Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

Vidar Lind Yttersian

Greenhouse gas emission assessment using OmrådeLCA: Case study of the Zero Emission Neighbourhood Ydalir

Master's thesis in Energy Use and Energy Planning
Supervisor: Helge Brattebø
June 2019

Illustration by Tegn_3

NTNU
Kunnskap for ei betre verd

Vidar Lind Yttersian

Greenhouse gas emission assessment using OmrådeLCA: Case study of the Zero Emission Neighbourhood Ydalir

Master's thesis in Energy Use and Energy Planning
Supervisor: Helge Brattebø
June 2019

Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

NTNU
Norwegian University of
Science and Technology

Preface

This report represents my master thesis, conducted during the spring semester of 2019 at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology, NTNU, in Trondheim, Norway. The student workload for a master thesis is 30 credits and continues the work of the project thesis "Assessment of the use of 'OmrådeLCA' in view of the ZEB and ZEN concepts" (Yttersian, 2018).

The master thesis is conducted in collaboration with Asplan Viak AS, where Mie Fuglseth has been the contact person and supervisor. The head supervisor from NTNU has been Professor Helge Brattebø at the Department of Energy and Process Engineering, with PhD Candidate Carine Lausselet at the Industrial Ecology Programme as a co-supervisor.

The objective of this master thesis is to further develop the life cycle assessment tool OmrådeLCA, made by Asplan Viak AS. To verify the improvement of the development, the tool has been tested on a specific case and compared to results from a tool made by NTNU. Furthermore, relevant literature has been reviewed, and the methodology of OmrådeLCA has been investigated and discussed.

I would like to thank my supervisor Professor Helge Brattebø, for his valuable guidance and feedback during the work with this master thesis. I would also like to thank Carine Lausselet for feedback and helpful discussions on how to go forward. Lastly, I would make a special thanks to my supervisor, Mie Fuglseth at Asplan Viak. She has given invaluable guidance and provided information whenever I have needed it.

I would also like to thank my friends Jonas Myklebost and Jolijn Van de Lar for proofreading my report, and for assistance and providing information, the Energy and Environment department at Asplan Viak and the following people: Eirik Resch (NTNU), Yngve Karl Frøyen (NTNU), and Øystein Engebretsen (TØI).

Trondheim 10.06.19.

V. Yttersian

Vidar Lind Yttersian

Illustration of Ydalir on front page made by Tegn_3

Abstract

The built environment, referring to buildings and transportation, is a major contributor to emissions of greenhouse gases (GHGs). There is increasing interest within the field of urban sustainability assessment regarding estimates on the neighbourhood scale. In order to correctly assess the climate change impacts of different measures and choices made in area development, it is essential to take the effects of building location into account. Life cycle assessment (LCA) provides a suitable methodology for such assessments.

This thesis aims at reviewing and improving the LCA tool OmrådeLCA, made by Asplan Viak. OmrådeLCA is used to assess GHG emissions from area development and compares different development scenarios with a reference scenario. The tool aims at answering the question: what is the best development path for a given project, with respect to minimising climate change impact?

In the effort of improving OmrådeLCA and validating its methodology and results, relevant literature and standards have been reviewed. A thorough examination of the methodological framework LCA has been carried out, as well as descriptions of calculation principles, methodology and approach of the improvements of the revised OmrådeLCA. Further, OmrådeLCA has been used to assess the GHG emissions from the Zero Emission Neighbourhood (ZEN) Ydalir.

OmrådeLCA's system expansion approach is a feature that sets it apart from most other calculation tools and makes it well suited to assess the overall consequences for emissions from area development. Compared to the original version, the revised version of OmrådeLCA provides more features and calculation alternatives to choose among, in addition to presenting results in a more transparent way.

In the assessment of the GHG emissions from Ydalir, results show that transportation contributes to 64% of the total GHG emissions, while materials and operational energy use account for 35% and 2%, respectively. Sensitivity analyses emphasize that choices made, and data used in modelling of transportation, significantly impact resulting GHG emissions. Thus, conducting a thorough analysis of factors affecting transportation is vital for obtaining representative results when using OmrådeLCA, underscored by the fact that transportation constitutes to as much as 64% of GHG emissions for Ydalir. The results also show that Ydalir faces a substantial challenge in achieving its ambition of reaching the definition of zero emission used in this thesis. Considerable additional efforts to reduce GHG emissions need to be made, especially for transportation.

The results from the assessment of Ydalir using OmrådeLCA have been compared with results for the same case assessed with a tool developed by NTNU. NTNU's tool is intended for a much later phase of a project than OmrådeLCA and uses project-specific data to a much greater extent. The comparison shows relatively small differences in the calculated results. This small degree of variation in calculated results demonstrates that OmrådeLCA can provide reasonable estimates even at an early phase. As decisions made in the early planning phases of a project have the highest potential for emission reductions, this is a great advantage for OmrådeLCA as a decision-making tool.

Sammendrag

Det bygde miljø, relatert til bygninger og transport, er en stor bidragsyter til utslipp av klimagasser. Det er en økende interesse innen bærekrafts vurderinger på områdenivå. For å kunne vurdere klimaeffekten av ulike tiltak og valg ved utvikling av områder på en korrekt måte, er det viktig å ta hensyn til effekten bygningers beliggenhet har. Livssyklusanalyser (LCA) gir en egnet metode for slike vurderinger.

Denne studien har som mål å gjennomgå og forbedre LCA-verktøyet OmrådeLCA, laget av Asplan Viak. OmrådeLCA brukes til å vurdere klimagassutslipp fra områdeutvikling og sammenligner ulike utviklingsscenarier opp mot en referanse. Verktøyet tar sikte på å svare på spørsmålet: Hva er den beste utviklingsbanen for et gitt prosjekt med hensyn til å minimere klimaeffekten?

I arbeidet med å forbedre OmrådeLCA, samt validering av metodikk og resultater, har relevant litteratur og standarder blitt gjennomgått. En grundig undersøkelse av det metodiske rammeverket LCA er utført, samt beskrivelser av beregningsprinsipper, metodikk og tilnærmingen til forbedringer av den reviderte versjonen av OmrådeLCA. Videre har OmrådeLCA blitt brukt til å vurdere klimagassutslippene fra nullutslippsområdet Ydalir.

OmrådeLCA sin bruk av systemutvidelse er en funksjon som gjør OmrådeLCA forskjellig fra de fleste andre beregningsverktøy, og gjør verktøyet velegnet til å vurdere de samlede konsekvensene for utslipp fra områdeutvikling. Sammenlignet med den opprinnelige versjonen av OmrådeLCA, gir den reviderte versjonen mer transparente resultater og flere funksjoner og alternativer å velge blant.

I beregningene av klimagassutslippene fra Ydalir utgjør transport 64% av de totale klimagassutslippene, mens materialer og energibruk i drift bidrar til henholdsvis 35% og 2%. Sensitivitetsanalyser viser at valgene som gjøres, og data som brukes i modellering av transport, har de mest betydelige innvirkningene på de resulterende klimagassutslippene. Derfor er det viktig å gjennomføre en grundig analyse av faktorer som påvirker transport for å oppnå representative resultater ved bruk av OmrådeLCA, underbygget av det faktum at 64% av de totale klimagassutslippene kommer fra transport. Resultatene viser også at Ydalir vil møte betydelige utfordringer i målet om å bli et nullutslippsområde. Det må gjøres betydelige tiltak for å redusere klimagassutslippene, spesielt for transport.

Resultatene fra analysen av Ydalir med OmrådeLCA er sammenlignet med resultater fra samme case vurdert med et verktøy utviklet av NTNU. Dette verktøyet brukes vanligvis i en mye senere del av en planfase enn OmrådeLCA, og bruker prosjektspesifikke data i en mye større grad. Sammenligningen viser relativt små forskjeller i de beregnede resultatene. Denne lille variasjonen i beregnede resultater viser at OmrådeLCA kan gi rimelige estimater selv i en tidlig planfase. Ettersom det er i en tidlig del av planleggingsfasen beslutninger i et prosjekt har størst potensial for utslippsreduksjoner, er dette en stor fordel for OmrådeLCA som et verktøy for beslutningstaking.

Table of content

List of figures

List of tables

1. Introduction

The first section of the introduction presents the background and motivation of this thesis. The next sections describe the problem statement and how this thesis progress.

1.1. Background and motivation

The built environment, referring to the building and transportation sector is a major hotspot of environmental impacts, accounting for 55% of worldwide greenhouse gas (GHG) emissions (Lotteau et al., 2015). Several measures and actions need to be implemented to reduce the impact the built environment has on the climate (European Environment Agency, 2018). Constructing Zero Emission Buildings (ZEB) is an example of one such measure. These buildings produce enough renewable energy to compensate for the buildings' total greenhouse gas emissions throughout its lifecycle. Another measure on a bigger scale is Zero Emission Neighbourhoods (ZEN), being the same as ZEB just for a neighbourhood (ZEB, 2018). The Research Centre on Zero Emission Neighbourhoods, FME ZEN, is a joint NTNU/SINTEF unit working with ZENs to reduce the impact of the built environment on climate change. To document the effect ZENs have, and to be able to compare solutions and alternatives, it is essential to perform assessments which estimate GHG emissions resulting from such building projects.

There is a growing interest for the neighbourhood scale in the field of urban sustainability assessment (Lotteau et al., 2015). When developing areas according to the ZEN principle, robust quantitative estimation methods for GHG emissions on the neighbourhood scale, applicable at different phases of the planning process are necessary. These methods and tools must meet the best practice of assessing GHG emissions and be in line with relevant frameworks and standards.

OmrådeLCA, developed by Asplan Viak AS, is a calculation tool for assessing GHG emissions from area development. The tool is based on the analytical framework life cycle assessment (LCA). The tool considers emissions associated with building materials, operational energy use in buildings, and transportation of building users. Over the course of work with this master thesis, the tool has been developed further from its original version, tested on a case and compared with a similar tool made by NTNU.

The increased focus on building more environmentally friendly, with an overall approach of including all parts of the built environment, not only GHG emissions from buildings, put the improved version of OmrådeLCA in centre of attention, being a tool that can ease decision maker's opportunity to choose low emitting solutions. Therefore, the relevance of this thesis, improving OmrådeLCA, is high. Tools like OmrådeLCA need to exist for all sectors in the attempt of quantifying and lowering GHG emissions.

1.2. Problem statement

The objective of this thesis has been to examine how the tool OmrådeLCA could be improved, and how it serves the need for robust estimation of GHG emissions in the early phases of planning. This has been done by using the Ydalir development project as a case study, and comparing OmrådeLCA to LCA methods used in FME ZEN. The following tasks and questions are answered:

- What does the existing literature say about assessments of GHG emissions of urban areas or neighbourhoods, regarding methodology, results and key findings?
- How are the results OmrådeLCA provides from Ydalir, and how are they in accordance with alternative analysis performed by NTNU for Ydalir?
- How do the results from OmrådeLCA for the Ydalir case compare with a reference scenario? What are the advantages of developing a reference to compare with?
- Implement necessary changes to OmrådeLCA in order to improve and further develop the original functionality.
- What are the strengths and weaknesses of the revised/improved version of OmrådeLCA compared to the original version, and compared towards NTNU's method?
- What are the main findings, and strengths and weaknesses of this thesis?

1.3. Approach

To answer the questions from the problem statement, literature on the topic is presented in Chapter 2. This includes potential methodologies that can be used for assessing GHG emissions, results from other studies, and how an assessment should be carried out according to two standards. The method will be presented in Chapter 3. This chapter explains the methodological framework LCA, the LCA tool for area development, OmrådeLCA, and how its methodology is, and how it is improved in this thesis. The chapter also presents Ydalir, a zero emission neighbourhood, and how OmrådeLCA is used to assess the GHG emissions of this neighbourhood. Chapter 4 provides results and discussions of the assessment of Ydalir for several different approaches. Further, an elaboration of the strengths and weaknesses of both the methodology of OmrådeLCA and the thesis in hand follows. Lastly, recommendations for further research, before a conclusion is provided in Chapter 5.

The work in hand has been performed in close collaboration with the developers of OmrådeLCA at Asplan Viak.

2. Literature study

This chapter presents a literature study of lifecycle-based assessments of greenhouse gas (GHG) emissions (often just referred to as emissions in this thesis) of buildings, with an emphasis on assessments carried out within the neighbourhood or urban area scale. The objective of the literature study is to map methodologies that can be used for the assessment of GHG emissions, investigating what previous studies on a neighbourhood scale have found and examining statements of methodological frameworks. This background provides a foundation for an evaluation of OmrådeLCA.

This review is focussing on LCA as a framework for assessing greenhouse gas emissions. Hence other frameworks are out of scope. However, to put LCA in a context, several other frameworks are shortly presented in Chapter 2.1. Moreover, this is also done to see how LCA differs from these frameworks. Chapter 2.2 presents the results from some assessments of greenhouse gas emissions from neighbourhoods.

The reviewed literature possesses similarities with the aim of OmrådeLCA, which is to assess GHG emissions of areas or neighbourhoods, and therefore, this literature is chosen. The Research Centre on Zero Emission Neighbourhood is presented because it is assessing GHG emissions of areas, identical to what OmrådeLCA does.

There are several ways of doing assessments on GHG emissions of buildings and areas. Differences stem from, for instance, changes in what to include and not, which phase the assessment is applied for, and availability of data. Answers to these questions will be presented in this chapter, together with two standards for environmental assessment of buildings.

2.1. Frameworks and methodologies for assessing greenhouse gas emissions of neighbourhoods

Several methodologies can be used when performing an environmental assessment of an area. Loiseau et al. (2012) have made an overview of existing frameworks and methods. They are grading them on a scale from zero to three, measuring how well they are scoring on the assessment of different environmental impact categories and other criteria. These categories and criteria are; Methodological framework, Life Cycle thinking, Non-Renewable Resources, Renewable Resources, Water resources, Greenhouse gas emissions, Pollutant emissions, Multi-Criteria Assessment and Spatial Differentiation. Since GHG emissions are the impact category examined in this thesis, this is the only impact category further discussed. Loiseau et al. (2012) have gone through nine frameworks and methods, where four of them are scoring two or better (higher) on GHG emissions. These four methods and frameworks are; The ecological footprint (EF), Material flow analysis (MFA), Physical input-output table (PIOT), all scoring two out of three, and Life cycle assessment (LCA) which is the only one scoring three out of three. The other frameworks and methods investigated, which all scored zero or one on GHG, were; Human and environmental assessment (HERA), Substance flow analysis (SFA), Ecological network analysis (ENA), Exergy and Emergy.

