Lessons learned from innovative energy solutions to enable zero emissions areas

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Abstract

In line with the EU's vision of "local energy communities", Campus Evenstad, a Norwegian university campus, takes energy actions that contribute to the clean energy transition. The campus has been developed over several years, demonstrating a number of innovative and sustainable technologies and energy solutions, for example, vehicle-to-grid (V2G), biomass-based combined heat and power (CHP), solar energy, energy storage, energy efficiency measures, and a zero-emission building.

The aim of this paper is to share experiences from operations of the energy solutions. The lessons drawn from Campus Evenstad demonstrate that, despite the difficulties associated with being an early adopter, there are valuable learnings and positive outcomes gained from putting solutions into action. The project yields significant insights and practical knowledge that have benefited the property owner, the wider construction industry, and the scientific community at large. Dissemination of the project's experiential knowledge has far-reaching implications for future property concepts and decision-making processes across the industry.

Campus Evenstad is a pilot in The Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). This paper summarizes the lessons learned from implementing innovative energy solutions, in the process of transforming an existing university campus into a zero-emission neighbourhood. A lot of operational experience has been gained, both on individual technologies and the interaction between these, and the interaction with the national energy system. Dedicated professionals, from the property developer, operating staff, and campus management to researchers, have been central to the realization of the solutions.

Introduction

THE UNIVERSITY CAMPUS EVENSTAD

EU has a vision of "local energy communities" as a mean to empower citizens to collectively drive the clean energy transition, fostering increased energy efficiency, reduced energy poverty, and the creation of local green job opportunities. They also play an important role in enhancing public acceptance of renewable energy projects and attracting private investments, thus restructuring energy systems towards sustainability. (European Commission, 2024).

Campus Evenstad (Figure 1) is a small department at Inland Norway University of Applied Sciences, with 220 students. The area consists of 22 buildings (10,000 m^2 building area) managed and owned by Statsbygg: the Norwegian government's building commissioner, property manager and developer. The oldest building is from the 18^{th} century and the newest is the administration centre (2017) which is a Zero Emission Building (ZEB) with the highest ambitions (ZEB-COM: The building renewable energy production compensate for greenhouse gas emissions (GHG) from construction, operation and production of building materials) (Wiik et al., 2018).

For Statsbygg, Campus Evenstad is a pilot property for testing new technological environmental solutions and exploring how various technological solutions can work together. The solutions have been developed and studied together with researchers and partners in the research centre FME ZEN (NTNU and SINTEF, 2023). The vision for Campus Evenstad in FME ZEN is "an energy-flexible Campus Evenstad in an emission-free Europe". The energy system at Evenstad consists of several innovative energy solutions that are new in the Norwegian and European context. They are combined in local infrastructure for electricity and heat, which has led to new knowledge and learning about how the solutions work together, and how the interaction is between the local and the national energy system. The solutions consist of solar cells (PV), thermal solar collectors, CHP based on wood chips, biofuel boiler, electric boiler, heat storage, stationary battery, and bidirectional electric vehicle (EV) charging (V2G).

Statsbygg has gained a lot of operational experience from Campus Evenstad – both from individual technologies and from the interaction between these, which benefits Statsbygg's 2,200 buildings and 3 million m^2 building area around Norway. Sharing of experiences is central, e.g. through a dedicated homepage (Dybesland et al., 2023). Evenstad has regular visits from politicians, decision-makers, researchers, environmental organizations, and energy- and building companies.

TOWARDS ZERO EMISSION NEIGHBOURHOODS

The work in this article is conducted within FME ZEN research centre in cooperation with the property owner. The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no GHG emissions and thereby contributes to a low carbon society. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m^2 and more than 30 000 inhabitants in total. In the ZEN research centre, a neighbourhood is defined as a group of interconnected buildings with associated infrastructure, located within a confined geographical area. A net zero emission neighbourhood aims to reduce and compensate its direct and indirect GHG emissions towards zero over the analysis period, in line with a chosen ambition level (Wiik et al., 2022). The ZEN solutions are important actions towards climate-neutral EU in 2050. The overall purpose of this publication is to demonstrate feasibility of different energy solutions and motivate society for further actions, based on our practical experiences from Campus Evenstad.

Lessons learned from implementing innovative energy solutions

Several key solutions have been important when aiming to achieve the goals of reduced emissions, increased self-sufficiency in energy, and an energy-flexible campus. This section summarizes key lessons learned from the real-life implementation.

