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Opportunities for Local Energy Supply in Norway: A Case Study of a University Campus Site

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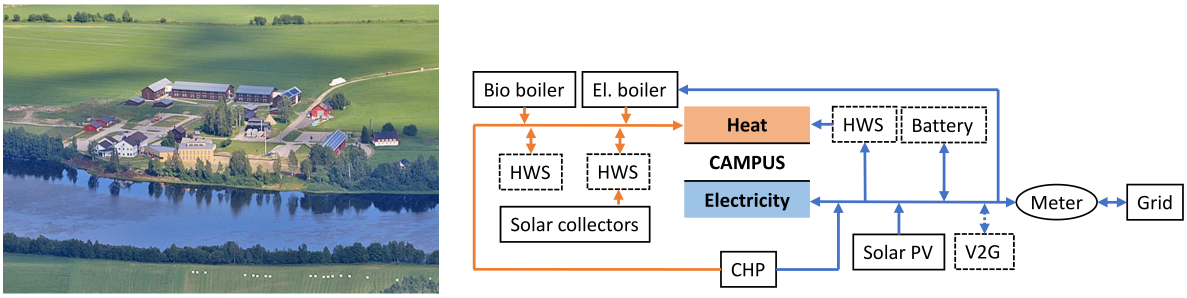
Abstract. Neighbourhoods can contribute to climate change mitigation by supplying and/or facilitating renewable energy sources (RES). In this context, we evaluate opportunities related to the energy system of a Norwegian university campus, Campus Evenstad, by quantifying monetary value of local energy resources like solar photovoltaics (PV) and a bio-based combined heat and power (CHP) plant in a cost analysis. Environmental value is discussed regarding operational control of energy units to minimize emissions. Using mixed integer linear programming (MILP), we also present results from an investment analysis for local thermal and electric energy system to achieve different levels of emission compensation. Results show that local electricity supply generates most monetary value through saved costs related to reduced power grid import, and that solar PV is the most cost-efficient resource to achieve compensation of GHG emissions.

1. Introduction

Within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN), the definition of a 'Zero Emission Neighbourhood' (ZEN) [1] highlights measures related to energy efficiency, renewable energy, flexible operations and economic sustainability.

A method for emission compensation for buildings has been developed in the Norwegian Zero Emission Building (ZEB) Research Centre [2]. A similar method is now used in a new Norwegian standard NS 3720:2018 [3]. The focus was on nZEBs [4], which are buildings with a low energy requirement. In addition, the delivered energy to nZEBs should to a significant extent be covered by local renewable energy sources (RES). This includes electricity and heat produced and delivered inside or nearby the building. The idea is to compensate for the total life-cycle greenhouse gas (GHG) emission measured in CO2 equivalents by producing more on-site energy than needed for self-consumption. The locally produced energy is based on RES, and the emission credits gained by feeding the grid with surplus energy lead to emission credits by using a marginal approach. A modular LCA approach inspired by the standard NS3720:2018 has recently been proposed for the neighbourhood level [5].

This paper presents a case study of Campus Evenstad which has a total floor area of 10,000 m^2, and consists of several buildings, local energy production and local energy storage. We



(a) Photo by Arne Nyaas (Fjellfolk Media)   (b) Sketch of energy system at Campus Evenstad.

Figure 1: Campus Evenstad (1a) and the connection between energy system units (1b). Blue arrows shows possible flow of electricity, while orange arrows shows possible flow of heat in the heating grid. Dotted boxes symbolize storage units. Some hot water storage (HWS) tanks are fueled by electricity, while others are connected to the heating grid. Vehicle-to-grid (V2G) is still under development.

investigate the following questions: (1) What economic and environmental value does the local energy production and storage represent at Campus Evenstad? and (2) Which investments in local energy production and storage is required to compensate for GHG emissions related to energy use at Campus Evenstad, in a cost-efficient manner?

