Designing a ZEN Campus: An exploration of ambition levels and system boundaries

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Designing a ZEN Campus: An exploration of ambition levels and system boundaries

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Abstract. The Norwegian University of Science and Technology (NTNU) is gathering from dispersed locations to one central campus at Gløshaugen, requiring an estimated 92 000 m^2 new buildings and upgrading 45 000 m^2 of existing buildings. NTNU has high environmental ambitions for the new campus, including zero-emission ambitions. This paper explores system boundary definitions and ambition levels in a Zero Emission Neighbourhood (ZEN) context. A key element is a plus energy campus that provides a surplus of renewable energy in the operational phase, that can compensate the carbon footprint of buildings, infrastructure and mobility. Preliminary energy and carbon analyses of the campus have been performed A key result is an overview of design choices and methodology choices for concept stage calculations for a zero-emission campus. Six system boundaries have been defined, with the production to consumption ratio varying from 19 % to 132 %. The lowest includes all buildings, the highest includes production from all buildings, but consumption only from new and renovated buildings. The main finding is that it is possible to realise a plus energy campus for new and renovated buildings, but not including non-renovated buildings. A plus energy campus requires a combination of PV and seasonal energy storage.

1. Introduction

The Norwegian University of Science and Technology (NTNU) is gathering the campus in Trondheim from dispersed locations around the city to one central campus at Gløshaugen. This is a significant building project both in the context of the university and in the context of Trondheim municipality. The project requires a substantial development of the existing campus at Gløshaugen; there is an estimated need for 92 000 m^2 of new buildings and upgrading of 45 000 m^2 of existing buildings. This means that the renovation will affect almost 15 % of the existing approximately 320 000 m^2 of buildings at NTNU, in addition to expanding the campus by almost 30 %. NTNU is partner in the Zero Emission Neighbourhood (ZEN) centre [1] and has high environmental ambitions for the new campus, including zero-emission ambitions e.g. as defined by ZEN. The ZEN concept of zero emissions builds on the work from the Research Centre on Zero Emission Buildings (ZEB) [2], which developed methodology for how to design and build zero-emission buildings. A ZEB building is a building where the production and export of renewable energy is exported, which offsets the carbon footprint of the building in a life cycle perspective.

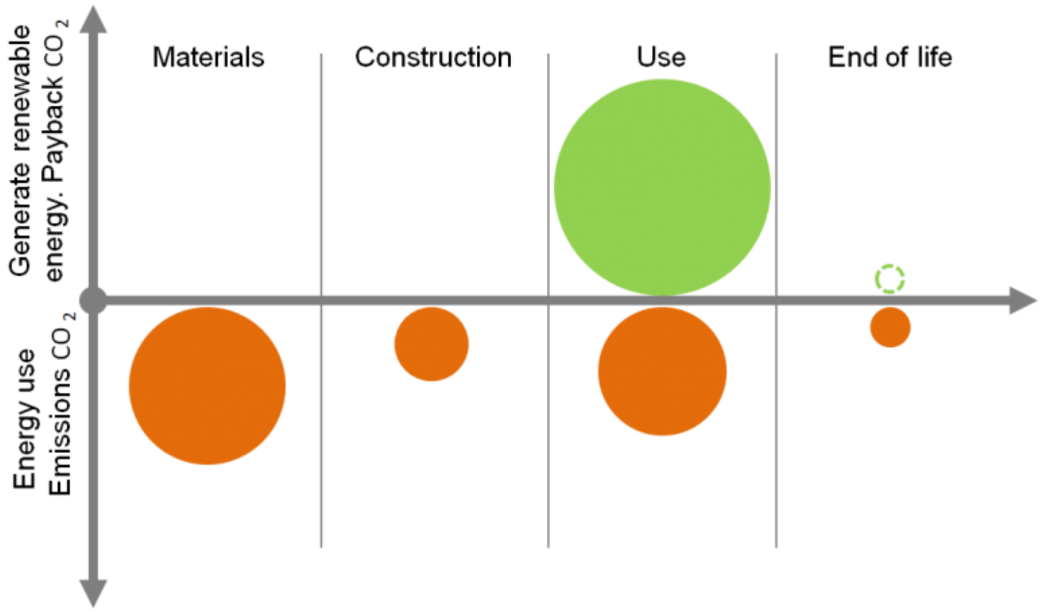

Figure 1: The Zero Emission Building framework [3, 4]