DEDICATED PROFESSIONALS

The public sector can play a prominent role in stimulating private innovation (Torregrosa-Hetland et al., 2019). For example, Green Public Procurement, when public authorities seek to procure goods, services or works to reduce environmental impacts, can be used as a tool for realizing innovative energy solutions (Sapir et al., 2022), as recognised by the EU Public Procurement Directive. A success factor often lies in the engagement of dedicated professionals, as experienced in Evenstad. Both Statsbygg's operating staff and researchers from FME ZEN have been central to the realization, together with dedicated management at the University campus. They demonstrated a great willingness to adopt new solutions not yet prevalent in Norway at that time. This collective effort not only fostered a sense of pride but also strengthened the identity of both Statsbygg and Campus Evenstad.

Statsbygg/Campus Evenstad contributes to the development through purchasing and demonstration of the solutions. This is a benefit for both end users, energy service providers and society at large. The Campus implementation also contributes to developing the local business community. For example, there is a local production of biomass chips for the CHP, and V2G-software was developed by a Norwegian startup company.

SOLAR ENERGY

A 70 kW$_p$ roof-mounted solar photovoltaic (PV) system was installed in 2013, when there were only a few grid-connected PV systems in Norway, as shown in Figure 2. Campus Evenstad

Figure 1. Photo of Campus Evenstad (Photo: Arne Nyaas, Fjellfolk Media).

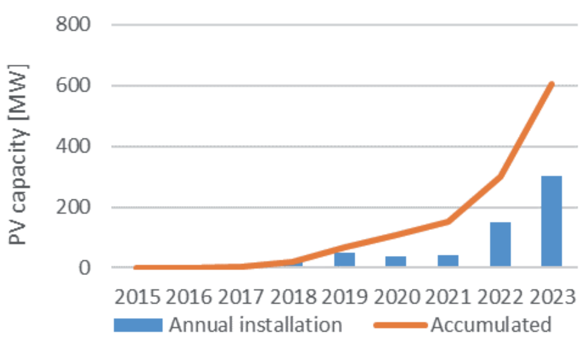

Figure 2, Installed PV capacity in Norway (annual and cumulative) (NVE, 2024b). In Evenstad, 70 kWp was installed in 2013.

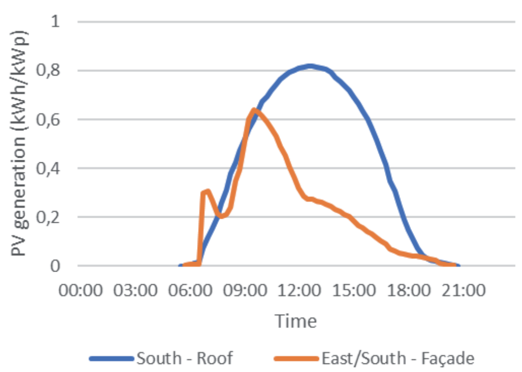

Figure 3. PV generation from the roof and façade mounted PV systems at Evenstad during an example day, April 19th, 2023.

became a prosumer in 2016, as the first with the local Distribution System Operator (DSO) Eidsiva. A prosumer can both use and generate electricity behind the same billing meter, and surplus electricity can be sold to the energy company (NVE, 2016). Evenstad was also one of the first three PV systems in Norway to receive green certificates under the joint Norwegian-Swedish electricity certificate scheme (NVE, 2024a). The PV system was important for changing the view on solar energy in Norway, where businesses, the public sector, and private individuals started seeing the potential for solar energy also this far north. The PV system has also contributed to Statsbygg's strong focus on solar energy in government buildings today. PV systems have now been installed on 30 Statsbygg buildings (approx. 2,300 MWh), and more are being planned.

In 2022, the PV system was expanded with a 15.3 kW_p PV system on the façade of the energy centre. The implementation of roof and façade mounted PV systems with different orientations, makes it possible to compare real-life energy generation from the different systems. Compared to the roof-mounted PV system facing south, the façade system will deliver a larger share of energy in spring and autumn (due to the steep angle) and in the morning (due to the east-facing solar panels). Similarly, the PV system facing west will deliver a higher proportion of energy in the afternoon. This is illustrated for an example day during April in Figure 3. The figure also illustrates the effect of a tree located near the façade system, casting a shadow around 8 AM in the morning.