Firstly, in the study of Loiseau et al. (2012), the EF method is adding up all the ecological footprint of all the inhabitants of a city, a population or a nation. EF is mostly used on the level of nations and cities and might not be a suitable method to employ in small areas like neighbourhoods. MFA is a suitable method for finding the input and output flows of the system, which could be on a neighbourhood scale. However, a drawback with the use of MFA on this scale is that there is no consistent methodology for it. Besides, difficulties lie within identifying and quantifying indirect flows, and MFA does not distinguish between different kinds of resources. Thirdly, PIOT is almost the same as input-output tables[1] but with physical and not monetary flows. The main advantage of this method is its ability to estimate direct and indirect flows between different sectors. A drawback, however, is that results are generally presented in an aggregated form (all materials are merged) and hence their applicability is limited. Therefore, it is not possible to distinguish between materials which have different environmental impacts. This method, as the previous ones, has also mainly been used on national levels, with a few exceptions on a regional level. Lastly, LCA is used to quantify environmental impacts and resource consumptions over the whole life cycle of a product, service or good. An advantage with LCA is that it quantifies the environmental efficiency, impact per functional unit, and not only the environmental burdens. These advantages make it possible to compare different studies and products, services or goods. Even though Loiseau et al. (2012) stated that LCA is the best method when it comes to assessing GHG emissions, they suggest several improvements to the methodology to

[1] Input-output (I-O) analysis is a form of macroeconomic analysis based on the interdependencies between economic sectors or industries. I-O tables include a series of rows and columns of data that quantify the supply chain for all sectors of an economy (Kenton, 2018)

increase the accuracy. One major bottleneck for the use of LCA on an area is LCA's multi-functionality and the difficulty defining a unique functional unit. However, in their conclusion, Loiseau et al. (2012) emphasise the strength of LCA as a method. It is the only method that can avoid burden shifting between life cycle stages, environmental impacts and territories.

Two main methodological approaches within LCA are attributional and consequential LCA, affecting the data needed to perform an analysis. Attributional LCA describes the potential environmental impacts that can be attributed to the analysed system over its life span. This system is implemented into a static technosphere, meaning that the systems being assessed do not modify the background system in which it is embedded. Consequential LCA aims at identifying the consequences that a decision in the foreground system has for processes and systems of the economy. Consequential LCA is part of a dynamic technosphere, meaning that the systems being assessed do modify the background system in which it is embedded. (Lotteau et al., 2015)

Furthermore, when collecting data, there are different approaches for an LCA. The two main approaches are process-based and Input-Output. Process-based is a bottom-up process analysis which means that the system is modelled by means of its specific information. Input-Output uses a top-down approach where economy or industry-wide inventory data is being broken down. A combination of these two approaches is called a hybrid-LCA. (Lotteau et al., 2015)

2.2. Greenhouse gas emissions from neighbourhoods

Lotteau et al. (2015) examined 21 case studies where LCA was used on a neighbourhood scale. They found significant differences in both the type of projects they were conducted on, the scope of the studies, functional units and system boundaries, although all case studies had the same objective of providing quantitative information to policymakers or designers. Regardless of the differences in the studies, they identified some trends. Buildings followed by transportation were the main contributors to GHG emissions. For the different phases; construction (including embodied emissions in materials), operation and demolition, the operation phase is predominant in terms of emissions. However, when the neighbourhoods are highly energy efficient, the significance of the construction phase becomes in the same order of magnitude as the operation phase because of the increase of the value of the embodied GHG emissions for low-energy buildings. Several of the studies Lotteau et al. (2015) investigated highlighted the relative insignificance of the deconstruction phase where, in terms of primary energy consumption, the deconstruction phase only accounts for 1-1.5% (Herfray, 2011, Herfray et al., 2011), also leading to a low share of the total emissions.

The predominance of the operational phase found in the study by Lotteau et al. (2015) is, to some degree, supported in a study conducted by Stephan et al. (2013). They found that the share of GHG emissions from materials and infrastructure constitutes 26.9%, the operational phase constitutes 39.4% and transportation constitutes 33.7% of the total emissions. As for the Lotteau et al. (2015) study, the operational phase is the most significant. However, each of the three phases has a considerable contribution to the total GHG emissions. The study by Stephan et al. (2013) was performed on a low-density suburban neighbourhood in Australia that complies with Australian standard building code and energy efficiency regulations. By replacing half of the built area of the suburb, consisting of single-unit dwellings, with apartment buildings, the total lifecycle GHG emissions per capita were reduced by 14.7%. The population of the area increased as a result of changing from single-unit dwellings to apartments. Stephan et al. (2013) conclude that there is considerable room for improvement within all three phases to lower GHG emissions, and the single most effective measure to reduce GHG emissions is to install additional renewable sources for electricity production. This solution has a lot to do with the fact that the emission intensity for electricity production in the study was based on coal and natural gas as the electricity source.

A study by Wiik et al. (2018a) on lessons learnt from embodied GHG emission calculations in zero emission buildings from the Norwegian ZEB research centre, found that the main contributors to total GHG emissions for building components are the building envelope (approx. 65%), and for the life cycle stages it is the production and replacement of materials (approx. 55–87%). The study by Wiik et al. (2018a) considered buildings adhering to a high building standard, resulting in a reduced need for operational energy. Dahlstrøm et al. (2012) compared GHG emissions from a single-family dwelling built according to conventional building standards with a higher energy (Passive House) standard, also considering the impact of the choice of emission intensity for electricity. The study highlights the increased significant the emissions from operational energy use of buildings has when shifting from both a higher building standard to a conventional one, and an electricity production mix with a low emission intensity to one with a higher intensity.

Norman et al. (2006) compared GHG emissions from high and low residential density in Toronto, USA, and found other amounts of emissions of the different phases, than the previously mentioned studies. Their results show that if the aim is to reduce GHG emissions in an urban development context, the primary target should be towards emissions from the transportation sector. This sector accounts for 40-60% of the total GHG emissions, which is more than the 33.7% in Stephan et al. (2013)'s study. This even though both are including public and private transportation, and average values for transportation distances and transportation-modes from national surveys.

Moreover, Norman et al. (2006) discussed the importance of the choice of a functional unit. When the functional unit is on a per capita basis, the low-density development is by a factor of 2.0-2.5 more GHG intensive, while if the functional unit is on a per unit living space basis, the factor is only 1.0-1.5. The functional unit is being brought up in the study by Lotteau et al. (2015) as well, where they state that "*because of the heterogeneity, complexity and multifunctionality of neighbourhoods, it appears difficult to define a unique and comprehensive functional unit to compare neighbourhoods or scenarios for a same neighbourhood*". Several kinds of functional units are presented in the study of Lotteau et al. (2015) and some of the studies they investigated suggest combining three types of functional units (spatial, per capita and absolute) to overcome the difficulties to define a unique functional unit.

The choice of lifetimes of both neighbourhoods and subcomponents is a challenge discussed by Lotteau et al. (2015). They state a lack of consensus around the choice of a lifetime, where different studies range from 50 to 100 years. Furthermore, the difficulties are discussed regarding how to implement improvements in technology over such long lifetimes. Dynamic models can be developed to improve the accuracy of analyses.

Peuportier and Roux (2016) used a dynamic model for electricity production in their study of urban settlements using LCA. This dynamic model considers the temporal variation of electricity production and consumption in buildings. This is done by evaluating the hourly energy consumption of buildings using dynamic simulation, allowing hourly use-specific production mixes to be estimated. Peuportier and Roux (2016) found that by applying a dynamic LCA model for the electricity mix, the results differ by 30% compared to an LCA using annual electricity mix. Peuportier and Roux (2016) conclude that the use of consequential LCA can improve the robustness of results. The difference of using a dynamic model for the electricity mix instead of a static one is also highlighted by Lausselet et al. (2019), who suggests using dynamic emission intensities for electricity in assessments of neighbourhoods.

Bastos et al. (2016) researched the significance of mobility in the LCA of buildings. They compared an apartment building in a city centre with a semidetached house in a suburban area, both with the same number of persons per household, and almost the same number of square metres available area per household. They divided the emissions into building construction, building use and user transportation. Results show that the suburban house (SH) had almost twice the GHG emissions compared to the city apartment (CA). This difference in emissions was almost solely due to the difference in transportation emissions, which was more than 350% higher for the SH. For both building use and building construction the emissions were almost the same regarding the SH and CA. The CA share of emissions from building construction, building use and user transportation is, respectively, 16%, 64%, and 20%, while for SH it is 11%, 38% and 51%. Bastos et al. (2016) conclude on the importance of evaluating building location when aiming at sustainable planning, and the importance of doing thorough analyses for transportation related emissions in LCAs.

2.3. Research Centres on Zero Emission Buildings and Zero Emission Neighbourhoods

Both the Research Centre on Zero Emission Buildings (FME ZEB) and Zero Emission Neighbourhoods (FME ZEN) are research centres for environmental friendly energy. The research centres are hosted by the Norwegian University of Science and Technology (NTNU), and organized as a joint NTNU/SINTEF unit, where SINTEF is an independent research department (ZEN, 2017). The research period of FME ZEB has ended, while FME ZEN is still on-going. The most important calculation principles for FME ZEB will first be presented before the same will be done for FME ZEN. (The Research Centre On Zero Emission Buildings, n.d.)

In FME ZEB, five different ambition levels are defined, setting the system boundaries for which stages of the building's lifecycle to include in each level. These boundaries range from only the inclusion of emissions from energy used during operation of the building, to emissions from the whole life cycle of the building. The ambition levels are made according to the national standard NS-EN 15978, presented in Chapter 2.4. A detailed description of the ambition levels can be seen in Appendix B.1. (Fufa et al., 2016)

FME ZEB looks only at the impact category climate change, measured in CO_2-equivalents. The CO_2 intensity for electricity from the grid is set to 130 grams CO_2-eq/kWh. Both bioenergy and waste incineration are given CO_2 intensities, resulting in these not considered to be climate neutral. (Fufa et al., 2016)

The functional unit used in FME ZEB is emissions per square metre of heated floor area over a reference period of 60 years. Alongside the functional unit, in FME ZEB, it is also required to state total embodied emissions of the building. The functional unit shall include information on building type, relevant technical and functional requirements, reference study period, and pattern of use. (Fufa et al., 2016)

FME ZEN, which is a continuation of FME ZEB, has expanded the system boundary from just looking at single buildings, to include whole neighbourhoods. FME ZEN is working on a broad range of categories, including GHG emissions, energy, power/load, mobility, economy and spatial qualities. (Wiik et al., 2018b)

When it comes to GHG emissions, FME ZEN is working on a methodology for assessing emissions. The approach is based on a modular one, as in NS-EN 15978 and NS 3720 presented in Chapter 2.4, and a life-cycle method. The framework is supposed to highlight which key performance indicators (KPI) that are important for ZEN. The KPIs are total GHG emissions and reduction in GHG emissions, and are based on existing standards and methods used in the building and construction industry, e.g. NS-EN 15978 and NS 3720. (Wiik et al., 2018b)

For the total GHG emissions, the KPI is calculated both for a building level and for an area level. Total GHG emissions are measured in tonne CO_2-equivalents. The KPI is divided into different functional units. On an area level, the functional unit is 'kg CO_2-eq/m^2 BAU[2]/year' with a 100 year analysis time, while it is 'kg CO_2-eq/m^2 BRA[3]/year' with a 60 year analysis time on a building level. In FME ZEN it is being worked on a functional unit of GHG emissions per user, either building- or area-user, 'tCO_2-eq/individual'. For the reduction in GHG emissions, the KPI is given as a percentage reduction compared to a base case. (Wiik et al., 2018b)

The analysis period in the method is usually 60 years, assuming a 60-year service life of buildings and 100-year life of infrastructure. The difference in service life means that two different results need to be provided regarding GHG emissions; one for the building assessment boundary level, and one for the neighbourhood assessment boundary level. (Lausselet et al., 2018)

Some LCAs have been conducted in FME ZEN. One of them is a study performed by Borgnes (2018) on Zero Village Bergen (ZVB), where an LCA model was made. ZVB is a neighbourhood located outside Bergen City, consisting of 695 zero emission dwellings constituting 85 000 m^2, in addition to 7 000 m^2 of non-residential buildings, and open spaces (roads, sidewalks and parking areas) constituting 127 000 m^2. The electricity demand is almost solely covered by local solar panels, while energy demand for heating is covered by district heating.

The main findings from the study by Borgnes (2018) for the different elements included; buildings, mobility, open spaces, networks, and on-site energy infrastructure, was that buildings constituted the largest share of the GHG emissions. Building constituted 52%, mobility 40%, while network and open spaces only constituted 2.3% combined. When splitting the emissions of buildings into embodied emissions, materials, and operational energy use, and then also including materials for solar panels, materials constitute 29% and operational energy use 28%, while transportation constitutes 40%. The total emissions from ZVB divided by heated building floor area and per year, results in an emission of 21.2 kg CO_2-eq/m^2/year.

The most critical parameters for ZVB in the LCA model were found to be the travel distance and the energy load for buildings. One factor found to have significant impacts when being changed were the choice of the electricity mix. Another was the assumption of allocating the emissions associated with the waste incineration to the waste management system or the district heating system, where the total emissions got reduced with 25% by allocating to the waste management system. By choosing a Norwegian electricity mix, the negative emissions by producing electricity by solar panels were smaller than the emissions embodied in the solar panels. The LCA model made in the study was a modular one, which made it possible to do changes for which modules to include, have several functional units and to compare different projects with different premises. (Borgnes, 2018)

---

[2] BAU - Outdoor area

[3] BRA - Available area

The choice of functional units was discussed in an article about LCA methodology to assess ZEN concepts by Lausselet et al. (2018). They argue for the use of a primary functional unit ‘per neighbourhood’ and a secondary functional unit ‘per person’ when conducting LCA on a neighbourhood scale, rather than a functional unit ‘per square metre’. Furthermore, they argue for the use of sub-units for the different sub-systems, like ‘per kilometre’ for different vehicle fleets, ‘per specific unit’ for infrastructure elements, and ‘per square metre floor area’ for the buildings.

In the study by Lausselet et al. (2018), they have identified four factors being beneficial for the overall GHG emissions of a ZEN if being reduced. These are; building floor area by house or inhabitants, passenger cars travel distance, energy use in buildings and carbon intensity of the electricity mix.