The Research Centre on Zero Emission Neighbourhoods builds on the ZEB concept and expands it both by lifting it up to a neighbourhood perspective and expanding the scope from carbon footprint to a total of eight aspects, as shown in Figure 2. Here the ambition level is linked to performance compared against a reference scenario for the neighbourhood. ZEN also includes mobility in the use phase (e.g. transport of students and employees to and from the university), and this requires significant further development of the methodology [5-7]. But achieving zero emissions is also in ZEN based on export of new renewable energy. The purpose of this paper is to analyse if and how the NTNU campus at Gløshaugen can generate more new renewable energy than is consumed by the campus itself and to explore how the definition of the system boundaries influence this. The results are a synthesis that is based on work performed in the campus development project at Gløshaugen.

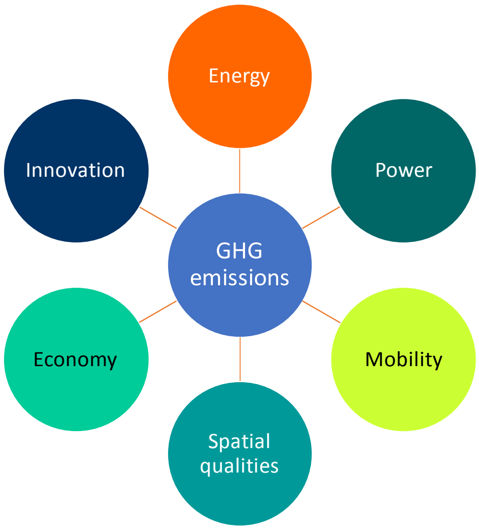

Figure 2: ZEN aspects (from presentation by I. Andresen)

Although the main purpose of this paper is on the energy surplus from the campus, it should be recognised that this is only one aspect of many that are important for a ZEN pilot project. ZEN has developed key performance indicators (KPI) for all the eight aspects shown in Figure 2, and these aspects should not be seen in isolation as there is a complex interaction between them.

2. Method

This paper explores system boundary definitions and ambition levels for a zero-emission campus in a ZEN context, outlining key design choices both for the technical system and for the definition of the system boundary, which all have carbon footprint impacts. To reach the carbon ambitions in a neighbourhood perspective it is necessary to reduce the carbon footprint of the buildings (including their infrastructure and foundations), to build and renovate energy-efficiently, and to produce new renewable energy onsite. A key element is a plus energy campus that can provide a surplus of renewable energy in the operational phase that can be used to compensate for the carbon footprint of buildings, infrastructure and mobility. Renewable onsite energy production onsite is photovoltaics (PV), other technologies were considered but not included (e.g. building integrated wind).

This paper presents a synthesis of the system boundary discussion, based on work performed in relation to the campus development project at Gløshaugen. Preliminary energy and carbon analyses of the campus have been performed by several consultancy companies through the pre-project period, and these identify both energy flows and the potential carbon footprint of the planned campus [8, 9]. In addition, a document outlining the environmental premises for the campus project has been developed in the pre-project stage by NTNU and Statsbygg, with contribution from ZEN [10]. These outline the technical aspects of energy production and generation, and this is interpreted in light of the zero-emission ambition using the ZEN framework. A limitation of this work is the exclusion of the quick clay challenge related to infrastructure and foundations, which will require in-situ improvement before they can be used (e.g. buildings or seasonal thermal energy storage). Here the focus is primarily on how the campus can provide a surplus of new renewable energy. This paper systematises the work that has been performed in the pre-project and analyses the implications for the energy production and consumption at the campus.

3. System boundary choices

3.1. Introduction

The system boundaries of ZEN cover three categories: buildings, infrastructure and mobility. Although it is possible to have new renewable energy production from mobility, it is the infrastructure and buildings that may have the most significant contribution in the context of the campus. For this reason, the discussion here does not include mobility. For buildings, the system boundaries in ZEN build on the work from the Research Centre on Zero Emission Buildings (FME ZEB) [3]. However, when expanding to a neighbourhood perspective, this is more complex than adding up the sum of the individual buildings [5, 6]. Particularly, it is of interest to discuss how the system boundaries should relate to the existing buildings on campus that are outside of the project and how they should relate to the surrounding energy system (both heat and electricity).