The structure of the paper is as follows: Section 2 gives an overview of our case study with estimated and measured energy data. Section 3 quantifies monetary and environmental value of these energy assets. Section 4 presents our investment analysis of how to achieve a net zero emission balance at Campus Evenstad. Finally, Section 5 concludes the paper and suggests future work.

2. Background

Campus Evenstad is a pilot project in FME ZEN with a low-carbon energy system (see Figure 1). The campus was also a pilot in FME ZEB, where the new administration building became Norway's most ambitious ZEB pilot classified as ZEB-COM [6]. The end-users at Campus Evenstad include around 70 employees (academic employees, operators and administrative staff) and 250 students. The buildings range from the energy efficient ZEB-COM building and the passive house classified student dorms to buildings from the 1800s, 1970s and 1980s consuming large amounts of energy both for heating and ventilation. The site is connected to the power grid and has a local heat distribution grid.

Table 1 presents an overview of on-site energy supply assets (excluding the power grid). The annual production is estimated for the CHP and the solar collectors and is based on full-year measurements from 2016 for the bio boiler, the electric boiler and the solar PV. The numbers are preliminary since there have been changes since 2016 with more buildings connected to the local heating grid. In addition to the generation units in Table 1, there are eleven hot water storage (HWS) tanks of varying size and temperature-dependent storage capacity. There was installed a li-ion battery in 2018 that can store 204 kWh and charge/discharge at 120 kW. It can perform roughly two hours of island operation in winter times and can enable start-up of the CHP independent of grid import. Four electric vehicle (EV) charging stations are installed at the campus: One charging point delivers 20 kW and the three remaining deliver 10 kW each. A newly planned charging station will be able to draw energy from the EVs (vehicle-to-grid, V2G) turning them into mobile batteries.

Campus Evenstad consumes around $1,100,000$ kWh electricity including locally produced electricity annually (see Table 2). Based on Table 1, current local supply can deliver 20% of

Table 1: Generation of heat and electricity from local units at Campus Evenstad in 2016. Estimates are marked with *.

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

annual electricity consumption. Electric import is volatile and can at times reach over 400 kWh/h. The building with the highest consumption of electricity makes up around 26% of the total electricity consumption of the campus. Table 2 contains more details on the interaction between the campus and the power grid between 2015 and 2017.

Table 2: Key performance indicators (KPIs) for electricity at Campus Evenstad (the grid 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 [7]). Estimates are marked with *.

KPI, electricity	2015	2016	2017†
Net import [kWh]	1,012,941	1,058,962	906,955
Max import power [kWh/h]	436	479	468
Average power [kWh/h]	116	121	104
Grid utilisation factor [%]	27	25	24
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*	21*	24*

†*Excluding January*

Energy used for heating purposes adds up to around $620,000$ kWh. Comparing this to the heat production listed in Table 1 and electricity import listed in Table 2, the CHP plant has not yet been utilized to its full potential (4,000 hours of operation) during the first years in operation. The thermal demand varies between 250 and 350 kWh/h throughout the year, depending on both space heating (SH) and domestic hot water (DHW) demand. Most thermal demand is distributed through the heating grid, and the remaining demand is supplied by electric heaters in buildings. The CHP is first priority supply for the heating grid. The CHP unit alone cannot always meet heat demand and can neither ensure fully reliable heat supply, so the bio boiler is second priority. Table 1 shows that the CHP and the bio boiler could meet current heat demand when combined. When bio-based supply is unavailable, the electric boiler supplies heat demand (third priority). When heating demand is met by the CHP, electricity is produced (CHP produces 0,4 kWh of electricity per kWh of thermal energy). Avoiding use of electric boiler can thus (1) save imports from the grid and (2) facilitate more electricity generation by the CHP.