2.4. National standards for environmental assessment of buildings

When making a product, providing a service or going through work processes, there are frameworks for how this should or can be carried through. This can either be frameworks made by governmental or private organisations. In Norway, Norwegian Standard (NS) is an example of frameworks or standards that should be followed. NS is made and published by Standard Norge, an independent and private organisation. Their standards are often based on The European or International Organization for Standardization (CEN and ISO) (Hofstad, 2018). Two examples of Norwegian standards that should be followed for sustainable construction and GHG calculations for buildings are NS-EN 15978:2011(Standard Norge, 2011) and NS 3720:2018(Standard Norge, 2018). A short description of these follows.

NS-EN 15978:2011 - Sustainability of construction works, Assessment of environmental performance of buildings, Calculation method

The standard provides calculation rules for assessment of the environmental performance, based on LCA and other quantified environmental information, of new and existing buildings. It is intended to support decision-making processes and documentation of the assessment of the environmental performance of a building.

The standard defines physical system boundaries for the assessment of a building, including everything within the building site, over its lifecycle. To have a transparent and unbiased comparison of different buildings, it is required that the major functional requirements of the building shall be described together with the intended use and relevant specific technical requirements.

The system boundary for new buildings include the life cycle steps shown in Figure 2.1, except module B8. For existing buildings, the system boundary shall include all steps representing the remaining service life (B1-B7), and the end of life of the building (C1-C4). A further explanation of the modules in Figure 2.1 can be found in Chapter 3.1.

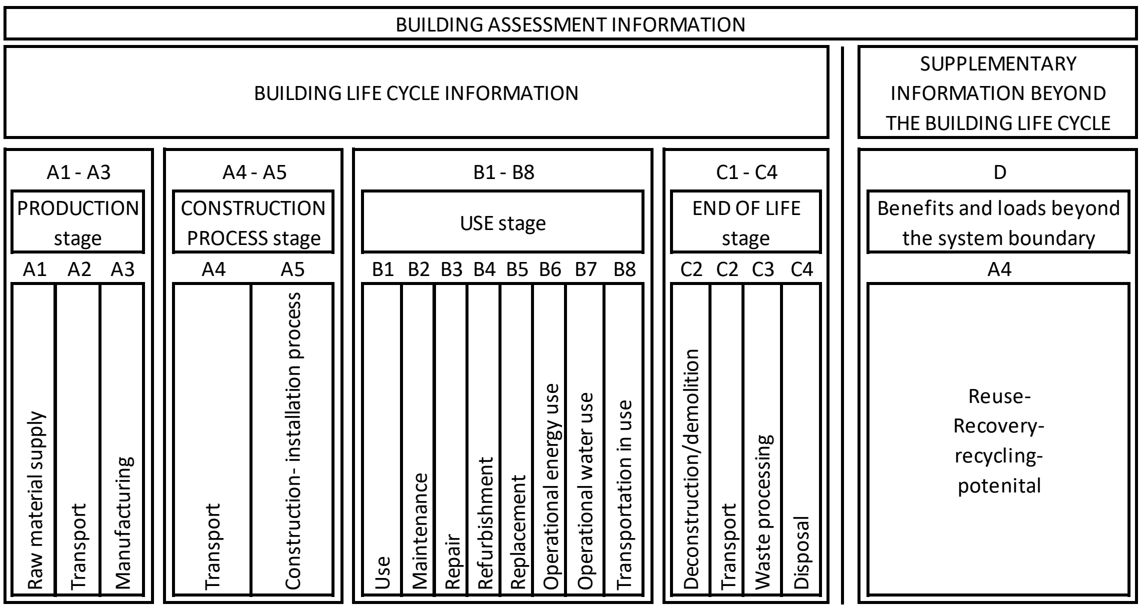


Figure 2.1 Lifecycle modules of NS-EN 15978 and NS 3720

The standard is as mentioned, an “Assessment of environmental performance of buildings”. This implies that more environmental impact indicators than global warming potential (GWP) should be included. In addition to environmental impact indicators, indicators describing resource use, waste categories and output flows leaving the system shall also be described.

NS 3720:2018 - Method for greenhouse gas calculations for buildings

This standard provides a calculation method for GHG emissions for a building through its lifecycle. The methods for GHG calculations given in NS 3720 refer to the requirements described in NS-EN 15978, briefly explained in the previous subsection.

The calculation method presented in NS 3720 is based on an attributional LCA, as opposed to a consequential LCA approach. These two approaches are both presented in Chapter 2.1. The physical system boundaries defined in NS 3720 are the same as of NS-EN 15978. The standard can also be used for a plot containing several buildings provided that the characteristics of the different buildings are presented to enable comparison of results.

Functional equivalents describing the building(s) must be made. These concerns the type of building(s), technical and functional demands, gross- and available area, heated available area, use pattern and necessary lifetime. A functional unit must be made based on the functional equivalents to makes it possible to compare different projects.

The system boundaries are almost the same as in NS-EN 15978, Figure 2.1, but with some changes. ‘Operational water use’, module B7, has been excluded, while ‘Transportation in use’ has been included as module B8. Module B8 includes transportation of residents, employees, visitors and other users of the building. Further, the emissions from transportation shall include both transportation to and from the building. Transportation by walking and bicycle have neglectable emissions and are therefore not included. Module D is not mandatory, and if used, it must be reported separately.

As for NS-EN 15978, depending on the purpose of the calculations, several different scenarios describing the future life of the building shall be made. This is to see the effect of possible choices taken for the building in the future. Different scenarios can be for different needs of maintenance, for different technological development and number of users. Furthermore, sensitivity analyses of the most contributing elements to emissions must be performed. Furthermore, for the electricity supply of the building(s), there must be used at least two different scenarios. The standard suggests these two to be Norwegian electricity consumption mix and European electricity consumption mix. Emissions from waste incineration or waste heat as the energy source in district heating shall be allocated to the producer of the waste.

For the calculations of the GHGs, a GWP-100 characterisation factor shall be used, where the calculations are lifecycle based, and where infrastructure is included. The boundaries for energy use in the buildings are set to “delivered” energy to the building. If there are any local production of energy, emissions from the production, distribution and instalment of this energy source shall be included.

3. Methodology

In the first section, the life cycle assessment (LCA) framework is presented. Next follows a description of the greenhouse gas (GHG) assessment tool OmrådeLCA, including an explanation of how it works and is improved. The last section describes the Zero Emission Neighbourhood (ZEN) Ydalir and how OmrådeLCA has been used to assess the neighbourhood with different approaches.

3.1. Life cycle assessment

LCA, or life cycle assessment, is a methodological framework used to analyse the environmental impact of goods, services, materials, etc. The standard ISO 14044 (Standard Norge, 2006) applies for how to perform an LCA. According to Strømman (2010), *"The objective of a Life Cycle Assessment is generally to perform consistent comparisons of technological systems with respect to their environmental impacts."*

According to the previous mentioned ISO standard, there are four stages of an LCA; defining goal and scope, the life cycle inventory analysis, the life cycle impact assessment, and the interpretation stage. An illustration of the LCA phases can be seen in Figure 3.1.

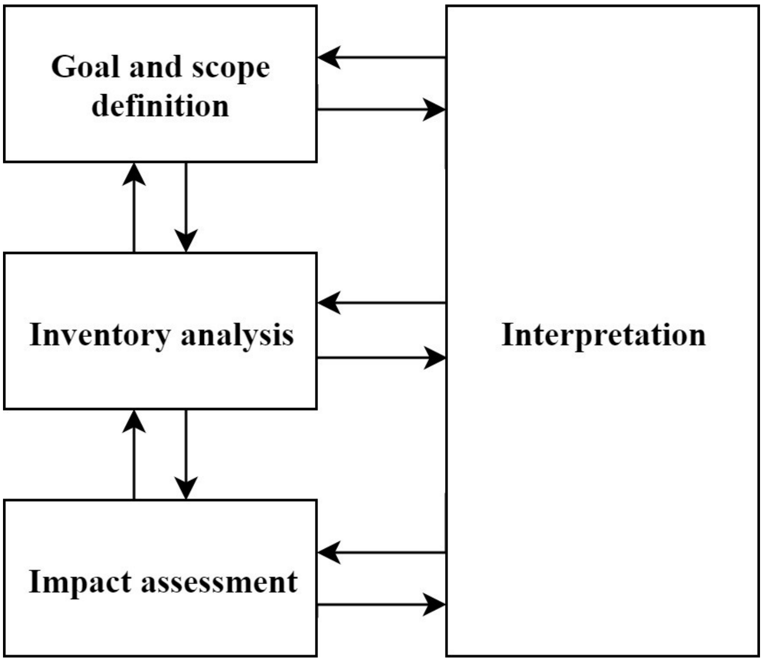


Figure 3.1 Stages of an LCA (Standard Norge, 2006)

The goal and scope stage answer to the following questions: what the aim of the LCA is, where are the system boundaries and what are the included functions in the system, and what assumptions are made. For the inventory analysis, LCI, it answers: which products are produced, which products and materials are used, which raw materials/emissions are used/produced, and how are these different in- and outputs allocated to the system. In the third stage, life cycle impact assessment, LCIA, provides answers to: which impact categories are considered, what are the impacts of the system, should there be performed a weighting/normalising or included a value choice. In the last stage, the interpretation, presents a conclusion, identified weaknesses of the study and the reliability of the results, and recommendations. (Solid Works, n.d.)

One crucial factor in LCA, which enables different products, services or other entities, to be compared is the use of a functional unit. The functional unit can be defined as "a quantified description of the performance requirements that the product system fulfils" (Consequential-LCA, 2017). The functional unit when it comes to a building or a neighbourhood could be environmental emissions per square metre, per user, per building or per neighbourhood.

In Figure 2.1 in Chapter 2.4 of the modules included, of both NS 3720 and NS-EN 15978, for the different stages of an LCA of a building, the boundary of the processes that are taken into account is determined. The modules are divided into A, B, C and D, where A is the production stage, B is the use stage and C is the end of life stage. The last module, D, is added as a supplemental information module that goes beyond the building's lifecycle, constituting reuse-, recovery-, and recycling potential.

As mentioned in the literature study, in Chapter 2, attributional and consequential LCA are the two main methodological approaches used for LCA. Attributional LCA describes the potential environmental impacts that can be attributed to the analysed system over its life cycle. Consequential LCA aims at identifying the consequences that a decision in the foreground system has for processes and systems of the economy. (Consequential-LCA, 2015)

In an LCA, if the assessment process provides more than one function, i.e. delivering several buildings and transportation solutions, the process is multifunctional. In a consequential LCA, system expansion is an approach that can be used to solve the multifunctionality of processes. This can imply to add another, not provided function to make two systems comparable or to subtract not required function(s) substituting them by the ones that are superseded/replaced. (European Commission Joint Research Centre Institute for Environment and Sustainability, 2010)

Two other methods of solving the problem of multifunctionality of processes are substitution and allocation, often called partitioning (European Commission Joint Research Centre Institute for Environment and Sustainability, 2010). The substitution method involves identifying the product or function that is replaced or "substituted" by the co-product/co-function of the main product which is being studied, and then quantifying the emissions which would have occurred if this product had been produced. The emissions which would have occurred are then credited to the main product which is being studied (Brander, 2012). The partitioning approach proposes to deal with multiple outputs by assigning a share of the total impacts using a chosen property. This can be mass, energy, exergy, price, or others (Strømman, 2010).

An essential aspect of an LCA is to address temporal variations regarding when emissions are occurring. Emissions happening at different points in time can be calculated with different climate effect, considering a calculation with a given time-horizon. A 100-year time-horizon is often used. Different time-horizons will result in variations of the global warming potential (GWP) of greenhouse gases, because of how much of the gas that will still be in the atmosphere at the end of the time-horizon. As an example, forest being chopped down and burned will result in emissions of CO_2 equalling the CO_2 being embodied in the new growth of forest, resulting in carbon neutrality. However, until the CO_2 gets taken up by the new forest, it will be in the atmosphere having a climate effect. Two possible approaches in dealing with temporal variations are static and dynamic LCA. In a static LCA, emissions, regardless of when they are occurring, are given the same significance. Since a static LCA do not consider the time-horizon, emissions of biogenic carbon are not ascribed any climate effect, since the bioproduct get sowed and grown back again. Also, all emissions for a given pollutant throughout the life cycle are typically added into a single aggregatet emission in a static LCA. In a dynamic LCA, the temporal profiles of emissions are considered so that the result for each impact of emissions is a function of time rather than a single number. In this way, it is assumed that emissions happening today are of a higher significance than emissions happening in the future. Biogenic carbon is in a dynamic LCA given a climate effect because of the impact the CO_2 has until it gets taken up by new crops. (Levasseur et al., 2010, Solli et al., 2016)

3.2. OmrådeLCA

Underlying methodology and functionality of OmrådeLCA with calculation principles of the tool follow in this section. The motivation for why improving OmrådeLCA and how to do it is also a part of this chapter, together with an in-depth explanation of calculation principles of OmrådeLCA, and an explanation of how new data implemented into the tool has been found and processed.

3.2.1. Underlying methodology and functionality

OmrådeLCA (which can be directly translated into English as AreaLCA or Neighbourhood-LCA) is a calculation tool developed by Asplan Viak in order to assess accumulated GHG emissions of area development. The underlying methodology of OmrådeLCA aims to shed light on the following question: What is the best development path regarding GHG emissions for a given project? (Borg and Fuglseth, 2018a, Dahlstrøm and Solli, 2018)

OmrådeLCA, in its original form, was developed for a specific project, namely Landbrukskvartalet, and was further developed from the original version to be applicable for other projects. OmrådeLCA has been used in a total of four projects. The project work prior to this thesis (Yttersian, 2018) investigated, among several aspects, the use of OmrådeLCA in these projects. For a thorough explanation, beyond what is explained in this thesis, of the original version of OmrådeLCA and the use of it in these four projects, it is recommended looking at the preliminary thesis "Assessment of the use of 'OmrådeLCA' in view of the ZEB and ZEN concepts" (Yttersian, 2018).

The tool is intended mainly for use in an early planning phase, often before a regulation plan is approved, to compare different scenarios for the development of an area or neighbourhood. Choices under consideration may concern the mix of building functions (such as apartments, single-unit dwellings, kindergarten and offices), and energy- and transportation solutions. Energy solutions may involve different energy standards for buildings or energy supplies as heat pumps, district heating and solar panels. For transportation, type of transportation method, the evolution of the vehicle fleet and different travel patterns for several areas and cities are examples of design criteria under consideration.

