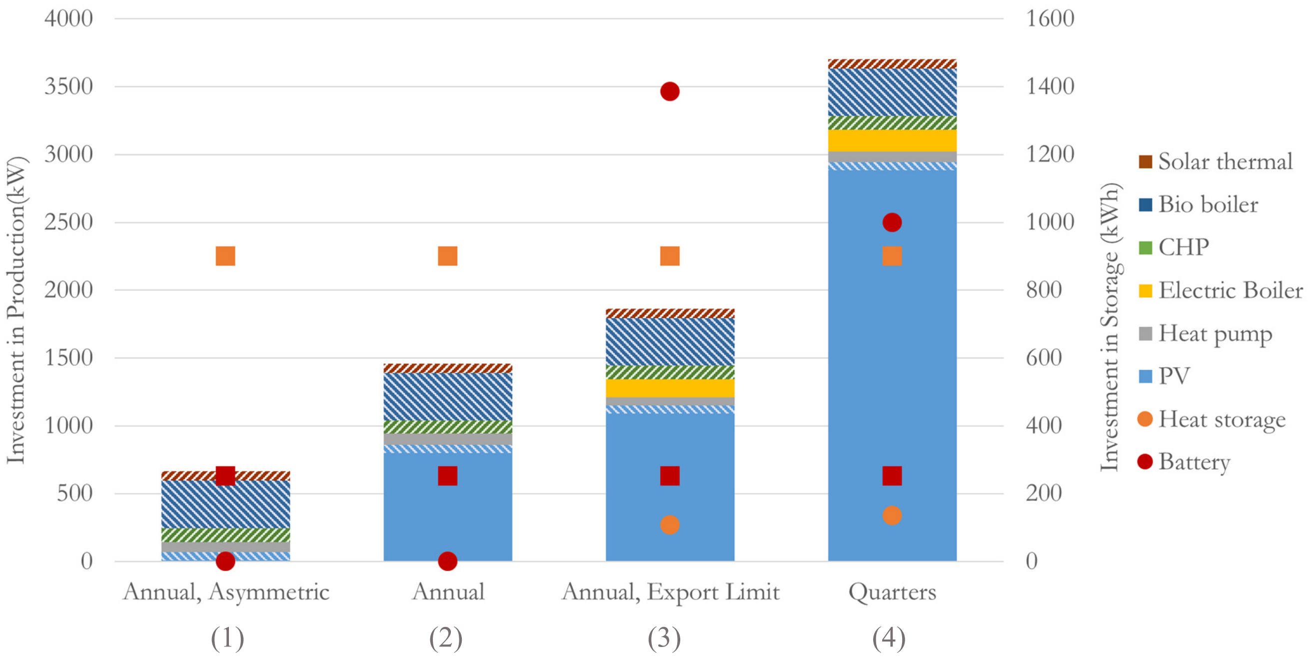
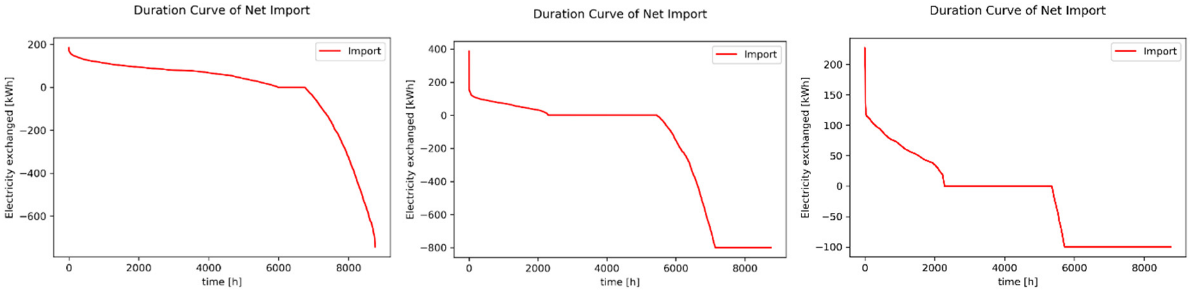


Figure 13 Results from four instances in ZENIT assuming (1) annual compensation w/ asymmetric emission factors, (2) annual compensation w/ symmetric emission factors, (3) annual compensation w/ symmetric emission factors and 100 kW export limit and (4) quarterly compensation w/ symmetric emission factors. The striped bars represent existing generation and the non-striped bars represent additional generation (left axis). For the storage technologies, the square represents already installed capacity and the circles additional capacity (right axis).