At Evenstad, there is also a thermal solar collector system installed, covering 100 m^2 of the roof of student dormitories. The system supplies 117 dormitories with domestic hot water (DHW). Originally, the system supplied heat to the apartment buildings exclusively, but there was little demand for DHW during the summer vacation period when the solar collectors produced the highest output. Consequently, in 2022, the solar collector system was integrated with the local heating system, allowing surplus energy to be distributed to other buildings on the campus. The main heat source of the local heating system is bioenergy, and solar energy and bioenergy complement each other at different times of the year. From Evenstad, Statsbygg experienced how solar collectors are most suitable for buildings with stable heating needs in the summer. Statsbygg is now installing solar collectors on several prison roofs, with year-round DHW demand.

ZERO-EMISSION BUILDING AND BIOMASS-BASED COMBINED HEAT AND POWER

A new administration and educational building was built as a Zero Emission Building (ZEB) in 2017, with ZEB-COM ambition level (Wiik et al., 2018). 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. This was the first ZEB-COM building in Norway, and learnings from the building process are available in (Selvig et al., 2017; Wiik et al., 2017). The building is highly energy efficient, and within the definition of a low-energy building (Standard Norway, 2012). The experiences have proved useful for other projects, e.g. when developing construction sites with low emissions in Norway (Wiik et al., 2023).

To compensate for emissions, two renewable energy generation options were considered: Solar PV generation and biomass-based CHP. The decision to implement a CHP unit was chosen, since there already were PV modules on campus, which generated energy during the summer season. The CHP unit mainly generates energy (heat and power) during the winter/heating season, which gives a good match with the existing solar energy system. In addition, this was the first small scale wood chip-based CHP unit in Norway, and Statsbygg wanted to gain experience from the technology. Figure 4 shows photos of the ZEB COM building and the heating central with the CHP unit.

The CHP unit (type Volter), commissioned in 2016, uses locally produced wood chips to generate up to 100 kW of heat and 40 kW of electricity. However, it is not possible to generate electricity from the CHP plant without simultaneously delivering heat. The heat from the CHP plant is supplied to the local heating system, which provides heat to approximately 8000 m^2 building area.

Operational experience has highlighted the CHP plant's high requirements for wood chip quality. The wood chips must be dry and of the correct size to ensure optimal efficiency. Furthermore, the plant requires daily supervision and operates best when running consistently at around 80 % capacity. The CHP plant is connected to a thermal storage tank with a capacity of 10,000 litres, which is an advantage to ensuring steady operation. The use of the CHP plant is prioritised in the local heating system, before the use of the biofuel boiler (300 kW). An electric boiler is in addition available, for backup (315 kW).


Figure 4. Left: Photo of the new administration and educational building at Evenstad. Right: The heating central at Evenstad (Photos: Anne-Lise Aakervik).

DEMONSTRATING VEHICLE-TO-GRID

V2G equipment was realized at Evenstad in 2019, demonstrating the first bidirectional EV charging in Norway. The main aim of the implementation was to gain increased knowledge and practical experience from purchasing, installing, and operating the V2G solution.

From 2025, all new cars in Norway must be zero-emission, and in 2023 the sales share of EVs was 88 % (International Energy Agency, 2023). The use of EVs poses both opportunities and challenges. On one hand, EVs contribute to the reduction of emissions from mobility. On the other, the need for EV charging can create challenges for the electricity grid capacity (Sadeghian et al., 2022). V2G technology offers a promising solution: the batteries in EVs can supply power back to buildings or the power grid. This provides new possibilities, where EVs e.g. can be charged when there is surplus solar energy generation, and supply energy to buildings during the evenings to reduce grid peaks.

The potential benefits of V2G are described in numerous articles (Gonzalez Venegas et al., 2021; Mastoi et al., 2023; Sadeghian et al., 2022), including providing services to the grid, such as frequency regulation, or achieving cost, energy, or climate goals for the end-users, e.g. by increasing the self-consumption of solar PV energy, or reducing power peaks. There are register about 130 V2G projects worldwide (V2G Hub, 2024), however, the technology is still not readily available on the market. V2G implementation still faces several challenges (Gonzalez Venegas et al., 2021), including the lack of communication protocols, possible EV battery degradation, and needed systems for interacting with EV users. Further practical experiences are needed to overcome the barriers.