To be comparable, these different scenarios must be assessed using the same functional unit, as stated in the LCA standards ISO 14040 and ISO 14044 (International Organization for Standardization, 2006b, International Organization for Standardization, 2006a). This is done using a methodological approach in LCA known as system expansion, explained in Chapter 3.1. Each scenario is assessed based on the same overall functional mix of built area or number of inhabitants, per building category. The functional unit is set according to the scenario providing the largest built area or number of inhabitants, for each separate building category. This means that different scenarios can set the functional unit for each separate building category. Each scenario that does not have the largest built area or number of inhabitants for each separate building category must provide this in another way. Providing this in another way is done by expanding the system boundaries, saying that each scenario must build buildings in an alternative location to fulfil the functional unit. The alternative location represents traditional development. An illustration of the system expansion approach is given in Figure 3.2. The functional mix given in this example is a mix of apartments, offices and a kindergarten. The difference between scenario 1 and 2 is the area of housing and kindergarten that needs to be compensated in the "alternative fulfilling of the function". Since most other assessment tools use an attributional LCA approach, where only the environmental impact of each scenario as it is defined is assessed separately, this system expansion approach differentiates OmrådeLCA from other tools (Borg and Fuglseth, 2018a, Dahlstrøm and Solli, 2018).

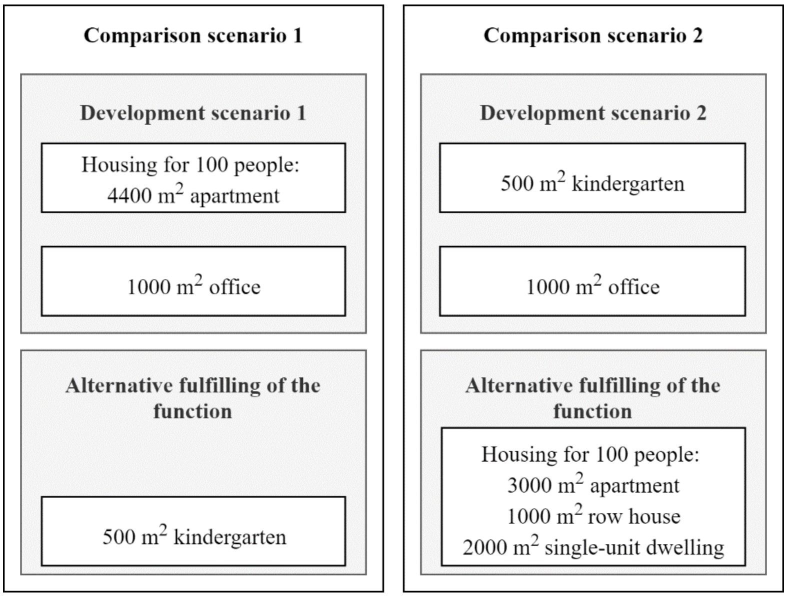


Figure 3.2 Methodological approach in OmrådeLCA

The tool uses built area (BRA) as a basis to set premises for calculating emissions. The BRA is the minimum amount of input data required to be entered into OmrådeLCA to obtain results. Beyond this, the user of OmrådeLCA has the option to affect many methodological choices and premises to make the analysis more project specific. If project specific information is not available, default values being a part of OmrådeLCA can be used.

The calculations in OmrådeLCA are performed for three primary modules, all dependent on their separate calculation principles further dependent on the number of users, BRA or other parameters. These modules are materials, operational energy use, and transportation. The modules included in the tool, adapting the NS 3720's modular structure can be seen in Figure 3.3. Green parts represent modules included, while grey parts represent module B7 which is not a part of NS 3720, nor OmrådeLCA.

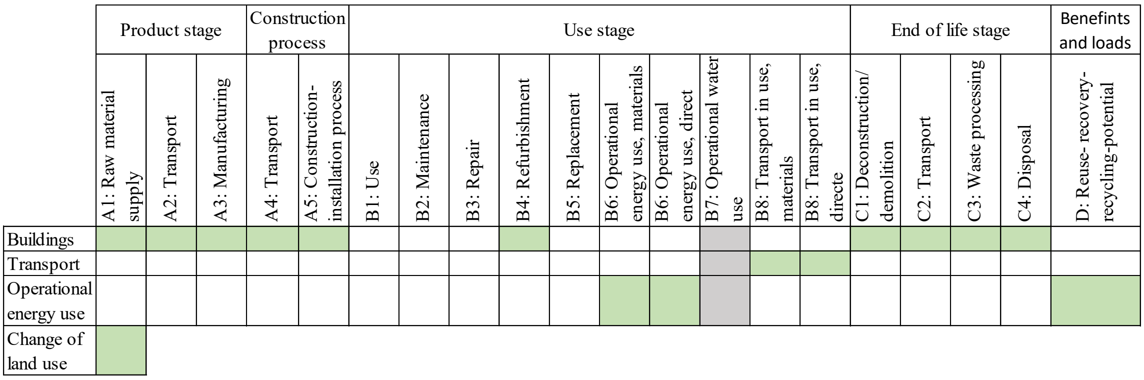


Figure 3.3 Modules included in OmrådeLCA according to NS 3720

In contrast to NS 3720, OmrådeLCA split module B6 and B8 into one module for materials or infrastructure (indirect) and one for use (direct), to provide more transparent results. Also, "Change of land-use" has been added to provide more thorough results. Benefits and loads beyond the system boundary are, according to the standard, given in module D. OmrådeLCA uses data from national and local statistics, travel surveys, LCA databases and other LCA studies. These generic data are combined with case-specific data which can be entered in the tool. Different modelling choices and scenario selections can also be selected within the tool in order to tailor the analysis to a specific area development case. In Appendix A.2, several of these scenarios and choices are presented.

Using a system expansion approach, OmrådeLCA's methodology is approaching being a consequential LCA, but because the tool does not include changes in the background system because of marginal technologies and changes caused by the foreground system, it cannot truly be called a consequential LCA tool. E.g. if the use of concrete in an area where OmrådeLCA is used to assess emissions has effects causing changes in the concrete supply, OmrådeLCA do not calculate the consequences this has for change in emissions. As OmrådeLCA includes some features based on a consequential approach but does not fully incorporate the methodology of consequential LCA, it is more accurate to describe it as an LCA tool with a system expansion approach.

3.2.2. Motivation for revision

The preliminary project for this master thesis pointed out several potential improvements for the original version of OmrådeLCA (Yttersian, 2018). When OmrådeLCA is used to support decision-making processes for area development, the tool's usefulness lies as much in how the results are presented, as in how calculations are performed. More distinct and transparent presentation of approach and results were suggested as improvements in the preliminary project. Specific suggestions involved including results based on more functional units, based on the modular structure of NS 3720, and showing results of sensitivity analyses. Further, to improve the quality of the tool, the inclusion of more energy infrastructure, improvement of data for transportation and evaluation of underlying data, particularly for materials were suggested. As mentioned in Chapter 3.2.1, OmrådeLCA were originally developed for one specific project, and then further developed to be applicable to three other projects. OmrådeLCA has provided satisfactory results for all of these projects, but the result has been four different versions of OmrådeLCA applicable to each separate project. This is one of the main motivations to improve OmrådeLCA, to make it applicable for several kinds of projects without needing to use a lot of time to improve or change the tool each time of use.

The potentials for improvement presented in the project thesis prior to this thesis have been used as a basis for improving OmrådeLCA in this master thesis. Some of the most important improvements are explained as a part of the in-depth calculation principles of OmrådeLCA in Chapter 3.2.3, but a full overview of all the changes made to the original version is given in Appendix A.2. Also, a guideline (in Norwegian) made for the revised version of OmrådeLCA can be found in Appendix A.4. The most significant improvements involve the suggested improvements mentioned above, together with cleaning up and making the tool more user-friendly, and calculating and presenting results on a per year basis for all modules and building categories.

3.2.3. In-depth calculation principles

Here follows an in-depth description of the calculation principles of OmrådeLCA that is built on the overall explanation of OmrådeLCA in chapter 3.2.1. This description applies for the revised version of OmrådeLCA. Several choices and implementation of data needed to be performed in OmrådeLCA to run an assessment are described in this chapter. These choices or inputs of data do not need to be case-specific since default values are already implemented in OmrådeLCA. All choices and opportunities within OmrådeLCA are shown in Appendix A.2, where the default value or choice for each option is highlighted. An overall equation is shown for the three modules materials, operational energy use and transportation in the following sections, with supplementary equations in Appendix A.1.

3.2.3.1. System expansion and dynamic approach

To use the same functional mix of building mass as the basis of assessment for all considered scenarios, as mentioned in Chapter 3.2.1, data from Statistisk Sentralbyrå (SSB) are used to find values for how many people that are living or working per square metre of a building. For living, this number varies depending on which kind of a residential building this is, apartment, row house or single-unit dwelling, and the site-specific location of the building. An example of how the calculation principles of finding the functional mix based on statistical data are shown in Appendix C.1. The number of people living or working per square metre of a building, together with the square metres of the different building categories, is used to find what the function for the specific area is, regarding inhabitants and workers. In this way, it is possible for the different scenarios that require building mass outside the development area to fulfil the functional mix, even though it might be another kind of building pattern regarding residential building types. This is the reason for the different number of square metres for residential use in the two scenarios in Figure 3.2. To have comparable scenarios, one needs to have an opinion on where different kinds of buildings will be built if it is not on the specific area of the project. Therefore, it is used statistic on the historical development and local plans in each specific case where OmrådeLCA is used. (Borg and Fuglseth, 2018a, Dahlstrøm and Solli, 2018)

OmrådeLCA uses dynamic LCA, with the option of using static LCA, to calculate the climate effect. By using a dynamic LCA, emissions happening today are assumed to have a more significant impact than the ones happening in the future, as explained in Chapter 3.1, where the static and dynamic LCA approaches are described. Factors from the model DynCO2[4](CIRAIG, 2016) are used in the calculations. As explained in Chapter 3.1, by using a dynamic LCA approach, emissions of biogenic carbon also get a climate effect, in difference to what is the case using a static LCA. This can have an effect on the results if district heating or electricity from the grid used in the calculations have bioenergy in their energy-mix. (Borg and Fuglseth, 2018a, Dahlstrøm and Solli, 2018)

3.2.3.2. Materials

The module Materials consists of materials used to build buildings, waste treatment of materials for new buildings, materials for rehabilitation and demolition of buildings, and the process of demolishing buildings. Each of these elements is distributed among the appropriate module according to the modular structure of NS 3720. The modules included for materials are shown in Figure 3.4, where A5 is split up into three different modules, construction phase, demolition of old buildings, and loss/assembly at the construction site. The modules in green have default values for emission intensities, while the blue either can be assigned a percentage emission intensity factor of module A1-A3 or be given case-specific values. The white ones must be ascribed case-specific values if they are going to be used. Benefits from local energy productions are not included in the figure since the figure only applies to emissions from materials.

	A1-A3	A4	A5: Construction phase	A5: Demolition	A5: Loss/assembly	B4	C1-C4	D
Materials								
Local energy production								

Figure 3.4 Modules included in OmrådeLCA for calculating emissions from materials

4 DYNCO2 is a dynamic LCA software tool used to calculate temporal carbon footprinting. It assigns a climate effect on the use of biomass.

As the original version of OmrådeLCA presented emissions as an aggregated sum of the included modules, this is a new feature of the revised version. Demolition of buildings is included to make it possible to compare cases where there is an existing building mass that needs to be demolished. The tool uses key figures, expressed as emission per square metre (CO_2-eq/BRA) over the total calculation period of different building types. The key figures are multiplied with the number of square metres of the different building types to find the total emissions. These emissions per square metre are gathered from klimagassregnskap.no[5] (Statsbygg and Civitas, 2012), and apply to a simple structural design, a reference building, with conventional material use following the TEK 10[6] building standard. The emission intensities for the production phase and refurbishment of materials vary depending on the building standard that is chosen for the given buildings.(Borg and Fuglseth, 2018a, Dahlstrøm and Solli, 2018, Dahlstrøm, 2018c)

An overall equation of how OmrådeLCA calculates emissions from materials can be seen in equation (1):

$$E_m = \sum_{b=1}^{n} \left(\left(\left(e_{module_{(A1-A3+B4)_b}} \cdot f_m \right) + e_{module_{(B,C)_b}} \right) \cdot A_b \right) + E_l \qquad (1)$$

Where E_m are emissions from materials, e_{module} emission intensity of a module, f_m emission intensity factor of the buildings chosen compared to TEK 10, A area of a building category, b building category, and E_l emissions from materials for local energy production.

For emission intensities for waste treatment of materials, the calculations are based on empirical numbers for average waste amounts for different types of buildings per square metre. The numbers are gathered from the NHP network's waste guide[7], in combination with Asplan Viak's climate reporting tool for recycling companies. (Dahlstrøm and Solli, 2018)

For emission intensities for the demolition of buildings, the calculations are based on costs for demolition in Norsk Prisbok[8] (per square metre). Cost data is translated into emissions per building activity, corrected for material-inputs, using emission intensities from the

---

[5] Do not exist any longer, but a documentation report of klimagassregnskap.no can be found in the reference (Statsbygg and Civitas, 2012).

[6] Byggteknisk forskrift of 2010. Building standard of minimum technical requirements of buildings being built. TEK 10 is an old version. TEK 17 is the current building standard (Direktoratet for byggkvalitet, 2011).

[7] A guide on amounts of waste made by NHP, National plan of action for construction waste (NHP, n.d.).

[8] Norsk Prisbok is a reference book for the Norwegian construction industry, and consists of a price database with information regarding costs for a construction project (Norconsult Informasjonssystemer AS, n.d.).

Klimakost model. Klimakost is an input-output-model, explained in Chapter 2.1, and can thus be used to connect demolition costs to emissions. (Dahlstrøm and Solli, 2018)

3.2.3.3. Operational energy use

The module Operational energy use has been comprehensively changed compared to the original version of OmrådeLCA. Previously it calculated the net energy demand based on a few predetermined energy supply solutions together with net energy demand according to building standards, with the option to include solar panels. The revised version also uses building standards as a basis, but adaptions and changes of variables are now easier to make. The revised version consists of the energy used in the buildings during the use phase, together with local energy production. The energy demand from the different building categories can be estimated in one out of two ways. Either from a project-specific demand or the energy demand (kWh/m^2 of different building categories) according to the frameworks in Byggteknisk Forskrift (TEK) and NS 3720 for Passive Houses and low energy houses. These energy demands are divided into heating, cooling, or direct electricity demand, expressed as annual demands, and are further multiplied with the square metres of each building category to find the net energy demand.