Case (1) in Figure 13 was performed using asymmetrical CO2 factors for the annual zero-emission balance. There can be good reasons for choosing asymmetrical CO2 factors. Indeed, one can consider that the exports from the neighbourhoods makes it possible to reduce the production of the most expensive unit in the system. It is then possible to estimate this CO2 factor. Ideally, every hour would have a CO2 factor associated with it depending on the marginal units in the grid (see Section 3.5). However, obtaining this data is complicated. The CO2 factors for import of electricity remained at 17 gCO2/kWh but was set at 136 gCO2/kWh for exports from renewable on-site sources following the new standard NS 3720:2018 [8]. In both cases only a small additional PV investment (around 10kW in addition) and an investment in a heat pump (around 80kW) was obtained as a result. This highlights the impact of the choice of CO2 factors in resulting designs. Note also that embodied emissions are not included in this study. In future studies a better estimate of the dynamic CO2 factors will be used.

Case (2) in Figure 13 indicate that in order to meet the annual zero-emission balance, Campus Evenstad would need a large investment in PV and a heat pump. No additional investment in heat storage or battery would be required. Those investments would come in addition to the already existing system of bio boiler, CHP, and solar thermal. Note that in this study, the roof area was not used to limit the amount of PV that can be installed. Case (2) in Figure 13 would need around 4 000 m^2 of PV, depending on the efficiency of the panels.

The study was conducted for the annual balance including the limitation of 100kW on exports in case (3) in Figure 13. This regulatory limitation can be replaced by a tariff based on the amount of exported energy since January 2019 [3]. With the export limit, the results suggest a slight increase in the PV investment, investment in an electric boiler, and a large investment in batteries. This can be explained by the necessity to smoothen out the export of the PV production that can no longer be delivered to the grid. In case (4) in Figure 13, the objective of Evenstad is to have a quarterly/seasonal zero-emission balance, a massive amount of PV and a large battery is needed.



(2) (4) (3)

Figure 14 Duration curve of net import using symmetrical emission factors for the annual balance (left), the quarterly balance (middle), and the annual balance with export limitation (right)

The duration curve of net import is shown in Figure 14 for the case (2), (4) and (3). In case (2) and (4), the 100kW export limitation is violated during approximately 900 and 2000 hours in the year, respectively. The need to smoothen out exports can be observed both for case (4) and case (3) on the duration curve (see middle and right graph, Figure 14). With the export limit in case (3), the peak import remains unchanged from case (2), but the self-consumption of electricity is greatly increased. Peak import is increased in case (4) compared to the other cases.

The total cost for investment and operation of the neighbourhood during the lifetime discounted was estimated as 39 MNOK (€ 4 100 000) for the annual zero-emission balance with symmetrical emission factors and 800kW connection. Total costs increase with 41-42% for case (3) with the export limit and 111-112% for case (4) with the quarterly balance.

The emissions and compensation of CO2 are presented on Figure 15. With the export limit, the additional batteries needed make it possible to use more of the self-produced electricity from the PV. This effect can also be observed on the duration curves in Figure 14. In the case of quarterly balances, the compensation far outweighs the emissions. Indeed, the amount of PV resulting from the optimization represent what is necessary to fulfil the balance in Q4 (see Figure 15). In other quarters, this amount of PV is over-dimensioned and results in a lot of electricity production which results in high exports, thus a lot of compensation, and low import, thus little emissions.