To implement V2G, a bi-directional charger with an energy management system (EMS) is needed, as well as an EV that is capable of supporting V2G. In Evenstad, we experienced how bi-directional chargers were not easily available on the European market. The purchasing process started in 2017, and there were few possible products available. The bi-directional charger we finally got access to in 2019 was a prototype, delivered by Nissan/AME, and the EMS was thereafter developed by Current AS. The prototype was replaced by two bi-directional chargers in 2021.

The EV is connected to the bi-directional charger using the direct current (DC) connector in the EV. DC is converted to alternating current (AC) in the bi-directional charger, before being used in the buildings on campus. Only EVs with CHAdeMO charging technology/protocol can use the chargers, and in Evenstad, Nissan Leaf cars are used as they comply with the protocol. It is clarified with Nissan that the battery warranty for the EVs remains valid with the planned V2G usage patterns at campus, shifting energy loads in time. However, the number of EVs with CHAdeMO connectors is decreasing in Norway, while the use of CCS connectors is increasing. This may become a challenge for the use of the V2G units in the future.

The power of the bi-directional chargers is 10 kW, and an EV can deliver about 9.5 kW to the campus grid. Within 2 hours, a Nissan Leaf car can thus supply around 20 kWh. For a car with a 40-kWh battery, this means that the battery's state of charge (SoC) is reduced from, for example, 80 to 30 %. There are energy losses during the charging process, as DC from the car's battery is converted to AC during discharge, and then back to DC during charging to the same SoC. For example, 23 kWh was discharged in a session in May 2020, and the car then had to charge 28 kWh to return to the same SoC. This means that the efficiency for the total charging cycle (roundtrip efficiency) was around 82 % (calculated as 23 kWh discharged / 28 kWh charged). Such energy losses have to be taken into account when evaluating how V2G (and stationary batteries) can assist achieving cost, energy, or climate goals for a building or neighbourhood.

Figure 5 (right) shows an example of how V2G can be used at Evenstad. The illustrated situation shows how two EVs deliver a total of 40 kWh twice a day: in the morning and evening. The cars charge around 48 kWh (in the afternoon and at night) to return to the starting SoC. Assuming an energy cost of NOK2 (~0.2 Euro) per hour during discharge and NOK1 (~0.1 Euro) per hour during charging, this would result in a savings of NOK16 (~1.6 Euro) per car per charging session. In this price example, a car with two daily charging sessions in one year would therefore save approximately NOK11,000 (~1,100 Euro) which is low cost-effective, especially taking into consideration possible degradation of the car battery. In the future, also other economic incentives may become available for end-users in Norway, such as frequency reserve markets (Stai et al., 2023). The figure shows the total power loads for Evenstad, and how V2G use can alter the power loads.

ENERGY STORAGE

Stationary battery storage has been installed at Evenstad, serving as backup power for critical loads and during peak power demands. The battery system is among the 5 largest grid-connected electrical batteries in Norway (Berg, 2019). In total, three batteries with a total capacity of 120 kW and 200 kWh are installed at the Campus. To the surrounding grid, the use of batteries can contribute to greater flexibility in a microgrid and enhance grid security (Li and Wang, 2021). Furthermore, batteries can reduce the need for grid expansion. When relying on renewable energy sources with variable production, batteries can serve as frequency support. Batteries are also a crucial component in ensuring stable operation during power outages.

In the period before the battery storage was installed, Evenstad was facing challenges with repeated power outages leading to damage to technical equipment. Therefore, a decision was made to install a stationary battery system that could provide assistance during power outages. The batteries are used to store electricity generated locally on site.

Campus Evenstad experienced several challenges with the implementation and operation of the battery system. The procurement process showed that larger battery storage systems were not widely available on the Norwegian market and required a very technically specific design during the planning and ordering of the investments. The battery system at Evenstad would ideally serve several aims: Assistance during power outages, delivering start-up power to the CHP unit, increasing self-consumption of solar PV electricity, and reducing peak power loads.

After the installation of the battery system, a substantial disparity was discovered between the specified energy capacity and the actual operational energy capacity of the battery system. Operational experience with the system has demonstrated that the campus experiences short power outages during transitions from grid-connected to off-grid operation. Moreover, the use of other technical equipment, such as for example CHP or PV, together with the battery storage system has proven to be challenging. A critical takeaway from battery storage operations is the necessity to maintain realistic expectations regarding battery system capacity and the type of problems the system is intended to address. The battery system has been in operation since the summer of 2022, and so far, the benefits compared with the costs have been low.