To supply this energy, the user can select different energy solutions. Some default options are included in OmrådeLCA, like electricity from the grid, district heating, district cooling, heat pumps, and refrigerating machines. It is also possible to use a combination of these. All of these has default values for system efficiencies and/or coefficient of performances (COP). It is also possible to define project specific energy solutions by choosing efficiencies and energy carriers/source. The energy solutions chosen, must be assigned to heating, cooling, and/or direct electricity demand for all of the locations of buildings (inside and outside the developing area, and new and refurbished buildings), to find the demand of delivered energy.

To estimate the emissions for the chosen energy solutions of all the buildings, emission intensities from different district heating companies[9] has been used, together with emission intensities for Norwegian and European electricity mixes according to NS 3720. The emission intensities of these electricity mixes can be seen in Appendix A.5.

Further, local energy production, in difference to the non-local mentioned above, can also be included in an assessment in OmrådeLCA. This can be by solar panels, combined heat and power (CHP) or other case-specific solutions. Annual production and emission intensities need to be ascribed to the local energy source together with the energy supply it is compensating. These intensities are used to calculate either if the local energy production is

[9] The GHG emission intensities have been gathered from fjernkontrollen.no that uses declarations from the different district heating companies. (Norsk Fjernvarme, 2018)

increasing or decreasing the emissions, depending on if the emission intensity of the local energy supply is higher or lower compared to the non-local.

Energy production and emission intensities for materials per square metre of a solar panel unit are included within the tool. These values for solar panels are based on the assessment of GHG emissions from solar panels at Powerhouse Brattørkaia (Dahlstrøm, 2018b). Emission intensities for materials for any other local energy production can also be added but is not included as a default value, as it is for solar panels. The emissions from materials from local energy production will, if included, be calculated in the Material module.

Equation (2) show the overall calculation principles for the emissions related to operational energy use, calculated for every year:

$$E_{eu} = \sum_{b=1}^{n}\left(\left(\sum_{p=1}^{n} NE_p \cdot \eta_p \cdot e_p\right) \cdot A_b\right) + P_{lp} \cdot (e_{lp} - e_{re}) \qquad (2)$$

Where E_{eu} are emissions from operational energy use, NE net energy demand, p heat, cooling or direct electricity, η efficiency, e emission intensity, P energy produced, lp locally produced, and re replaced (non-local).

3.2.3.4. Transportation

The module Transportation calculate emissions related to transportation of the users belonging to the buildings being a part of the development area. Either as inhabitants, employees or users of commercial buildings. The calculations are based on data in Klimagassregnskap.no, the national travel survey (RVU)(Hjorthol et al., 2014) and numbers of users (inhabitants/workers/other) per square metre of the different building types. As of now, the national travel survey of 2014 is used. The new national travel survey applying for 2018 was not published in time to be used in this thesis. The travel survey data give values for which kind of travel mode used for different areas in Norway and in different parts of some cities, together with the distance travelled. These travel modes are within the tool divided into walking/bicycle (which is assigned no emissions), public transportation and by car. These are again divided into different kinds of travel purposes, where the main categories are to/from residence, retail office, and services. By multiplying the data for the number of travels and distance for different kind of users and travel modes with the number of users (inhabitants/workers/other) of the area, total travel distances over a year for different travel modes can be found. The trip both to and from the destination is as a default value allocated to the buildings of the area, as in the guideline of NS 3720. However, transportation can also be chosen to be allocated between the destination and buildings of the area in OmrådeLCA. (Borg and Fuglseth, 2018a, Dahlstrøm and Solli, 2018, Borg and Fuglseth, 2018b)

Furthermore, to find the emissions from these travel distances, different emission intensities for cars and public transportation have been used. For travel by car, numbers from Transportøkonomisk institutt's (TØI)[10] scenarios for the share of different cars (diesel, gasoline, electric and hybrid) from today and into the future (constant after the year 2050) have been used (TØI, n.d.). TØI's average estimate, or trend path, is the default choice, where TØI's "ultra-low emission scenario" is another choice, which is assuming a higher share of electric cars in the future than the average estimate. Both the trend path and the ultra-low emission path can be seen in Appendix A.6. To find the emissions related to driving, TØI's average estimates for emission intensities for driving different kinds of cars are multiplied with the distribution of cars according to TØI's scenarios. In addition to direct emissions, emission intensities from Ecoinvent (n.d.-b) and a report made by Lausselet et al. (2019) from road infrastructure ascribed to driving, and productions, maintenance and end of life of cars are included. Each of them for per kilometre of driving on a per person basis. (Borg and Fuglseth, 2018a, Dahlstrøm and Solli, 2018, Borg and Fuglseth, 2018b)

To account for the effect of varying parking space availability on travel methods, a calculation factor reflecting the number and types of parking spaces of different areas is applied. This factor affects the share of transportation happening by walking/bicycle, driving by car and public transportation. This factor ranges from 0 to 1, where 0.1 is no parking options, 0.4 is taxed public parking, 0.6 is taxed parking by the employer, and 1 is free parking. Free parking is the default choice. By decreasing the factor, the share of transportation by private cars decrease, while the share of transportation by public transportation or bicycle/walking increases. (Dahlstrøm and Solli, 2018)

For public transportation, the total distance travelled on public transportation is allocated between different public transportation modes (passenger train, subway, tram, city bus and boat), according to travel survey data. The emissions of driving one kilometre of this public transportation mode are then multiplied with the travel distance for this transportation mode. The emissions of driving one kilometre of this transportation mode are on a per person basis. This means that the total emissions for riding public transportation one kilometre are divided to each passenger. Total emissions per kilometre are gathered from NSB and Ruter (NSB-Konsernet, 2015, Ruter, 2016). Estimates for capacity and how full the transportation modes are on average are also provided by NSB and Ruter. In addition, emissions from infrastructure, and productions and maintenance of trains/busses are included. Each of them for per kilometre of driving. (Borg and Fuglseth, 2018a, Dahlstrøm and Solli, 2018, Borg and Fuglseth, 2018b)

[10] National Centre for Transport Research, responsible for driving and promoting research for the benefit of Norwegian society and industry (TØI, n.d.).

Equation (3) show the overall calculation principles for the emissions related to transportation, calculated for every year:

$$E_t = \sum_{y=1}^{n} \left(D_y \cdot N_i \cdot \left(s_{p_y} \cdot e_{p_y} + s_{c_y} \cdot e_{c_y} \right) \right) \tag{3}$$

Where E_t are emission from transportation, D_y total distance travelled by each person per year, N_i number of inhabitants/users/employees, s_p share of travel by public transportation, e_p emission intensity of public transportation, s_c share of travel by car, e_c emission intensity of transportation by car, and y year.

3.2.3.5. New features and results

Two newly added features of OmrådeLCA is the possibility to calculate emissions from soil stabilisation and change in land-use. For soil stabilisation, if it is needed, emissions due to extra materials this stabilisation generates can be calculated based on the depth to bedrock. Amounts of construction steel and concrete needed for soil stabilisation per square metre gross area and depth to bedrock is gathered from OneClick LCA[11]. Further, emission intensities for construction steel and concrete are gathered from edp-norge[12]. In reference buildings of Statsbygg[13], if the depth to bedrock is not known, 10 metres is the standard value (Dahlstrøm, 2019). This is, therefore, the default value used in OmrådeLCA.

The use of land for different production purposes (e.g. agriculture or forestry) or settlement can lead to substantial changes in the storage and turnover of carbon (CO_2) of an area (Hammervold, 2015). Therefore, the change of land-use is implemented into the revised version of OmrådeLCA. For the change in land-use, emissions caused by land take are calculated based on the type of land that is being destroyed and the total area of the development, i.e. the difference in direct or indirect emission in an urban or rural area. Emission intensities from a report of Hammervold (2015) for land take of different kind of topographic features, e.g. forest and farmlands, are used. To calculate the effect of the land take, the emission intensity of the chosen topographic feature is multiplied with the total area of the development area.

In using OmrådeLCA, several choices and alternatives must be made or chosen. These will affect the resulting calculated emissions. The choices and alternatives often deal with the choice of including different modules or aspects in the assessment, or choosing between

---

[11] OneClick LCA is a Building Life Cycle Assessment and Life Cycle Costing cloud-based software (Bugge, n.d.).

[12] Epd-norge is The Norwegian EPD foundation, which has a database for EPDs (The Norwegian EPD Foundation, n.d.).

[13] Statsbygg is a public administration company under the Ministry of Local Government and Modernization (Sytatsbygg, n.d.).

different calculation principles and different parameters. These can be seen in Appendix A.2, where default values are highlighted.

The calculations in OmrådeLCA are performed on a per year basis for all building categories. This allows for one of the new features of OmrådeLCA, to show resulting emission on a per year basis, together with the results presented in different functional units, both overall emissions, per square metre and per user, and given according to the different modules specified in NS 3720, as well as according to the different building categories considered. Also, to enhance the presentation of results, sensitivity analyses of different assumptions and parameters have been included in the revised version.

3.2.4. Gathering of new data

Here follows an explanation of how new data have been gathered, calculated and implemented into the revised version of OmrådeLCA.

Materials

Emissions occurring from construction materials for buildings were previously calculated based on one aggregated intensity for each building category. In the effort of splitting up these emissions into the different modules of NS 3720, a database (Skullestad, 2018), based on klimagassregnskap.no was used, developed by Asplan Viak. This database consists of emissions from the modules A1-A3 combined with B4, from several different reference buildings following the TEK 10 building standard. These reference buildings consist of several different buildings belonging to different building categories. To get one emission intensity of each building category, the average of each building category was calculated. This resulted in one emission intensity of each building category for the combination of the modules A1-A3 and B4 according to the building standard TEK 10.

To both split up the emission intensities in module A1-A3 and B4, and be able to get results for Passive Houses, a percentage difference between both different modules and standards was necessary to be found. To do so, it is crucial to compare studies that include the same data, especially when it comes to building components. Eirik Resch, a PhD candidate at the Norwegian University of Science and Technology (NTNU), has developed a comprehensive database consisting of several LCAs of buildings, and a tool using this database for systematic analysis of embodied emissions in buildings (Resch and Andresen, 2018). The tool has been used in this thesis to find emission intensities for the module A1-A3 and B4 for ZEBs when using the same building components as used in the database developed by Asplan Viak. This information was then further used to find the percentage share between the modules A1-A3 and B4 of Resch's database, to split the emissions of the aggregated modules A1-A3 and B4 of the Asplan Viak database in two, using the same percentage share. Further, the difference in emission intensities between the buildings following TEK 10 standard of the Asplan Viak database, and ZEB standard from Resch's database was implemented as a variable in OmrådeLCA.

Operational energy use

GHG emission intensities of district heating have been calculated for several district heating companies by use of ByggLCA (Fuglseth, 2019). ByggLCA is an LCA tool developed by Asplan Viak for conducting LCAs of single buildings. Within the tool, the energy mix of the district heating must be entered, if emissions from waste heat should be allocated to the district heating plant or not, and which emission intensity for electricity to use. The energy mix of district heating companies was gathered from an online tool within www.fjernkontrollen.no (Norsk Fjernvarme, 2018). ByggLCA uses emission intensities for several different fuels to do the calculations. The emission intensities within the tool were updated according to a study by Lien (2018) and the report "GHG accounting for district heating" (Otterlei, 2014). The resulting emission intensities of several district heating companies were implemented into OmrådeLCA, with Norwegian or European electricity mix according to NS 3720, and with and without waste heat allocated to the district heat production.

Transportation

Embodied emissions from cars have in the revision of OmrådeLCA been updated. Previously there was no distinction between different kind of cars, e.g. diesel and electric cars. An assessment done by Lausselet et al. (2019) has been used to find emission intensities [g CO_2-eq/km] from both the production and end of life for electric cars and diesel/petrol cars. The assessment provides emissions for the years 2018, 2030 and 2050. The emissions from these years have been implemented into OmrådeLCA with a linear calculation for the years between to find emission intensities for each year.

In the original version of OmrådeLCA, not all building categories had included calculations for numbers of users, inhabitants or employees per area. To assess the number of trips per year for all the building categories, this must be calculated. Therefore, values for either the amount of users or employees per square metre, and opening days if it is a commercial building, of the building categories not already included has been gathered either from table B.1 in NS 3720 (Standard Norge, 2018) or a report by Asker municipality (Asker Municipality, 2017).

3.3. Case Ydalir

In this section, a description of case Ydalir, followed by an explanation of how case Ydalir has been assessed in OmrådeLCA according to various approaches are presented. Assumptions and choices taken within OmrådeLCA for each of the scenarios or approaches are summarized in Table 3.5 in Chapter 3.2.4.

3.3.1. Ydalir, a future Zero emission neighbourhood

Ydalir is an area located 1.5 km outside the Norwegian city of Elverum. It is to be developed, over a period of more than ten years, as a residential area, consisting of approximately 100 000 m^2 of residential buildings, a kindergarten and a school (Elverum Vekst, 2017a, Elverum Vekst, 2017b). An illustrating made by Tegn_3[14] of a possible development of Ydalir can be seen in Figure 3.5. Ydalir is one of nine pilot projects within FME ZEN, the Research Centre on Zero Emission Neighbourhoods. A neighbourhood within FME ZEN must aim to reduce its GHG emissions towards zero over its life cycle (ZEN Research Centre). This will mean that all emissions of CO_2 for transportation, energy production, construction process (including material use) and operation must be compensated with local renewable energy production, which overall has lower emissions than what would be the case when choosing traditional energy supply solutions (Elverum Vekst, 2017a).

Figure 3.5 Illustrating of a possible development of Ydalir made by Tegn_3

Ydalir is being developed with the goal of creating a zero emission area, but there are no concrete goals for the development of Ydalir such as, for example, zero emissions over its

[14] Tegn_3 is an interdisciplinary architectural office (Tegn_3, n.d.)

lifetime, or zero emissions for the operation of the building stock. However, several measures are determined or suggested in the masterplan for Ydalir (Elverum Vekst, 2017a).