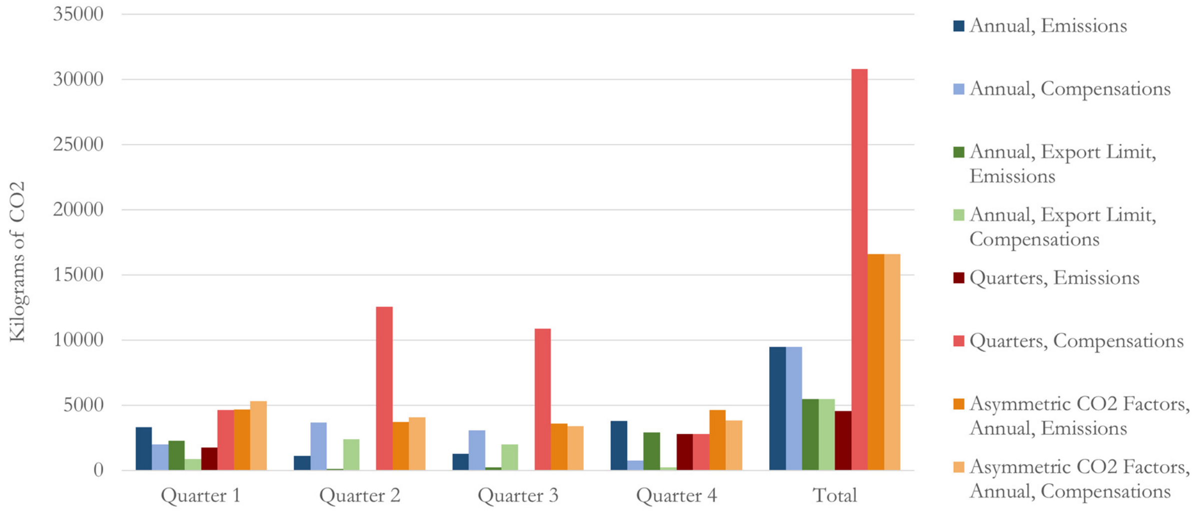


Figure 15 Results for emission credits imported (dark colour) and exported (light colour) in each quarter for all four cases. Most emission credits are exported during Q2 and Q3 as PV dominates. For case (4) with the quarterly balance, least emissions are imported in total and the annual export of emission credits exceeds the annual zero-emission balance.

Note that all the results from the analysis above only consider the zero-emission balance and tries to find the least costly solution; the problematic of reliability of supply of electricity and of self-consumption is not taken into consideration by the optimization. Those two criteria are, however, important for Campus Evenstad, as the location is prone to blackouts. It is thus important to remember it when analysing the suggested investment in heat pumps. Indeed, this investment further increases the dependence of the Campus on electricity, and the investment in PV is not sufficient (intrinsically to PV, not due to the amount) to reliably neglect the impact of blackouts. This suggests that, depending on the importance of the reliability issue, a more expensive solution than the one from the optimization should be chosen. The potential solutions would be:

- PV and bio-CHP/bio boiler
- An electrified heat system (such as suggested by the optimization) and a larger battery to reliably provide electricity to the Campus during blackouts
- Solar thermal could also be a solution to some extent but is limited by the roof area and the priority given to PV to reach the ZEN balance

4.3 Energy savings analysis using PI-SEC tool

Besides being smartly powered by local renewable energy sources, a ZEN should be highly energy efficient [4]. When reducing the energy use, the need for investments in technologies such as PV and CHP also decrease. Ambitious energy goals cannot be achieved without focusing also on energy efficiency.

Campus Evenstad has buildings dating from the late 1800’s to 2017. Some are energy efficient, such as new ZEB administration building and the student dorms. It also has buildings from the 1970’s and 1980’s that consume large amounts of energy both to heat and ventilate.

A planning tool from the project PI SEC is used to investigate the potential for energy savings [39]. In this tool, a baseline scenario with ten campus buildings are included. In the baseline scenario, the energy performance of the buildings is added according to historical energy standards, as shown in Table 7. In a new scenario, all the buildings are upgraded to TEK 10 standard. The result of this upgrade is then compared with a tentative goal of saving 30% energy. The result is shown in Figure 16 and show that an upgrade to TEK 10 standard nearly achieves a 30% energy saving. This may therefore be a realistic energy goal for the Campus. However, the potential for energy efficiency in each building should be investigated. Such mapping would identify the most cost-efficient measures.

Table 7 Input values to the PI SEC Planning tool.