3.2. Energy consumption
The energy consumption at Gløshaugen consists of heating, cooling and electricity. Electricity is today primarily supplied from the electrical grid. For heating the main supply is from the municipal district heating system, supplemented with internal surplus heat e.g. from high performance computers. There are considerable seasonal differences in consumption patterns, both due to the physical climate and to the characteristics of a university campus with significantly reduced activity in the summer.

3.3. Energy production
Multiple studies of the energy system at Gløshaugen were performed as part of the pre-project [8, 9], investigating the potential for on-site production of new renewable energy and for short term and seasonal energy storage .

3.3.1. Electricity from photovoltaics
An analysis of the potential for producing electricity from photovoltaics has shown that it is possible to generate 2.2 GWh from new buildings (plans are not yet fixed for the buildings, so this is based on an average estimate for the campus development project), 3.6 GWh from existing buildings (where 0.5 GWh will be from renovated buildings). All figures depend on a high degree of utilisation of roofs and facades.

3.3.2. Heat from heat pumps
Heat pumps have been a focus area at NTNU for many years and is also a technology that will be used in the campus project. There has been a continued effort to use heat pumps to increase energy efficiency [11], currently the consumption of district heating from the city grid is approximately 20 GWh [8]. Although the energy consumption has been reduced, there is still the challenge of high peak loads.

3.3.3. Other energy technologies
Other energy technologies—e.g. wind turbines, solar thermal energy collectors, combined heat and power from biomass—have been considered in the preliminary stages, but these technologies have not been analysed in detail. The main reason for this is that the initial results show that photovoltaics and heat pumps currently have the highest production potential.

3.4. Energy optimisation
Optimising the energy flows in the short and long term can provide additional benefits. Two key approaches have been investigated; short-term and long-term storage of energy. Short-term energy storage can provide benefits on energy and power demand, e.g. through load shifting and peak shaving. Long-term energy storage can provide benefits of reduced waste heat and reduced use of peak load, which is often based on non-renewable energy. For the long-term energy storage, NTNU has performed a concept study of a system termed Energihub Gløshaugen. The concept study Energihub Gløshaugen is a cooperation between NTNU, Statkraft Varme and Trønderenergi, investigating the potential role of Gløshaugen in relation to the surrounding energy infrastructure. Two key challenges addressed are short-term energy storage and long-term (seasonal) energy storage. In a ZEN context, the long-term storage of energy can have a high impact on the energy surplus, and this is therefore the main focus in here. This

storage is a borehole thermal energy storage (BTES) consisting of approximately 300 boreholes of 120 meters depth.

3.5. Buildings

There are currently around 320 000 square meters of floor area in the existing buildings at Gløshaugen. The campus project requires a substantial additional development, with an estimated need for 92 000 square meters of new buildings and upgrading of 45 000 square meters of existing buildings. The type and age of buildings vary considerable at Gløshaugen; from the main building (*Hovedbygningen*) in 1910 to the ongoing ZEB Flexible Lab that is currently being constructed.

In terms of system boundaries, there is a main distinction between buildings that will be directly affected by the campus project (e.g. new and renovated buildings) and existing building that will not undergo renovation. The energy consumption in the existing buildings is high, both due to the age of the buildings and due to a high number of energy-intensive activities such as laboratories and through-the-clock activities.

4. Results and discussion

A key result from the synthesis of the energy studies and the campus development plans is an overview of design choices and methodology choices for concept stage calculations for a zero-emission campus, as shown in Table 1. The system boundary consists of three building categories: new buildings, renovated buildings, and non-renovated buildings. Six system boundaries have been defined and evaluated in terms of energy production and consumption ratio in the operational phase. Depending on the system boundary definition, the production to consumption ratio is 19 % to 132 %. The lowest ratio is when all buildings are included, including non-renovated (F in Table 1). The highest ratio is when production from all buildings is included, but consumption only includes new and renovated buildings (E in Table 1). It should be noted that the system boundaries are inconsistent in variant E, where production is included for non-renovated buildings but not consumption.