Transportation by car will be limited by considerably lowering the share of parking lots per household, where the parking lots, in addition, are located in a separate shared parking house, prepared for charging of electric vehicles. Ydalir is located close to the city centre (1.5 km) where transportation by walking and biking are given priority in infrastructure development, together with preparations for better public transportation opportunities for the inhabitants of Ydalir. Adaptions for carsharing options and "mobility hubs" at Ydalir are brought up as other possible measures to reduce emissions from transportation. A mobility hub can be an infrastructure that can be used as parking for bicycles and charging for electric bicycles, but also for easy service such as bicycle workshop, sharing of cargo bikes, garden tools and hobby tools, ski preparation, and common areas/meeting places for residents (shared kitchen, co-work-space, work stations for local working etc.). (Elverum Vekst, 2017a, Elverum Vekst, 2017b)

In Table 3.1, minimum and maximum demands regarding car and bicycle parking spaces, respectively, at Ydalir are shown.

Table 3.1 Maximum and minimum requirements for car and bicycle parking spaces for different types of residences at Ydalir (Elverum Vekst, 2017b)

Type of residence	Number of car parking spaces (maximum requirement)	Number of bicycle parking spaces (minimum requirement)
1-room	0	1
2-room	0.5	2
3-room	0.7	3
4-room and larger	1	4

Local energy production by solar panels and CHP using bioenergy as an energy source are the primary measures regarding energy consumption, in addition to the implementation of the Passive House standard or higher in buildings (Elverum Vekst, 2017a). Geothermal energy is being investigated as a possible heat source, but nothing has been decided (Bugge and Jørgensen, 2017). For the construction of buildings, reused materials will be used where it is possible, in combination with materials with low embodied emissions. This must be documented with Environmental Product Declarations (EPDs)[15], and it should also be a focus on using wood in construction elements. Lastly, compared to reference buildings[16], buildings at Ydalir must have 50% lower amounts of emissions. To show this, emission assessments must be worked out for each development of buildings. (Elverum Vekst, 2017a).

[15] An environmental declaration is a concise document that summarizes the environmental profile of a component, a finished product or service in a standardized and objective manner (epd-norge.no).
[16] A reference building is a building of the same building category and size, built according to conventional building method with standard material use (Elverum Vekst, 2017b).

3.3.2. OmrådeLCA used at Ydalir

In the following section an explanation of choices taken, data that is used, and calculations performed to make OmrådeLCA adapted for the assessment of Ydalir for various approaches follows. These are, case Ydalir where Ydalir has been assessed on the basis of the explanation of Ydalir in Chapter 3.3.1, a reference where a traditional development of the same functional mix as Ydalir happens in an average location in Elverum, and the last approach where changes in calculation methods and improvements to Ydalir are implemented to see how and if Ydalir can achieve a zero emission target. The case-specific data for the different approaches can be found in Table 3.5 in Chapter 3.3.4.

3.3.2.1. Case Ydalir with OmrådeLCA

To assess the emissions from Ydalir, case-specific data, not already being implemented in OmrådeLCA as generic data, needs to be entered into OmrådeLCA. Now follows a description of how this data has been collected and calculated. No changes in the underlying methodology of OmrådeLCA has been performed, except for using static instead of dynamic LCA approach. The results of a sensitivity analysis of these two approaches follows in the result and discussion chapter.

As mentioned, OmrådeLCA requires the number of built square metres to be entered for each specific building category in the assessment. In OmrådeLCA, residential buildings are split into the categories apartments, row houses and single-unit dwellings. For Ydalir, it is not decided anything regarding the share of different residential building types. From the Masterplan part 2 version 3 of Ydalir, it is stated that "There should be a variation between higher apartment complexes and lower concentrated small houses..." (Elverum Vekst, 2017b). It is therefore chosen to be a 50-50 split between the apartment and the row house category of OmrådeLCA. It is further decided in the masterplan that Ydalir shall accommodate 2 500 inhabitants resulting in an average of 40 m^2 per inhabitant given the 100 000 m^2 of residential buildings (Elverum Tomteselskap AS, 2017).

To estimate the energy demand, all buildings are assumed to achieve the Passive House standard. The kindergarten and the school will be built according to the Passive House standard, while the residential houses will follow the ZEB guideline, explained in Chapter 2.3. It is still assumed Passive House standard for these too because ZEBs does not have specific demands in regards to energy consumption in its guideline. Also, ZEBs are often buildings following the Passive House standard, but that also has local energy production to be able to reach a zero emission target. Passive Houses can also have local energy production. The emission intensities computed for ZEBs mentioned in Chapter 3.2.4 are therefore used for all the buildings at Ydalir.

It is not defined how many solar panels will be installed at Ydalir. However, in a concept report (Bugge and Jørgensen, 2017) for Ydalir, 18 m^2 of solar panels for each dwelling is suggested. One thousand dwellings result in 18 000 m^2 of solar panels at Ydalir. This amount of solar panels is used to calculate the energy production and emissions from materials associated with solar panels. In the same concept report, a solution for the CHP production at Ydalir is also estimated. The estimations are based on the use of a Volter production unit (Volter, 2018), which runs on bioenergy. This unit has an electrical power of 40 kW and a heat power of 100 kW. By assuming a high number of annual operational hours, each unit can produce between 220 000 and 250 000 kWh/year of electricity. It is further estimated 8-10 production units (Bugge and Jørgensen, 2017). The annual production of electricity is calculated in equation (4), and the annual production of heat is calculated in equation (5). It is assumed average values for the above-mentioned electricity production and number of units.

$$9\ units \cdot 235\,000\ \frac{kWh}{unit} = 2\,115\,000\ \frac{kWh\ electricity}{year} \tag{4}$$

$$9\ units \cdot 235\,000\ \frac{kWh}{unit} \cdot \frac{100\ kW\ heat}{40\ kWh\ electricity} = 5\,287\,500\ \frac{kWh\ heat}{year} \tag{5}$$

It is assumed that the solar panels are replacing electricity from the grid. However, it is not that straight forward what the CHP is replacing when producing both heat and electricity. It is in this thesis made a simplification saying that the CHP primary produces heat with electricity as a by-product. Therefore, the heat produced by the CHP is given all the emissions from the CHP units which replace district heating, while the electricity produced is given no emissions and replaces grid electricity. However, often it is the electricity production being used as the design factor, with heat as a by-product.

To calculate the emission intensity from energy produced by the CHP units based on pellets, equation (6) is used, with the following explanations of each part of the equation. The Volter production units are the same as has been tested at Campus Evenstad, another ZEN pilot project. There it uses pellets as fuel, a bioenergy-product calculated by Lien (2013) to have an emission intensity of 14.4 g CO_2-eq/kWh. Pellets with the same emission intensity are used for the assessment of case Ydalir. The lower heating value of pellets is estimated to be 4.5 kWh/kg (Lien, 2018). The Volter unit converts 1 kg of biomass to 1 kWh of electricity and 2.5 kWh of heat, resulting in a total energy amount of 3.5 kWh/kg pellets (Lilleberg, 2019). The second part of the equation is, therefore, an efficiency term, stating how much energy there is in the pellets compared to how much energy is delivered by the CHP. The last part of the equation is a conversion factor changing the emission intensity yielding for only the amount of pellets used to produce heat, also to include all pellets used to produce electricity.

$$\begin{aligned} 14.4\frac{g\ CO_2}{kWh} \cdot \frac{4.5\frac{kWh}{kg}pellets}{3.5\frac{kWh}{kg}pellets} \cdot \left(1\ part\ heat + \frac{1\ part\ electricity}{2.5\ part\ heat}\right) \\ = 29.62\frac{g\ CO_2}{kWh\ produced} \end{aligned} \tag{6}$$

The heat demand at Ydalir not covered by the CHP units is produced by a geothermal heat pump with a COP of 4 (Elverum Tomteselskap AS, 2017).

There are no specific travel survey data for Elverum that can be used. Instead, it is chosen to use travel survey data for "smaller cities" from the travel survey data key report for 2013/2014 (Hjorthol et al., 2014) since Elverum is considered as a "smaller city" in this report. This travel survey data state how much of the transportation happens by car, public transportation or by bicycle/walking, and the distance of travelling each day per person. It is assumed that measures for transportation at Ydalir mentioned in Chapter 3.3.1 will decrease the share of transportation happening by car. Therefore, the travel survey data for Elverum needs to be adjusted to fit for Ydalir. Measures regarding better bicycle infrastructure have been shown to have a negligible effect on transportation choices (Frøyen, 2019), and kindergarten and school in the vicinity is something assumed to not have an effect in this study of Ydalir. Therefore, it is chosen to just look into the effects of limited parking possibilities.

In a study by TØI, Christiansen et al. (2015) have investigated the effects on the different transportation modes and how they change when people either have their own parking space on their property, their own parking space but not on their property, or they do not have a parking space at all. The relative changes between these three options regarding the different transportation options are used to find the effects at Ydalir. An assumption has been made that in a "smaller city" (where the original travel survey data is taken from) everyone has their own parking space on their property. For Ydalir, on the other hand, it is assumed that 70% have their own space but not within their property, while 30% do not have a parking space at all. These numbers are based on Table 3.1, where it is assumed that the average accommodation is a 3-room, because of a higher share of families with children living in 3- or 4-rooms than people living in 1- or 2-rooms. If the average is a 3-room, this results in on average 70% of households having a parking space, but not on their property and 30% not having a parking space at all. These numbers, together with the findings from the study by TØI are used to calculate and find the change for the various means of transportation for Ydalir compared to Elverum. It is assumed that it is only the distribution of means of transportation that will change, not the travel distance each day. The resulting travel survey data of Ydalir and the travel survey data of Elverum can be seen in Table 3.2.

Table 3.2 Resulting travel survey data of Ydalir and the travel survey data of Elverum

	Travel by car	Travel by public transportation	Travel by walking/bicycle
Elverum	67.3%	7.2%	25.5%
Ydalir	49.5%	13.1%	37.4%
Relative change	-26.5%	81.9%	46.7%

To find the distribution of public transportation, a report for Ydalir (Elverum Tomteselskap AS, 2017) is used. It is there estimated that out of the 38% of future transportation of the users of Ydalir by public transportation, 3% will be by train and 35% by bus. This result in 7.9% of the total public transportation happening by train, and 92.1% by bus for Ydalir.

Ydalir is today a construction site used for extraction of gravel and does, therefore, have limited amounts of existing vegetation. It is therefore assumed no additional emissions because of change of land-use. Therefore, the feature of OmrådeLCA, allowing for estimating emissions from the change of land-use, is not used. The same goes for the feature of soil stabilisation, which is not used because of the lack of data found concerning the depth to bedrock.

A sensitivity analysis has been performed for Ydalir where the feature within OmrådeLCA of varying different parameters has been used. Each of the parameters was varied with a 25% increase.

3.3.2.2. Reference scenario

A reference scenario has been made in OmrådeLCA in the effort of assessing how well Ydalir performs, regarding GHG emissions, not only compared to the ZEN definition but also compared to traditional development. The reference in OmrådeLCA should follow the development pattern in the same region as Ydalir, representing as good as possible how a traditional development of the same built area with the same functional mix would have occurred. Therefore, the development pattern, meaning inhabitants per building and share of different building types, of Elverum municipality where Ydalir is located has been used. This data is collected from Statistisk Sentralbyrå (Statistisk Sentralbyrå, 2013, Statistisk Sentralbyrå, 2019). How the calculation of inhabitants per area of different residential buildings and share of different residential building types for Elverum is performed is shown in Appendix C.1.

Since all new buildings in Norway must follow building standard TEK 17 (Direktoratet for byggkvalitet, 2017) or better, the heat and electricity demands, according to TEK 17, are used. The emissions associated with construction materials for buildings should also follow TEK 17. Since OmrådeLCA only has TEK 10 and ZEB/Passive House (126.8% of TEK 10) emission intensities, it is chosen to set TEK 17 standard to a 10% higher emission intensity of materials compared to TEK 10 ,due to the requirement of more materials to achieve a higher energy standard.

Selections for energy systems for the reference scenario also needs to be made. In Elverum, there is a regulation (Lovdata, 2004) saying that new building projects must attach to the district heating system of Elverum. However, district heating is not assumed being the heat source in the reference because of the scattered building mass in Elverum municipality leading to uncertainties in whether new buildings will be attached to the district heating or not.

Instead, FutureBuilt[17] calculation rules for reference scenarios are used. They state that: 60% of the heating demand for the reference project should be covered by heat pumps (system efficiency 2.25) and 40% by electric boilers (system efficiency 0.86). In cases of a cooling requirement, it should be covered by local cooling machines with a system efficiency of 2.45 (Selvig et al., 2014). These values are therefore used. The use of electricity as a heat source instead of district heating is lowering the resulting emissions from operational energy use because of slightly lower emission intensity of the Norwegian electricity mix compared to the emission intensity of the district heating of Elverum. The resulting emissions are also lowered because of the use of a heat pump and electric boiler in total achieving a higher efficiency than the district heating.

For transportation, the same distribution among public transportation as in the case Ydalir scenario has been used. Regarding travel survey data, the same version, "smaller cities", as for case Ydalir scenario is used but with no adjustments.

All variables and data not mentioned in this section are the same as for case Ydalir. In Table 3.5, data and choices that show the difference of the reference and case Ydalir scenario are shown.

3.3.2.3. Reaching the goal of being a Zero Emission Neighbourhood

Ydalir is one of several pilot projects within the FME ZEN, where the target is to reach zero emissions during the lifetime of the neighbourhood. How zero emission is defined, is not yet been fully decided within FME ZEN. As part of this thesis, it will be attempted to reach a zero emission target for Ydalir. To do so, a definition of zero emission must be established. The ZEB definition ZEB-COM has been used as a basis. This states that all emissions related to construction, operation and maintenance must be included in the calculations. A complete definition of ZEB-COM and other zero emission definition within FME ZEB can be found in Appendix B.1. In ZEB, transportation is not a part of the calculations. Since it is for ZEN, emissions from transportation are added to the ZEB-COM definition to be the definition of zero emission in this thesis.

In the attempt of reaching a zero emission target for Ydalir, physical and technological improvements of Ydalir are implemented. This involves possible measures that can be implemented at Ydalir. Improvement and assumptions are performed regarding the results of sensitivity analyses, showing which parameters are the most decisive ones. To include the effect of reduced emissions due to solar panels, the emission intensities of the European electricity mix is used in the calculations.

[17] FutureBuilt is a showcase for the most ambitious stakeholders in the construction industry, where the goal is to reduce greenhouse gas emissions by 50% in the areas of transportation, operational energy use and material use (FutureBuilt, 2016).