Building	*Year of construction*	*Area [m2]*	*Performance input baseline scenario*	*Performance input TEK10 scenario*
Sentralbygg	1990	1570	TEK 87	TEK 10
Låven	2007	1119	TEK 07	TEK 10
Hybelbygg 1+2 (passive house)	2015	4200	Passivhouse	Passivhouse
Administrasjonsbygg (ZEB COM)	2016	1141	Low energy	Low energy
Lærebolig	1880	166	Older	TEK 10
Sveiserbolig	1956	95	TEK 69	TEK 10
Stabbur	1860	90	Older	TEK 10
Grise- og hønsehus	1936	5	Older	TEK 10
Verksted	1980	45	TEK 69	TEK 10
Biotopen	1960	138	TEK 49	TEK 10
Total		**8569**		

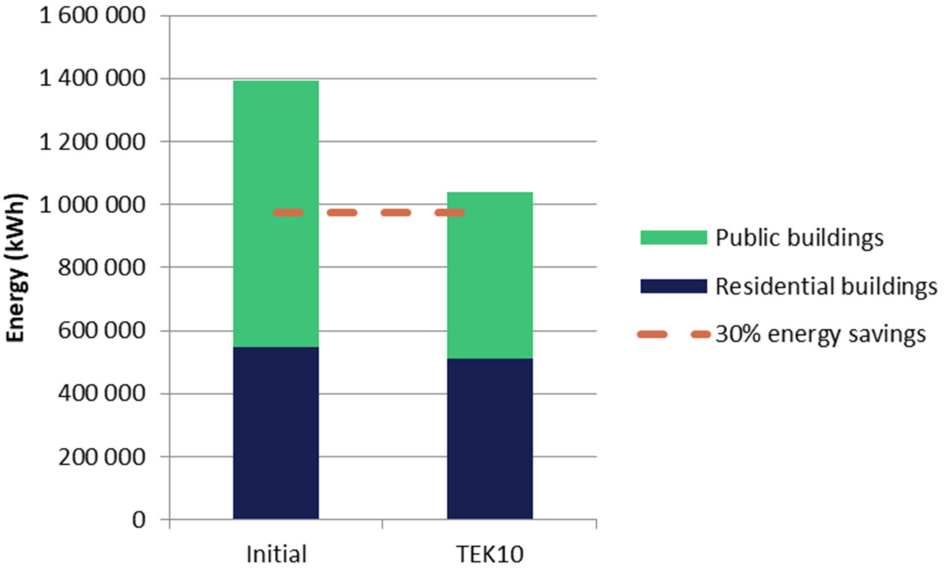


Figure 16 Potential for energy savings in Campus Evenstad, if upgrading older buildings to TEK10 standard [39].

4.4 Energy saving experiment: partly closing a building during summer

This section is based on the (preliminary) results from an experiment in the old administration building on Campus Evenstad during July 2018. The experiment was a “living lab” experiment conducted mainly to analyze social impacts of implementing an energy saving measure. The experiment included one main action: from 01.07- 01.8.2018 the heating and ventilation systems in the old administration building were shut down (this did not include the ventilation system used in the canteen on the ground floor)[12]. One of the less efficient buildings at Campus Evenstad is the old administration building. This building has three floors. The campus canteen and library are located on the ground floor, as well as some office spaces, the first floor has office spaces and meeting rooms, and the top floor is primarily a loft space used as an open workspace by master students and PhD candidates. The building is described as demanding in terms of energy costs by the technical management. It is estimated that the ventilation systems use 90 000 NOK during the summer (3-month period) to cool the building. Staff who have offices in the building are away on summer holidays (July and August) or doing fieldwork at this time of the year.

The “living lab” experiment was useful to highlight energy costs associated with different buildings on campus. Positive effects of such a “living lab” experiment can enable similar measures. It also highlights the challenges associated with energy savings for different user groups. The experiment was proposed by the technical management, who regarded it as a concrete action that would not impose too many social challenges (e.g. protests from the few building users in the summer).

To close the old systems when they are not in use was considered an interesting strategy by the group associated with the planning and development of the campus. It is a low-tech solution which demands few resources in terms of time, economy, or technology. The experiment also meant that the technical staff took the time to study the ventilation systems.

The summer of 2018 was particularly warm and dry. Technical challenges due to power cuts prior to the experiment, meant that the technical staff did not have the capacity to follow up the temperature measurements. Temperatures or air quality were therefore not measured, and results are based on experiences by users and technical staff. Offices facing south-east got very warm, whereas offices facing the north-west maintained a comfortable temperature throughout the day.