The large HWS tanks are connected to the local heating network with some flexibility to match heating demand. The flexible operation of the heating system is dependent on (a) the dimension of the heat supply system, (b) the volume of the water storage tank, (c) the placement of the temperature sensors in the water tanks (if temperature-based), (d) the hysteresis set-points and (e) the layout of the storage tanks in combination with the heat distribution system.

3. Value of energy assets

3.1. Monetary value

Campus Evenstad has a prosumer agreement facilitating cost savings through self-consumption of electricity and revenue from selling surplus electricity not exceeding 100 kWh/h. It is based on net metering of delivered energy (import) from the grid (consumption minus production). Electricity produced at Campus Evenstad has additional value through a Norwegian-Swedish system for market-based electricity certificates. This income is independent of whether the produced electricity is self-consumed or exported. To allow for higher export, Campus Evenstad could apply for concession to become an electricity producer subject to fixed and variable grid feed-in costs.

The billing contract with the retailer follows the daily varying spot price of the power market in addition to a fixed monthly price. The grid tariff has three parts: (1) a fixed annual part, (2) an energy part related to transportation losses, and (3) a power part based on the highest hourly average power from the last 12 months.

Based on cost data from the energy retailer (Ishavskraft and spot prices from Nord Pool) and the distribution system operator (Eidsiva Nett), we present estimates of the power purchase rates at Campus Evenstad in Table 3.

Table 3: Estimate of power purchase rates for Campus Evenstad based on open sources. The energy part of the energy rate is linked to the wholesale spot price in Nord Pool. The energy dependent tax charges include an excise tax for electricity and a charge for electricity certificates.

Cost category	Fixed part	Energy part	Power part
Energy rate (ex. VAT)	588 NOK/yr	0.06-2.07 NOK/kWh	-
Grid tariff (ex. VAT)	13,200 NOK/yr	0.04 NOK/kWh	432 NOK/kWh/h
Tax charge (ex. VAT)	800 NOK/yr	0.1658+0.02 NOK/kWh	-

Assuming an average spot price of 0.50 NOK/kWh, total energy savings (including savings on VAT and grid charges and tax charges based on Table 3) from consuming locally produced energy at Campus Evenstad can be estimated to 0.91 NOK/kWh plus 0.02 NOK/kWh from electricity certificates. Annual savings based on the numbers from Table 1 can be estimated to:

$$(62,000 \text{ kWh} + 160,000 \text{ kWh})(0.91 + 0.02 \text{ NOK/kWh}) = 206,460 \text{ NOK} \tag{1}$$

Maximum annual savings could thus amount to 17-18 % of the total electricity bill with currently installed assets.

The normal payment for prosumer export is spot price plus a positive or negative charge (+/- 0.05 NOK/kWh) to compensate for local grid losses. If we assume the local grid charge is 0 NOK/kWh, energy export is only worth the spot price plus electricity certificates (0.52

NOK/kWh). Compared to self-consumption (0.93 NOK/kWh), and depending on the spot price of electricity, this is about half as profitable. Campus Evenstad currently has very high self-consumption (see Table 2).

The deployment of demand side flexibility by activating thermal and electric storages is remunerated under current agreements if they can be utilized to (1) maintain a high degree of self-consumption (which is more valuable than export) and (2) reduce the maximum peak load over 12 months (very demanding task). This requires a reliable data logging system and advanced processing of data to plan and react to high loads. The battery, with a potential to deliver 120 kW for 2 hours, could contribute to peak shaving. Other flexible resources, like V2G and flexible energy loads at campus, could also contribute. The challenge is to ensure reliability of the flexible resources, so that they are prepared to respond when the load is peaking.

3.2. Environmental value

It is possible to distinguish emissions related to electricity from the grid and to the local energy system at Campus Evenstad through an estimation of a CO2eq. intensity [8]. Furthermore, it is possible to define 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 [9].