The assumptions and data used in OmrådeLCA, for the previous mentioned case Ydalir, have been adjusted to account for measures to reduce emissions in case Ydalir. These assumptions and data can be found in Table 3.3.

Table 3.3 Measures of improvement to reduce emissions at Ydalir

<table>
<tr><th>Measures of improvement of Ydalir</th><th>Implementation in OmrådeLCA</th></tr>
<tr><td>Since the parking spaces at Ydalir will be adapted for charging of electric cars, it is assumed a faster increase in the use of electric cars in the years to come for Ydalir than the average or default values used for case Ydalir, following the trend path.</td><td>The car fleet technology mix is chosen to follow the ultra-low emission path of TØI (TØI, n.d.), explained in Chapter 3.2.3.4.</td></tr>
<tr><td>Assuming lower emission intensities per square metre of the buildings. Using the numbers calculated for emissions per square metre for the actual buildings that will be at Ydalir used by the ZEN-tool explained in Chapter 3.3.3 (Context AS, 2018b, Context AS, 2018a).</td><td>Changing the emission intensities per square metre of modules A1-A3 and B4 for all the building categories, as shown below.
<table>
<tr><th>CO_2-eq/ m²/year</th><th>A1-A3 old</th><th>A1-A3 new</th><th>B4 old</th><th>B4 new</th></tr>
<tr><td>Apartments</td><td>5.27</td><td>3.00</td><td>3.03</td><td>1.04</td></tr>
<tr><td>Row houses</td><td>4.48</td><td>3.00</td><td>2.57</td><td>1.04</td></tr>
<tr><td>Kindergarten</td><td>5.15</td><td>2.45</td><td>2.97</td><td>0.18</td></tr>
<tr><td>School</td><td>5.54</td><td>2.67</td><td>3.20</td><td>0.11</td></tr>
</table></td></tr>
<tr><td>Increasing the electricity production from solar panels by 50%, resulting in a considerable increased amount of solar panels needed to be installed at Ydalir.</td><td>Increasing the production and materials of solar panels with 50%.</td></tr>
<tr><td>20% decrease in emissions from materials due to reuse of materials from other buildings, which is planned for the development of Ydalir, and using materials at the end of life of Ydalir in other projects.</td><td>Module D has been assigned a negative emission equalling 20% of the emissions of module A1-A3.</td></tr>
<tr><td>The assumptions in case Ydalir for both the length and type of transportation are conservative considering that only measures regarding limited parking are examined, and not all the other measures to reduce transportation that are planned at Ydalir. In an assessment of the kindergarten (Context AS, 2017a) and the school (Context AS, 2017b) performed by Futurebuilt, a comparison of the emissions from transportation of a reference kindergarten and school and an estimate for the kindergarten and school of Ydalir were performed. They found a 47.5% and 54.5% decrease, for Ydalir compared to the reference, in emissions from transportation of the kindergarten and school. It has therefore been assumed that the same difference in emission will happen for the residential buildings.</td><td>Therefore, based on this, a 50% reduction is assumed of the daily travel distance of the original travel survey data of Elverum, which will correspond to a 50% reduction in emissions.</td></tr>
</table>

3.3.3. Comparison towards FME ZEN

As part of this thesis, a comparison towards another LCA tool has been conducted. This tool is explained in Borgnes (2018) master thesis. The tool, further called the ZEN-tool, is developed in the FME ZEN centre at NTNU and has been used to assess emissions from Ydalir. It is the same tool as used on Zero Village Bergen introduced in Chapter 2.4, but further developed for use at Ydalir.

The tool calculates GHG emissions of neighbourhoods and is based on the modular structure of NS 3720. The tool is intended for use in a later phase than OmrådeLCA and relies therefore mostly on case-specific data. A lot of the background data used in the ZEN-tool are the same as in OmrådeLCA. In Table 3.4, a comparison of the ZEN-tool and OmrådeLCA is made of the most decisive differences, and choices important for the assessment of Ydalir.

Table 3.4 Comparison of the ZEN-tool and OmrådeLCA

	The ZEN-tool	OmrådeLCA
Opportunity to compare to a reference by system expansion	No	Yes
Calculating emissions from construction materials	Yes	Yes
Modules included for construction materials	A1-A3, B4	A1-A3, A5 loss/assembly, B4
Data used for emission intensities of buildings (construction materials)	Case-specific for school and kindergarten, data from similar residences as will be on Ydalir[18]	Generic data for either TEK 10 or ZEB standard
Calculating emissions from operational energy use in buildings	Yes	Yes
Energy consumption/demand buildings	According to building standards	According to building standards
Emissions related to materials of on-site energy production	Both solar panels and district heating	Only solar panels
Calculating emissions from transportation of inhabitants	Yes	Yes
Building categories transportation	Residence	Residence and offices
Data used for travel distances and modes	National travel surveys	National travel surveys
Including productions of vehicles	Yes	Yes
Including road infrastructure ascribed to driving	No	Yes
Including local infrastructure	Local roads, sidewalks and lighting	No
District heating production mixes	Eidsiva Bioenergy mix	Norwegian average, Hafslund District heating, BKK mix, Eidsiva Bioenergy mix
Electricity mixes	Norwegian (NO) and European (EU28+NO)	Norwegian (NO) and European (EU28+NO)

[18] The emission intensity per square metre for the school is gathered from a report made by Context AS (2018b), while for the kindergarten from a report by Context AS (2018a), and for the residential buildings from a report by Kristjansdottir et al. (2018).

Table 3.4 shows the similarities and differences between the two tools. However, when comparing the two tools used at Ydalir, the same modules and assumptions must be used. This means that emissions from local infrastructure and emissions associated with materials for on-site district heating pipes are left out of the results from the ZEN-tool. OmrådeLCA does not include emissions from infrastructures such as roads and parking lots since OmrådeLCA is intended at an early phase where information on the size and amount of such infrastructure will rarely be available. In addition, if it was to be included in OmrådeLCA, it must also be accounted for in the alternative location of built area in order to fulfil the functional mix, which will be challenging to estimate with sufficient accuracy.

For OmrådeLCA, emissions from roads allocated to vehicle operation and emissions from waste/loss at the construction site of building materials are left out. Also, only the modules A1-A3 and B4 are included for building materials.

Regarding assumptions, both tools are set to use the Norwegian electricity mix, the same travel survey data and travel distance, and other data applicable to Ydalir specified in Chapter 3.3.1. Regarding differences of data used, the two tools use different emission intensities for operating and producing vehicles, and emissions from materials for solar panels and emission intensities for the materials of buildings.

An adaption has been made in the calculation of emissions from the CHP units to make the assessment with OmrådeLCA more comparable with the ZEN-tool assessment. Originally, in the assessment of Ydalir, OmrådeLCA uses emission intensities for pellets, but since the CHP units in the ZEN-tool assessment is set to use the same emission intensity as the district heating in Elverum, this emission intensity is also used for the CHP units in OmrådeLCA for this comparison. The reason for the difference in emission intensity for the CHP units of the two assessments is because they use different masterplans for Ydalir as a basis. In the OmrådeLCA assessment, it is used the same bioenergy as is used for the same CHP unit installed at Campus Evenstad as planned at Ydalir, while the ZEN-tool uses the same emission intensity as the district heating has in Elverum, as a simplification.

There is likely to be some differences in what the assessment of emissions from materials used in buildings in the ZEN assessment include in regards of building elements, compared to what the emission intensities of OmrådeLCA include. For example, the assessment of the school at Ydalir, used in the ZEN assessment, do not include any windows in the calculations (Context AS, 2018b).

Choices taken for the assessment of Ydalir with OmrådeLCA to compare results with the ZEN-tool can be found in Table 3.5.

3.3.4. Assumptions and modelling choices of the assessments

Assumptions and modelling choices of the different assessment approaches of OmrådeLCA can be seen in Table 3.5. Not all options within OmrådeLCA is included in the table. Only the more important ones, and the ones changing for the different scenarios.

Table 3.5 Choices taken within OmrådeLCA for various approaches

	Choices	**Case Ydalir**	**Reference development**	**"Reaching zero emission"**	**Comparing to the ZEN-tool**
General choices	Start year	2020	2020	2020	2020
	Emission intensity district heating	Eidsiva Bioenergy	Eidsiva Bioenergy	Eidsiva Bioenergy	Eidsiva Bioenergy
	Emission intensity grid electricity	Norwegian (NO)	Norwegian (NO)	Norwegian (NO) for use, European (EU28+NO) for local energy production	Norwegian (NO)
	GWP-method	Static	Static	Static	Static
	Calculation period	60 years	60 years	60 years	60 years
Development pattern	Development pattern (type of residential buildings)	50/50 apartments/ row houses	According to Elverum 2018 development pattern	50/50 apartments/ row houses	50/50 apartments/ row houses
	Area per inhabitant	40 m^2	According to Elverum 2018 development pattern	40 m^2	40 m^2
Materials	Building standard	ZEB	TEK 17	Same as the ZEN-tool uses	ZEB
	Modules included	A1-A3 + A5 loss/assembly + B4	A1-A3 + A5 loss/assembly + B4	A1-A3 + A5 loss/assembly + B4	A1-A3 + B4
	Reduction in emissions caused by reuse or recycling	No	No	20% compared to module A1-A3	No
	Local energy production	A1-A3 + B4 for 18 000 m^2 solar panels	No	A1-A3 + B4 for 27 000 m^2 solar panels	A1-A3 + B4 for 18 000 m^2 solar panels
Operational energy use	Building standard	Passive House	TEK 17	Passive House	Passive House
	Heat source	Heat pump with COP of 4	60% heat pump with COP of 2.25, 40% el boiler with 86% efficiency	Heat pump with COP of 4	Heat pump with COP of 4
	Cooling source	Direct electricity	Cooling machine with system efficiency of 2,25	Direct electricity	Direct electricity

	Direct electricity source	Direct electricity	Direct electricity	Direct electricity	Direct electricity
	Local energy production	18 000 m² solar panels, CHP producing 7.4 GWh energy per year	No	27 000 m² solar panels, CHP producing 7.4 GWh energy per year	18 000 m² solar panels, CHP producing 7.4 GWh energy per year
	Emission intensity CHP	14.4 g CO_2-eq/kWh	-	14.4 g CO_2-eq/kWh	24.4 g CO_2-eq/kWh
Transportation	Technology mix personal vehicles	TØI trend path	TØI trend path	TØI ultra-low emission path	TØI trend path
	RVU (travel survey) used	Ydalir	Elverum	50% reduction of Elverum	Ydalir
	Building categories included	Residential	Residential	Residential	Residential
	Include vehicle production	Yes	Yes	Yes	Yes
	Include road infrastructure	Yes	Yes	Yes	No
	Divide emissions from transportation between the start and end destination	No	No	Yes	No
Other	Include soil stabilization	No	No	No	No
	Include change of land-use	No	No	No	No

4. Results and Discussion

This chapter answers the questions raised in the problem statement in the Introduction. The results and the discussion are divided into five parts. First, the results from the assessment of case Ydalir with OmrådeLCA are presented. Second, the results from and methodology of OmrådeLCA and the ZEN-tool are compared. Third, the strengths and weaknesses of OmrådeLCA are discussed. Fourth, the strengths and weaknesses of this thesis are presented. Fifth and last, a range of recommendations is made: recommendations for how to further improve OmrådeLCA, recommendations for Ydalir as a ZEN, and some general recommendations and policy implications. These recommendations suggest directions for further research.

4.1. Results for case Ydalir

The results from the assessment of case Ydalir with OmrådeLCA will be shown and discussed in this section. The results, together with sensitivity analyses, will be presented for Ydalir, followed by a comparison of these results with a reference scenario. At the end of the section, the effort of trying to reach the goal of a zero emission neighbourhood will be discussed.

4.1.1. Case Ydalir

The total greenhouse gas (GHG) emissions from the assessment of case Ydalir, equivalent to 167 087 tonnes CO_2-eq, can be seen in Figure 4.1, divided into the primary categories of materials, operational energy use and transportation. Local energy production is a part of operational energy use but is shown as a separate category to highlight its effect.

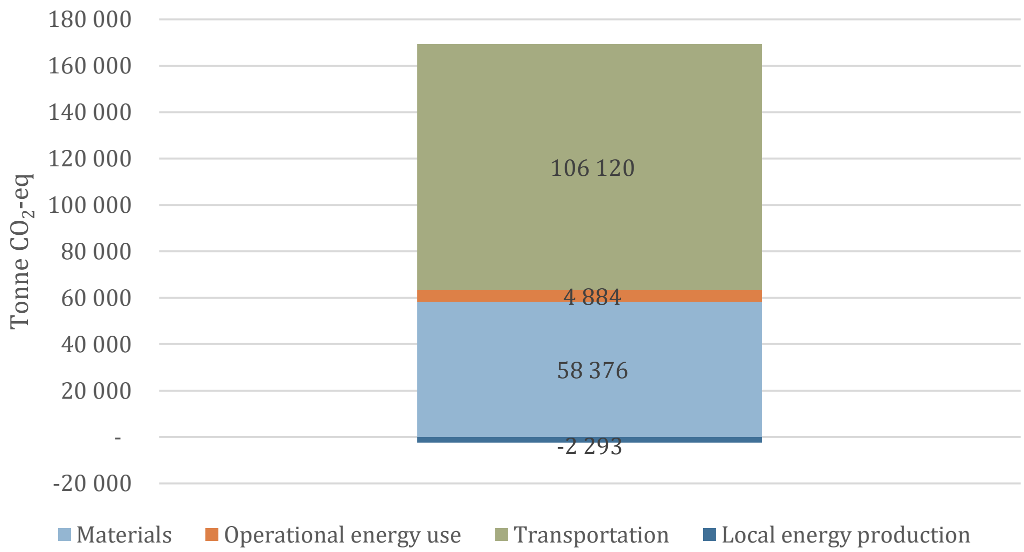


Figure 4.1 Emissions from the assessment of case Ydalir

Materials make up 35% of total emissions, operational energy use, 2%, and transportation, 64%.

The relative insignificance of emissions deriving from operational energy use is primarily due to buildings following a high building construction standard and the use of an electricity mix with a low emission intensity. Dahlstrøm et al. (2012) also found that the significance of emissions from operational energy use decreases with improved building standards and an electricity production mix with a low emission intensity, explaining the low share of emissions arising from operational energy use in case Ydalir.