Table 1: System boundaries of production/consumption and coverage ratio [10]

	Production			**Consumption**				
	New buildings	*Renovated buildings*	*Non-renovated buildings*	*New buildings*	*Renovated buildings*	*Non-renovated buildings*	*EnergyHub*	***Coverage ratio***
A	X			X				**30 %**
B	X	X		X	X			**23 %**
C	X	X	X	X	X			**49 %**
D	X	X		X	X		X	**107 %**
E	X	X	X	X	X		X	**132 %**
F	X	X	X	X	X	X	X	**19 %**

As we can see from the column *Coverage ratio* in Table 1, only two of the six alternative system boundaries will lead to an energy surplus with the defined system boundaries. These are options D and E, where the EnergyHub contributes to the increased coverage ratio.

Option A and B provide the most clear-cut system boundary options. Here only affected buildings are included, and the difference is whether renovated buildings are included or not. The main drawback of this option is that it does not provide a full picture of the extent of the campus project, thus providing simple system boundaries at the cost of losing system complexity and interplay.

Option C expands the system boundaries to include the production from all buildings at Gløshaugen, but only the consumption of the new and renovated buildings is included.

Option D and E both include the effect of seasonal storage, through the EnergiHUB Gløshaugen project. Option E is the same as option C plus seasonal storage. These two options are the only ones that can provide an energy surplus, which shows that without seasonal storage it will be difficult to achieve the zero-emission ambition.

Finally, option F encompasses all of Gløshaugen. This option does not differentiate between existing buildings, renovated buildings and new buildings. A key strength of this option is that it is the entire campus that is included within the neighbourhood system. However, it also means that the campus project not only must offset its own carbon footprint, it must also atone for past building traditions.

A key challenge that is immediate from Table 1, is that it is not obvious how the system boundaries should be defined when we are dealing with a complex development project within a neighbourhood. We see that there can be challenges in how existing buildings should be included, in particular if the buildings are only partially renovated. For example, how should we define the system boundaries if we install PV on the roof of an existing building, but without making any other renovation? Here there is no clear-cut approach that can be recommended, but there are three options that could be further explored. The first is to leave out the building entirely, also excluding the PV production. The challenge in this case is that if it is the campus project that is the cause of the PV, then it will have the expenses without any of the benefits. The second option is to include the building entirely. The challenge in this case is that the energy performance of the existing building will also be included, without the campus project having any influence on this. A third option can be to allocate energy production from such buildings based on the influence the campus project has had. E.g. we can have a situation where the PV installation is initially planned to happen during a major renovation 20 years in the future, but the campus project makes it happen in 5 years. In this case, it could be argued that the PV production is within the system boundaries in the 15 years between planned and actual instalment.

This illustrates the challenges with the system boundaries. If there were multiple partners, economic boundaries could be used. E.g. if neighbourhood developer x pays building owner y to install PV, the share could be considered "nearby production" and the allocation be based on the business model between x and y. For the campus, there are few such distinctions, as there is one owner.

These initial results also highlight the need for accommodating for different time horizons and the need for different time resolutions. The campus is a continually evolving entity, and this should be reflected when analysing it as a zero-emission neighbourhood e.g. in defining the system boundaries or reference neighbourhood. For energy, the short-term and long-term analyses depend on having a relevant time resolution. This can for example by the hour or minute for electricity, whereas district heating might only need weekly or monthly data.

This study has focused on the system boundaries from the perspectives of energy and carbon footprint. This means that cost barriers are not explicitly addressed here, although some of the underlying studies have included aspects of cost (e.g. when selecting energy technologies to include in the analyses). Other barriers that should be addressed in future work include the technological, organisational and economic integration between stakeholders.

5. Conclusions

A plus energy campus is a basis for a zero-emission campus. The main finding is that it is not possible to realise a plus energy campus for the entire Gløshaugen campus. This is based on the initial analyses—the volume of existing buildings and the energy use in these are currently just too high. However, it is possible to reach a plus energy campus for the campus project itself (i.e. the buildings affected by the campus development plans). In this case it is dependent on a combination of PV and seasonal energy storage. This stresses the importance of seeing the zero-emission neighbourhood in the context of the surrounding energy system. A significant future challenge is the energy consumption of existing buildings not included in the campus development.

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