The technical staff also found at least four ventilation systems in the building currently producing warm rather than cool air for the building due to a heat recovery module on the system. Surprisingly, closing the ventilation system resulted in colder indoor temperatures. This can be explained by the simultaneous closing of the heat recovery system built into the ventilation system. When there was no ventilation or heat recovery in the morning, the cool morning temperature was kept throughout the day with natural ventilation through opening windows and doors.

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[12] The same action took place in the barn (låven), but as this building does not deal with the same social needs, it was not included in the main experiment (it is primarily used for lectures and meetings with students. There are no offices in the building)

Table 8 Comparison of consumption and peak load of the old administration building at Campus Evenstad in July 18 (ventilation off) and Aug 18 (ventilation on).

Time	Electric consumption in building	Peak load
July 2018 (ventilation system off)	15 MWh	40 kW
August 2018 (ventilation system on)	22 MWh	60 kW

The initial plan for the experiment in the old administration building was to save energy. The results from this are promising. The average load throughout July 2018 decreased from around 28 kW to 22 kW. The load varied between 15 and 40 kW. Comparing with the following month (August 2018), the power peaks and the total energy consumption were lower when the ventilation system was closed (see Table 8). The variation in load was also higher in August (ranging from 20-60 kW). The development of these values may be due to other differences between July and August (e.g. higher activity in August). Unfortunately, data for the previous year (July 2017) does not exist anymore. Data from the current experiment will be saved for later reference and comparison.

The experiment reduced the costs of supplying energy to the campus. A more long-term benefit of the experiment was less wear on the technical system, which extends its lifetime. It also showed that the aging technical systems in the building were not only expensive to run; they were actually decreasing user comfort by delivering warm rather than cold air to the building.

The experiment cannot just be seen in terms of energy saved because it also highlighted challenges in terms of user comfort and interaction with the building. When engaging with energy use on campus, the question of "what is in it for us?" arises. Actor motivation is important when developing and assessing involvement [40]. During a workshop prior to the experiment, building users stated that the experiment should lead to improvements in comfort. It was therefore proposed that, in addition to closing down the heating and ventilation systems, the building temperature before, during, and after the experiment should be measured. This action was intended to gather data about building temperature that could support the employees' complaints about comfort.

The main challenges are associated with the use of the building as a workspace during the summer. The office spaces and the library are all located on the south side of the building. The offices get too hot when it is sunny, and offices on the first floor have sun on the windows for most of the day. Workspaces on the ground floor have some shade from the ZEB administration building. Sun shading is important in the offices. However, it is not possible to both open a window to let in air and use the sun shading. This is because the windows will not open more than 2 cm when the sun shading is down.

The initial response on campus from building users showed that the potential to save energy only has limited ability to engage and did not balance out the cost in terms of time required to participate in meetings and workshops. Nor did the potential to save energy motivate the staff from moving out of the building while the experiment took place. What does engage is improving comfort within workspaces? Any scenario for achieving zero emissions on campus should consider the motivation by user groups to support the measures applied to achieve zero emissions. User motivation is currently based on how the campus functions for educational purposes and as a workspace.

5 What should be the goal related to self-supply in ZEN?

5.1 Three alternative scenarios

As a starting-point for this study, three alternative scenarios were discussed:

- Scenario 1: Optimize the energy system available today, without new investments in local production units and energy efficiency.

- Scenario 2: 100% self-sufficient by local renewable energy on average per year. The Campus is still connected to the grid, and electricity is exported during summer and imported during winter.

- Scenario 3: 100% self-sufficient by local renewable energy per hour. The scenario requires greater investments in energy efficiency, local production, and storage.

Table 9 gives a brief description of investments needed to achieve the three scenarios, as well as estimations for heating and electricity need.

Table 9 Overview of investments and consumption related to three relevant Goal scenarios for Campus Evenstad.

	Investments	Heating estimation	Electricity estimation
Scenario 1	System optimization	Around 620 000 kWh. Up to 95% of heat need from bioenergy and solar	Around 1 000 000 kWh. Up to 20% from PV and CHP.
Scenario 2	System optimization Energy efficiency New energy production Heating to more buildings.	Around 620 000 kWh. New backup added, to avoid using electric boiler.	Around 800 000 kWh.
Scenario 3	System optimization Energy efficiency New energy production Energy storage Heating to more buildings	Around 620 000 kWh. New backup added.	Around 800 000 kWh.