COMBINATION OF SEVERAL TECHNOLOGIES

The energy system at Evenstad is managed with the goal of ensuring stable operation and providing optimal comfort for the users. Additionally, there is a desire to reduce energy consumption and peak loads, in order to reduce the energy costs at campus. Different technologies are supplied by various vendors, each with its own principles for control and management. The operational experiences from Evenstad show that it can be challenging to control various technologies within such a complex energy system. Signals from the energy technologies are not necessarily easily available in the same energy monitoring system. In addition, it is important to measure the most important energy flows and operational parameters, to detect faults, and provide opportunities for improved control and energy savings. Work is still ongoing to find optimal solutions for the energy management at Evenstad.

Conclusion

This paper summarizes lessons learned from implementing innovative energy solutions, in the process of transforming an existing university campus into a zero-emission neighbourhood. A lot of operational experience has been gained, both from individual technologies, the interaction between these, and the interaction with technologies and the national energy system. Dedicated professionals, from the property developer, operating staff, campus management, and the researchers, have been central to the realization.

The project yielded invaluable insights with far-reaching implications for future conceptual solutions across the entire construction industry. A diverse array of cutting-edge technologies and solutions was tested, enabling the attainment of high energy and environmental standards. Moreover, the interplay of these technologies gave a deeper understanding of how systems can enhance each other. At the same time, it became clear that due to the complexities arising from the integration of diverse technological approaches, it is sometimes difficult to achieve an overall optimal result.

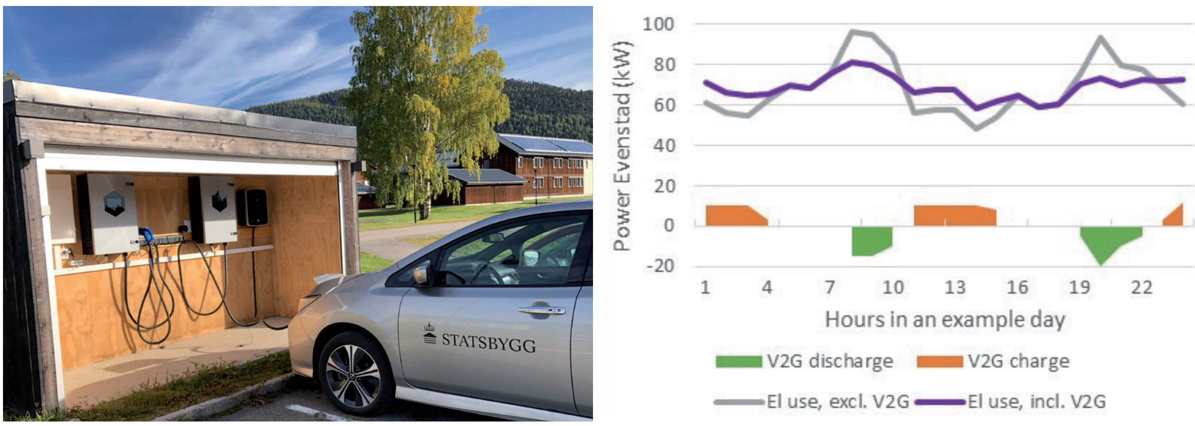

Figure 5. Left: Photo of the V2G equipment at Evenstad (photo: SINTEF). Right: Illustration of an example day with charging/discharging of two EVs, and its effect on the total power loads for Campus Evenstad.

This project served as a catalyst for the expanded utilization of advanced technologies in other construction endeavours. Additionally, Statsbygg, by pioneering these advanced solutions, demonstrated to society the transformative potential and limitations of modern technologies. This project motivated the construction industry, real estate sector, policymakers, and decision-makers to embrace a more ambitious and forward-thinking approach to energy efficiency in buildings and neighbourhoods. About 20 scientific publications and master's theses were produced (FME ZEN, 2024), disseminating the project's valuable insights to the scientific community at both the national and international levels. The lessons drawn from Campus Evenstad demonstrate that, despite the difficulties associated with being an early adopter, there are valuable learnings and positive outcomes gained from putting solutions into action.

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