In Norway, electricity is mainly produced from hydropower with a low average CO2eq. intensity. The CO2eq. intensity in the Norwegian grid is strongly dependent on electricity exchanges with neighbouring countries relying on more carbon-intensive fuels, such as gas or coal. 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 CO2eq. intensities during the nights and lower average CO2eq. intensities during the day (see Figure 2).

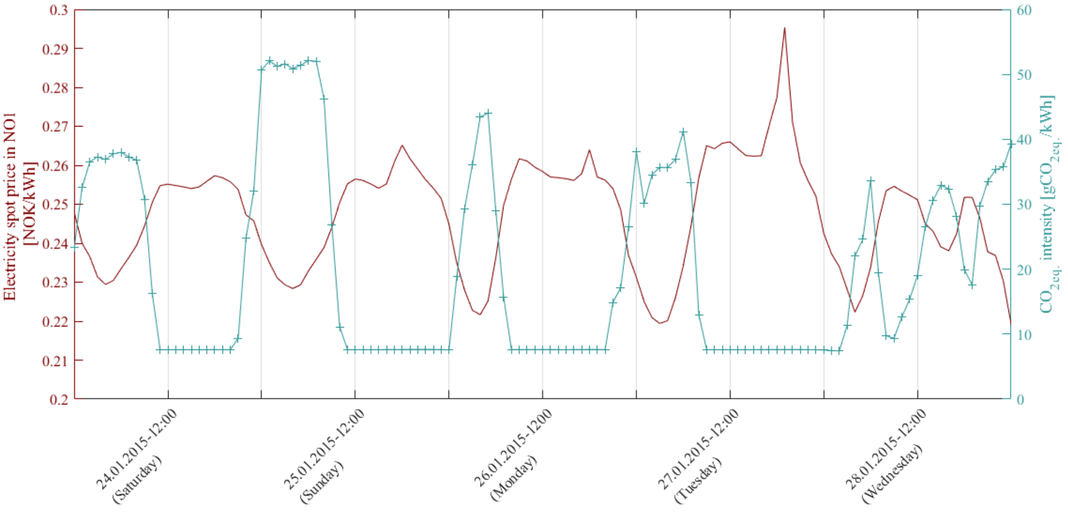


Figure 2: Electricity spot price and CO2eq. intensity in NO1 during 5 days in January 2015. Reference: [8]

If controlling the electricity import according to an average CO2eq. intensity at Campus Evenstad, electricity import will increase during peak hours. Already existing peak loads may be amplified, potentially leading to higher electricity prices and grid congestions. Furthermore, Figure 2 shows that a price-based control and a CO2-based control would lead to contradictory operation periods, meaning that minimizing CO2 emissions at the same time as minimizing costs would be challenging. Maximizing self-consumption of local electricity production from solar PV and bio-based CHP will guarantee both: (1) low emissions and (2) minimize energy transport losses.

Applying the CO2eq. intensity as a control signal for the energy system operation aims at supporting emission reduction goals, but reducing peak load is also a relevant goal at Campus Evenstad. Blackouts have been a problem at Campus Evenstad which increases the motivation for procuring and operating energy flexible assets to increase reliability of supply.

4. Investments to achieve a 'zero-emission balance' for the neighbourhood

The following section presents an investment analysis to achieve a Zero Emission target for Campus Evenstad. We apply the optimization model ZENIT (Zero Emission Neighbourhood Investment Tool) [10], which is a mathematical programming model to minimize the the cost of investing and operating the energy system of a ZEN during its lifetime.

It considers the investment cost of energy supply and storage technologies, as well as the operation and maintenance costs. We simulate one single year with hourly timesteps and scale the costs to the lifetime of the ZEN to limit the computation time. The lifetime of the system is assumed to be 60 years. We require emissions to be compensated through clean electricity exported from the neighbourhood assuming it reduces some of the more carbon-intensive production in other parts of the power system. We refer to this relation of equality between emission and compensation as the 'zero-emission balance', and it is modeled as a constraint in the optimization by using the product of CO2 factors (gCO2eq/kWh) and consumption (kWh) of the different fuels. Other constraints include load balancing of supply and demand for electricity and heating, as well as state-of-charge constraints for storage units. Technologies can be invested in at the building level and at the neighborhood level with different costs and characteristics. A more detailed description of the model can be found in [10].