Achieving Scenario 1 will lead to reduced operational costs and emissions through better utilization of resources. In scenarios 2 and 3, the most important aspect will be to reduce power peaks to save costs and emissions related to further investments in energy production and storage. Table 10 gives an overview of the importance of different aspects in scenarios 1, 2, and 3.

How Campus Evenstad contributes to reduction of GHG emissions will depend on assumptions related to the emission factor. The new Norwegian standard (NS 3720:2018) [8] suggests always using at least two factors for electricity from the grid. Investments ensuring efficient use of clean energy will save most emissions in the long run, and the emission factor related to local energy sources is easier to determine than the emission factor from the grid. All scenarios are possible under current regulatory framework, but scenario 2 requires the 100 kW export limit in “Plusskundeordningen” to be removed. It is feasible for Campus Evenstad to become a small-scale electricity producer with the newly changed tariff structure (without a hard export limit) [3]. As a pilot in FME ZEN, scenarios 2 and 3 are relevant for developing knowledge and experience of what it means in practice to pursue such an ambition.

Table 10 Overview of importance of different aspects in scenarios 1, 2, and 3 (darkness of colour reflects degree of importance)

Aspect	Scenario 1	Scenario 2	Scenario 3
Further investments		▒	█
EOS system	▒	▒	▒
Reduced delivered energy demand		▒	▒
Energy flexibility and storage		░	█
New electricity production		▒	█
End-user involvement	░	▒	█
Limiting regulatory framework		░	░

When implementing the improvements towards a scenario, the following order may be suggested:

- **Step 1:** EOS system in place, which allow O&M staff to follow electricity and heat production and use.
- **Step 2:** Energy efficiency measures to reduce electricity and heat need.
- **Step 3:** Shift electricity away from heat in heating plant. Consider if more heating needs can be covered by the district heating network. Consider temperature levels in DH network. Consider if solar thermal can be delivered to DH network.
- **Step 4:** Add new electricity production.

Having an EOS-system in place (Step 1) can also happen in parallel with the later activities. However, by making sure this is in place early, the improvements from implementing Steps 2, 3, and 4 will be measured and can be evaluated.

When implementing Step 2, the most relevant energy efficiency measures should be mapped. This mapping will identify the most cost-efficient measures. For example, Hovedbygget is a building with considerable potential for energy efficiency.

By implementing Step 3 with biomass-based heating, the need for electricity on campus will be reduced. This will reduce the need for electricity to be added in Step 4.

In Step 4, our analysis suggests additional PV to be the most relevant source of new electricity production. PV panels can be added to campus roofs or facades. Asplan Viak [41] did an analysis of roofs available for PV. The PV-area was estimated to be 111 m^2 for Musefarmen (east and west), 209 m^2 for Driftsbygning, and 225 m^2 for Låven, in total 545 m^2. In addition, having PV panels on the parking areas were discussed, providing around 725 m^2 PV-area. The available area and expected electricity production should be further analyzed. Also, other electricity sources can be considered in addition to PV (e.g. wind).

Energy flexibility and storage have economic value under current agreements if it can be used to successfully reduce the maximum peak load over 12 months (very demanding). This requires a reliable EOS-system and advanced processing of data to be able to plan and react to high loads. A stationary battery, V2G, and controlled operation of hot water storage tanks can all provide energy flexibility. Alternative agreements, such as shorter measuring period than 12 months, can make it easier to schedule flexible units for peak shaving. Electricity storage is also valuable for Campus Evenstad as it increases the reliability of the power supply and functions as a start-up for the CHP plant. If step 4 is pursued, energy storage and flexibility will have greater economic value under current agreements by maintaining a high degree of self-consumption with more on-site production (more valuable than export).

5.2 Future work

This study has conducted a detailed assessment of the operational phase of the Campus. It would be interesting to see how the different scenarios would be translated in terms of embodied emissions: in building materials when renovation to reach higher building standard are required to achieve energy reductions, but also in the energy infrastructure (PV, CHP, batteries, etc).

Typically, this type of combined study has already been conducted for the pilot building [21] which represents 10% of the total BRA of the campus. When assessing the rest of the building mass on Campus Evenstad, special attention will have to be paid to choice of materials and construction techniques, which are expected to differ from the pilot building. Evaluation of different outer walls construction techniques as well as lower energy standards (TEK10) have been analyzed in [21]. These inventories could be used to further assess the rest of the existing building mass of the campus.