We investigate fulfilling the 'zero-emission balance' both annually and seasonally. The analysis was conducted both with a grid connection of 800 kW and the limitation of 100 kW on exports. The revenue from export of electricity was based on historic spot prices.

We estimated the hourly energy load in the building stock as described in [11]. The CO2eq. factors used were 17 gCO2eq/kWh for electricity (inspired by average hourly emission factor in price zone NO1 [8]) and 7 gCO2eq/kWh for wood chips [12]. The emission factor for electricity from the CHP is 28 gCO2eq/kWh assuming a 25% efficiency of electricity generation from the CHP plant. Thermal efficiency of the CHP is assumed to be 40%. Emissions from the life-cycle stages other than the operational phase were not included, so we assume solar panels and solar thermal on-site emits 0 gCO2eq/kWh. We also performed an analysis using *asymmetrical* CO2eq. factors for the annual balance, meaning there is a different weighting on imported CO2eq. and exported (compensated) CO2eq. For the asymmetrical CO2eq. factors, we assumed import of electricity remained at 17 gCO2eq/kWh but were set at 136 gCO2eq/kWh for exports from renewable on-site sources inspired by the Norwegian standard NS 3720:2018.

The results are displayed in Figure 3. The striped part of each bar represents the existing energy system at Campus Evenstad, while the non-striped part represent additional capacity (left axis). For the storage technologies, the squares represent existing capacity while the circles represent additional capacity (right axis).

With annual asymmetric CO2eq. factors (Figure 3, far left), some additional PV (around 10 kW) and investment in a heat pump (around 80 kW) were obtained as a result. This highlights the impact of the choice of CO2eq. factors in resulting designs, i.e. emission compensation through export of electricity is very dependent on the estimation of CO2eq. factor and whether it is a marginal or an average estimation.

With an annual symmetrical CO2eq. factor (Figure 3, middle left), the results indicate that Campus Evenstad would need a large investment in PV and a small investment in heat pump.