Our investment analysis in Chapter 4.2 suggests that for Campus Evenstad to become a ZEN, large investments in PV would be required. Therefore, it might be interesting to investigate other solutions in addition to the ones included in this analysis. Indeed, increasing the efficiency of buildings and appliances in the older parts of the campus as a first step would reduce the load and make it possible to reduce the amount of PV needed. However, the effect of investing in insulation is not modelled by ZENIT so far. In addition, some options that were left out of ZENIT might be interesting to investigate in the case of Evenstad. For example, a local wind turbine might be a reasonable solution, either owned by the campus or through an agreement with a power producer. Such solutions would require further analysis.

Another topic up for analysis would be the reliability of the system against blackouts. With a simulation or optimization tool with a high temporal resolution (15 minutes or less), the potential energy system design could be tested against blackouts of different lengths and compared to the reliability of the current energy system.

References

[1] Person H, Berentsen TK. Solcellesystemer og sol i systemet. På oppdrag fra Solenergiklyngen, ; 2018.
[2] Zaitsev D, Rehbinder E, Heimdal K, Abbas A, Berkhahn A, Younes S. Mot lysere tider: Solkraft i Norge – Fremtidige muligheter for verdiskaping. WWF; 2016.
[3] Verlo KR, Eriksen AB, Fladen BA, Mook V. Høringsdokument nr 6-2018: Forslag til endring i forskrift om kontroll av nettvirksomhet. Digital publisering: NVEs hustrykkeri; 2018.
[4] Wiik MK, Fufa SM, Krogstie J, Ahlers D, Wyckmans A, Driscoll P, et al. Zero Emission Neighbourhoods in Smart Cities: Definition, Key Performance Indicators and Assessment Criteria: Version 1.0. The Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN), ; 2018.
[5] New Energy Outlook 2018. BloombergNEF, ; 2018.
[6] Parisio A, Rikos E, Glielmo L. A model predictive control approach to microgrid operation optimization. IEEE Transactions on Control Systems Technology. 2014;22(5):1813-27.
[7] Fufa SM, Schlanbusch RD, Sørnes K, Inman MR, Andresen I. A Norwegian ZEB Definition Guideline. FME ZEB - The Research Centre on Zero Emission Buildings, ; 2016. p. 48.
[8] NS 3720:2018 - Methods for greenhouse gas calculations for buildings (in Norwegian). Standard Norge; 2018.
[9] LOV-2017-06-16-60 - Lov om klimamål (klimaloven). Klima- og miljødepartementet.2017.
[10] SSB. Energi og industri. Statistisk Sentralbyrå (Statistics of Norway); 2018.
[11] SSB. Natur og Miljø. Statistisk Sentralbyrå (Statistics of Norway); 2018.
[12] Hagos DA, Gebremedhin A, Zethraeus B. Towards a flexible energy system–A case study for Inland Norway. Applied Energy. 2014;130:41-50.
[13] Trømborg E. IEA Bioenergy task 40 – Country report 2011 for Norway. IEA Bioenergy Task. 2011.
[14] Gullberg AT. The political feasibility of Norway as the 'green battery'of Europe. Energy Policy. 2013;57:615-23.
[15] Bakke AM, Paulen SL. Status og prognoser for kraftsystemet 2016 - Sammenstilling av data fra kraftsystemutredningene for regionalnettet fra 2016. Norges vassdrags- og energidirektorat, ; 2016.
[16] Selvig E, Wiik MK, Sørensen ÅL, Løkken S, Bergstrøm PK, Jørgensen PF, et al. Campus Evenstad – Statsbyggpilot. Jakten på nullutslippsbygget ZEB-COM.: Statsbygg; 2017.
[17] Nikolaisen HV. Statsbygg Miljøstrategi 2015-2018. 2014.
[18] Sartori I, Napolitano A, Voss K. Net zero energy buildings: A consistent definition framework. Energy and Buildings. 2012;48:220-32.
[19] Nes H. Load match study of photovoltaic production and charging demand of electric vehicles in a zero emission neighbourhood: case Campus Evenstad: Norwegian University of Life Sciences, Ås, 2017.
[20] Sørensen ÅL, E. Fredriksen, H.T. Walnum, K. Skeie, . IA. ZEN pilot survey: Initial plans for thermal and electrical use, generation, distribution and storage. ZEN project memo. Norway. 2017.
[21] Wiik MRK, Sørensen ÅL, Selvig E, Cervenka Z, Fufa SM, Andresen I. ZEB Pilot Campus Evenstad. Administration and educational building. As-built report. ZEB Project report. 2017.
[22] Wiik MK, Fufa SM, Kristjansdottir T, Andresen IJE, Buildings. Lessons learnt from embodied GHG emission calculations in zero emission buildings (ZEBs) from the Norwegian ZEB research centre. 2018;165:25-34.
[23] Sidelnikova M, Weir DE, Groth LH, Nybakke K, Stensby KE, Langseth B, et al. Rapport nr 2/2015 del 1 Kostnader i energisektoren Norges vassdrags- og energidirektorat; 2015.
[24] Hovedrapport: Regional kraftsystemutredning for Hedmark og Oppland 2018. Eidsiva Nett, ; 2018.
[25] Ipakchi A, Albuyeh F. Grid of the future. IEEE power and energy magazine. 2009;7(2):52-62.
[26] Faruqui A, Harris D, Hledik R. Unlocking the€ 53 billion savings from smart meters in the EU: How increasing the adoption of dynamic tariffs could make or break the EU's smart grid investment. Energy Policy. 2010;38(10):6222-31.
[27] Hansen H, Jonassen T, Løchen K, Mook V. Høringsdokument nr 5-2017