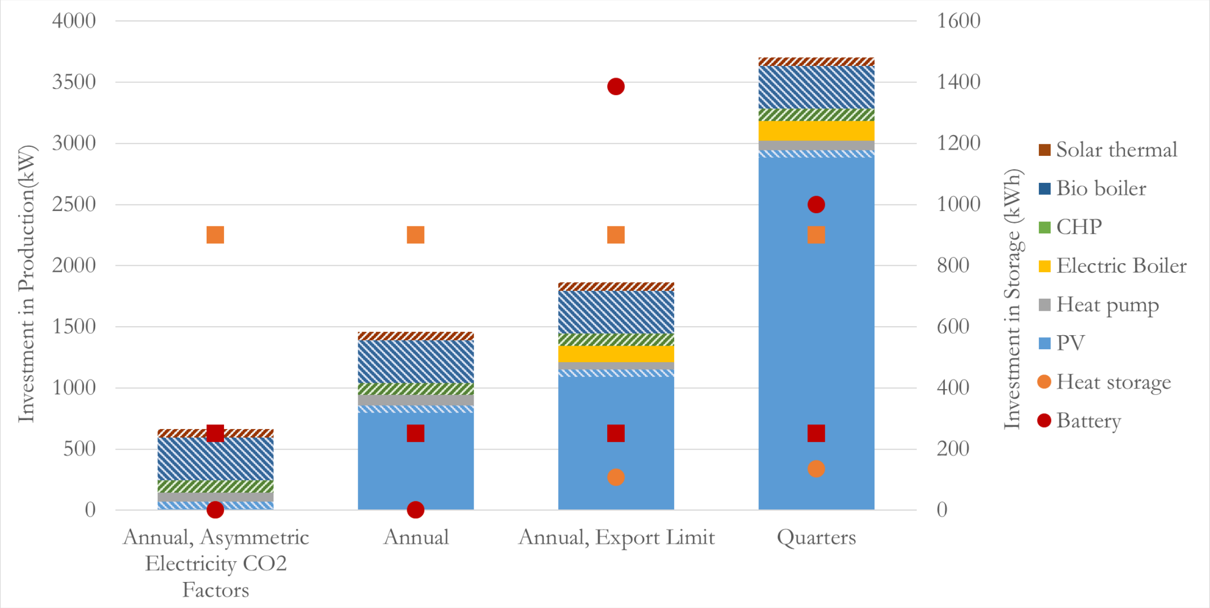


Figure 3: Results from four instances in ZENIT. From the left: (1) annual asymmetrical CO2eq. factor, (2) annual symmetrical CO2eq. factor, (3) annual symmetrical CO2eq. factor with 100 kW export limit and (4) seasonal symmetrical CO2eq. factor.

These investments would come in addition to the already existing system of bio boiler, CHP and solar thermal. Note that this is under the assumption that wood chips have a CO2eq. factor of 7 gCO2eq/kWh [12]. No additional investment in heat storage or battery would be required. The PV area would be around 4,000 m^2 (about 10 times the current area).

With an annual symmetrical CO2eq. factor with the 100 kW export limit (Figure 3, middle right), the results suggest a slight increase in the PV investment, investment in an electric boiler and a large investment in batteries. This is because the PV production that can no longer be sent to the grid directly, but is still needed to compensate for emissions. The peak import remains unchanged, but the self-consumption of electricity is greatly increased. Compared to the same case without the export limit, total energy system costs increase with 41%.

With a seasonal symmetrical CO2eq. factor (Figure 3, far right), massive investments in PV are chosen. A large battery is also chosen by the investment model. In the case of seasonal balances, the compensation far outweighs the emissions. Indeed, the amount of PV resulting of the optimization represent what is necessary to fulfill the balance in the highest demanding season, which is during the winter. In other quarters, this amount of PV is over-dimensioned and results in a lot of electricity production which results in high exports (high compensation) and low import (low emissions). Compared to the case with annual symmetrical CO2eq. factor, total energy system costs increase with 112%.

The model suggests investment in heat pumps and PV in all instances. However, a heat pump will increase the electricity demand (since heat supply is mostly based on bio) and more PV is not likely to increase reliability as the production follows solar conditions. Refurbishment of older buildings would also be a way to reduce energy demand and increase efficiency of buildings, which would in turn reduce the amount of PV needed to fulfill the ‘zero-emission balance’. Using a planning tool from the project PI-SEC [13], we find that an upgrade to TEK 10 standard for older buildings achieves energy savings in the range of 30%.

5. Conclusion

Self-consumption of generated electricity has higher economic value than export under current agreements. Self-consumption will contribute positively to emission reductions when based on renewable sources. The objective of operational control of electricity import through battery storage and demand response must be chosen carefully to balance conflicting objectives of monetary cost minimization and CO2eq. minimization. Alternative billing agreements based on power rather than energy will make remuneration related to operational control more feasible.

Across different ambitions and assumptions to achieve a 'zero-emission balance' at Campus Evenstad, investment in PV is a preferred strategy by the ZENIT optimization model when minimizing costs. Depending on the 'zero-emission' ambition and constraints related to power exports, battery storage is also key to achieving the target.

Further research should consider a more detailed mapping of the energy efficiency solutions, and it should separate between electric-specific and thermal energy efficiency. Embodied emissions should be considered for the energy infrastructure (PV, CHP, batteries, etc) and other materials. Ensuring reliable electricity supply or self-consumption should be further investigated as Campus Evenstad is prone to blackouts.

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