Forslag til endring i forskrift om kontroll av nettvirksomhet. Norges vassdrags- og energidirektorat (NVE); 2017.
[28] Sæle H, Bremdal BA. Economic evaluation of the grid tariff for households with solar power installed. CIRED-Open Access Proceedings Journal. 2017;2017(1):2707-10.
[29] Bjarghov S, Korpås M, Zaferanlouei S. Value comparison of EV and house batteries at end-user level under different grid tariffs. 2018 IEEE International Energy Conference (ENERGYCON). 2018:1-6.
[30] Roux C, Schalbart P, Peuportier BJJoCP. Accounting for temporal variation of electricity production and consumption in the LCA of an energy-efficient house. 2016;113:532-40.
[31] Van der Hoeven M, Houssin D. Energy technology perspectives 2015: Mobilising innovation to accelerate climate action. International Energy Agency: Paris, France. 2015.
[32] Wolfgang O. European power market analyses to be carried out within FME ZEN: ZEN deliverable D5. 3.1 for 2017. SINTEF Rapport. 2017.
[33] Clauß J, Stinner S, Solli C, Lindberg KB, Madsen H, Georges L. A generic methodology to evaluate hourly CO2 factors of the electricity mix to deploy the energy flexibility potential of Norwegian buildings. 10th International Conference on System Simulation in Buildings, Liege, Belgium, 10th-12th December. 2018.
[34] Pinel D, Korpås M, Lindberg KB. Cost Optimal Design of ZENs Energy System: Model Presentation and Case Study on Evenstad. International Symposium on Energy System Optimization (ISESO), Karlsruhe. 2018.
[35] Lindberg KB, Doorman G. Hourly load modelling of non-residential building stock. PowerTech (POWERTECH), 2013 IEEE Grenoble. 2013:1-6.
[36] Lindberg KB, Doorman G, Chacon JE, Fischer D. Hourly electricity load modelling of non-residential passive buildings in a nordic climate. PowerTech, 2015 IEEE Eindhoven. 2015:1-6.
[37] Conversion factors for electricity in energy policy: A review of regulatory application of conversion factors for electricity and an assessment of their impact on EU energy and climate goals. Technical report. Adapt Consulting AS, ; 2013.
[38] Dokka T, Sartori I, Thyholt M, Lien K, Lindberg KBJPN. A Norwegian zero emission building definition. 2013.
[39] Walnum HT. PI-SEC Scenario calculator. SINTEF Byggforsk; 2018.
[40] Parker G, Murray C. Beyond tokenism? Community-led planning and rational choices: findings from participants in local agenda-setting at the neighbourhood scale in England. Town Planning Review. 2011;83(1):1-28.
[41] Kallhovd M, Bernhard P. Energiforsyning Campus Evenstad - forprosjektrapport. Asplan Viak, ; 2015.

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