Both solar panels and CHP units contribute to the local energy production, causing negative emissions because both energy sources compensate for not using electricity from the grid or heat from the district heating system. Emissions from the solar panel materials are allocated to the category materials.

In a ZEN, local energy production should be able to compensate for all emissions - from transportation, materials, and operational energy use. The assessment of case Ydalir shows that the local energy production does not even compensate for the emissions deriving from operational energy use. One reason for this has to do with the emission intensity of electricity. The Norwegian electricity mix has a low emission intensity, meaning that emissions mitigated by producing electricity using solar panels are lower than the emissions associated with the production of the solar panels. Borgnes (2018) found the same in her assessment of Zero Village Bergen. If the European electricity mix had been used, the outcome would be different. This will be discussed in Chapter 4.1.2 in the sensitivity analyses section.

One prominent takeaway from the results is the significance of emissions from transportation. Previously, efforts were made to achieve zero emission buildings without including transportation. Now that transportation is included in zero emission neighbourhoods, it is challenging to reach zero emission targets, given that transportation contributes to more than 60% of total emissions. Local energy production compensates for 1.4% of the total emissions in case Ydalir. The results of the efforts to reach the zero emissions target will be presented in Chapter 4.1.4.

A comparison of the results from the case Ydalir assessment with the results from other studies presented in the literature study shows a number of both similarities and differences. The studies and results presented in the literature study have different boundaries and different assumptions, both compared with each other and with the assessment of case Ydalir. Still, there are some important takeaways, and to make the assessment of case Ydalir more comparable with the studies, some changes in assumptions and premises were made within OmrådeLCA. A European electricity mix was chosen, since this is more comparable to the electricity mix in the other studies, as these were mostly European or Australian. Furthermore, all local energy production, meaning the solar panels and the combined heat and power (CHP) units, was left out of the assessment of case Ydalir since the other studies probably did not include local energy production. Finally, it was decided to use grid electricity as a heat source in this comparison. The results of these measures can be seen in Figure 4.2.

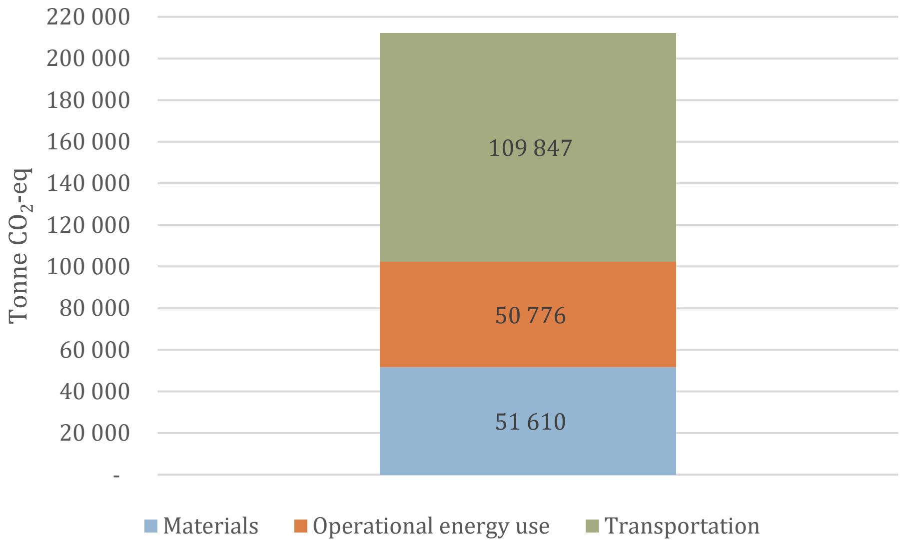


Figure 4.2 Emissions from case Ydalir, but with a European electricity mix, no local energy production and el-boilers as the heat source

After adjustments, materials make up 24% of the total; operational energy use, 24%; and transportation, 52%, while the total emissions constitute 212 233 tonnes CO_2-eq.

When comparing the construction, operation and demolition phases, Lotteau et al. (2015) found the operation phase to be the main contributor to emissions. However, when neighbourhoods are highly energy efficient, the significance of the construction phase (including embodied emissions in materials) reaches the same order of magnitude as the operation phase (operational energy use). This is quite analogous to the results from the adjusted Ydalir assessment. By looking at the results in Figure 4.2, the resulting emissions from operational energy use and materials are almost identical. Wiik et al. (2018a) found, however, for Norwegian buildings adhering to a high building standard, that the production and replacement of materials are of a much higher significance than emissions from operational energy use, as can also be seen for case Ydalir in Figure 4.1.

For transportation, results from the literature study varied from a share of 30% to 60% of total emissions. For the adjusted Ydalir assessment, transportation constitutes 52% of the total emissions. This shows that the transportation emissions given by OmrådeLCA are not that different from those presented in the literature. However, transportation is not as significant in most of the studies as it is in the adjusted case Ydalir assessment. The results from the literature show a more evenly spread out share of emissions from the three different categories compared to case Ydalir. Using OmrådeLCA, transportation is by far the most important cause of emissions, while operational energy use and materials are similar.

In Figure 4.3, the resulting total emissions are presented per building category, demonstrating which building categories contribute the most.

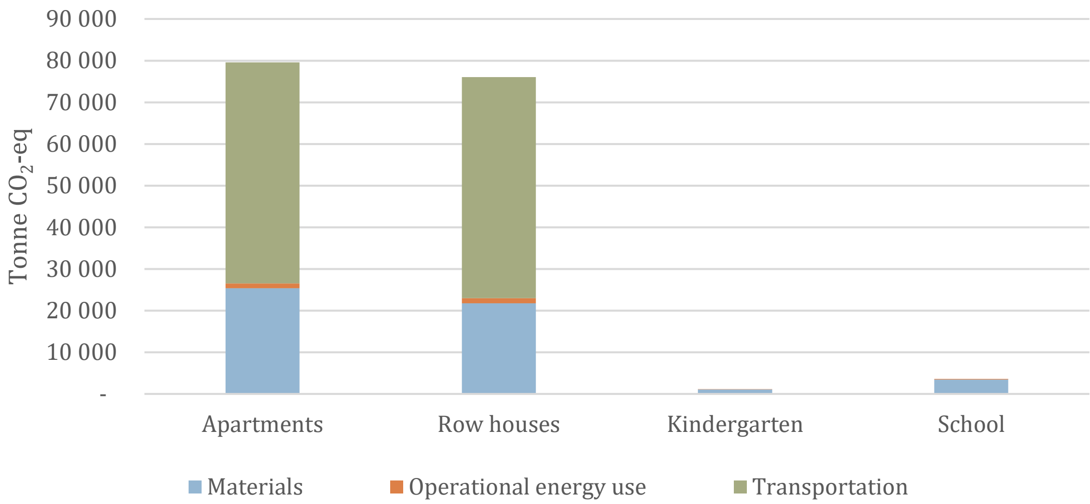


Figure 4.3 Emissions per building category for case Ydalir

In these results, less emission derives from row houses compared with apartments, even though both building categories had the same floor area in square metres. This can also be seen in Figure 4.4, where emissions are expressed per square metre and year. At first, this seems counterintuitive. Buildings with high residential densities, e.g. apartments, as stated by Norman et al. (2006) in the literature study, usually cause lower emissions than low residential density developments, e.g. row houses. The reason for this is that more people usually live per square metre in apartments than in row houses. By displaying the emissions per square metre and capita, this difference in inhabitant density would be counted for. However, in the assessment of case Ydalir, the same density of inhabitants for both apartments and row houses is assumed, resulting in the same difference in emissions derived from apartments and row houses even with the use of a per capita functional unit. Since no specific value for inhabitants per square metre for the two residential building categories was given, the same figure was therefore assumed for both.

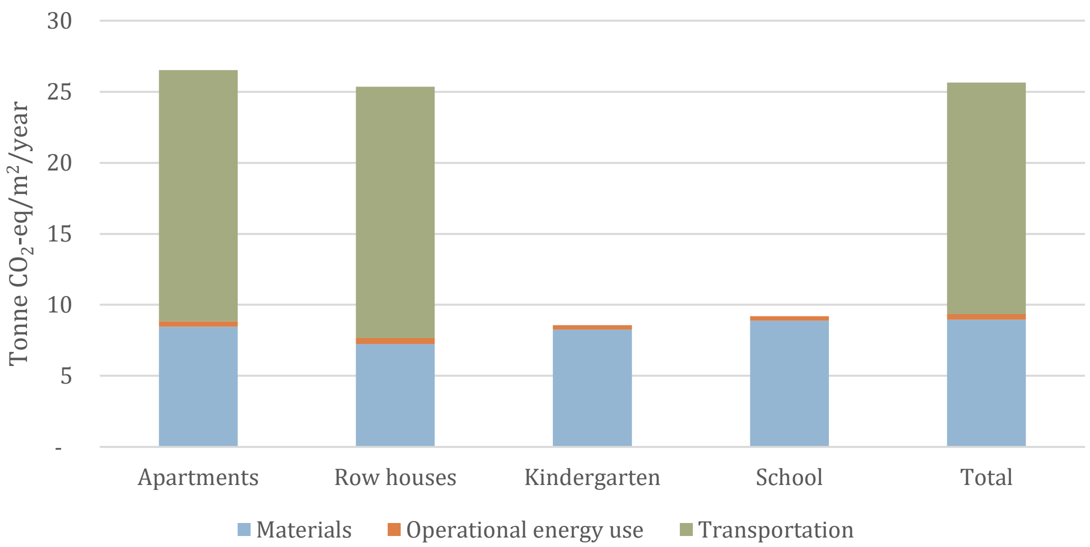


Figure 4.4 Emissions per square metre and year for each building category of case Ydalir

For both Figure 4.3 and Figure 4.4, no emissions from transportation are assigned to the kindergarten or school. This has to do with how calculations for transportation are executed. These calculations will be discussed in Chapter 4.3.3.

By comparing the results from the assessment of case Ydalir with the results found by Borgnes (2018) in Zero Village Bergen (ZVB), using the FME ZEN methodology and tool, several similarities can be seen. Total GHG emissions in the study by Borgnes (2018) are 21.2 kg CO_2-eq/m^2/year, which is a bit lower than case Ydalir's 25.6 kg CO_2-eq/m^2/year. This is not a big difference considering that it concerns two different ZENs assessed with different tools, that were also different in terms of system boundaries and the elements considered (in the assessments, for example, module A5 and the infrastructure ascribed to driving vehicles were not included in the ZVB assessment, while underground parking, open spaces and district heating infrastructure were). In terms of the source of emissions, Borgnes (2018)'s results show that materials constitute 29%; operational energy use, 28%; and transportation, 40%. This is significantly different from the assessment of case Ydalir, where the distribution is 35%, 2%, and 64%, respectively, for the same categories.

Figure 4.5 shows the results according to the different modules presented in NS 3720.

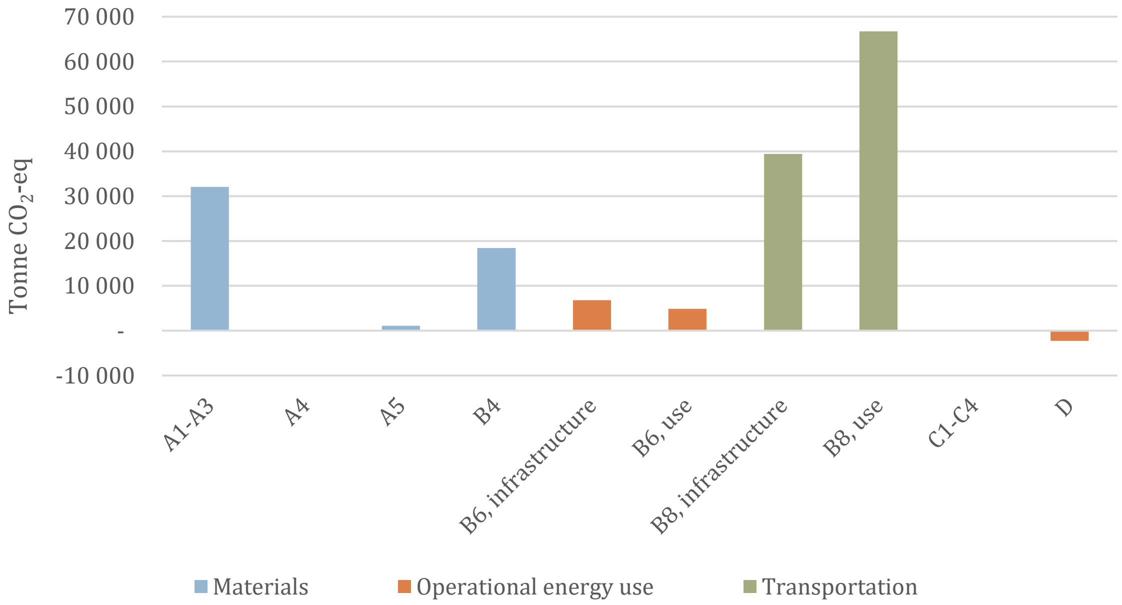


Figure 4.5 Emissions from case Ydalir per module according to NS 3720 (Standard Norge, 2018)

Here it is possible to see, for one thing, emissions associated with materials more transparently. Module A5, emissions from loss/assembly at the construction site, embodies a limited amount of emissions compared to modules A1–A3. Still, it contributes to the total. If more modules, like A4 and A5, relating to the construction phase, had been included, the contribution from materials would increase. Also, the refurbishment of buildings, module B4, included a significant contribution of about 36% of total emissions from materials. Furthermore, the emissions from operational energy use, B6, are divided into two, one module for emissions related to the materials from local energy production, called 'infrastructure', and one for the energy used in building operations, called 'use'. This split was made to see more clearly the contribution from both materials and local energy production. According to NS 3720 however, materials should be included in A1-A3. The benefits of avoiding emissions from electricity production due to local energy production have been ascribed to module D. The division of module B8, transportation, into two modules, one for emissions from vehicles and road infrastructure, called infrastructure, and one for the use of vehicles, called use, gives more transparent results for transportation. The use phase of vehicles provides almost twice the emissions compared to vehicles and road infrastructure. Still, the production of vehicles and infrastructure is the second largest contributor among the modules, demonstrating that not only the type of powertrain vehicles use but also the production of vehicles is highly relevant either when performing an LCA or in efforts to reduce emissions.

Figure 4.6 shows when the emissions are occurring during the calculation period of the assessment.

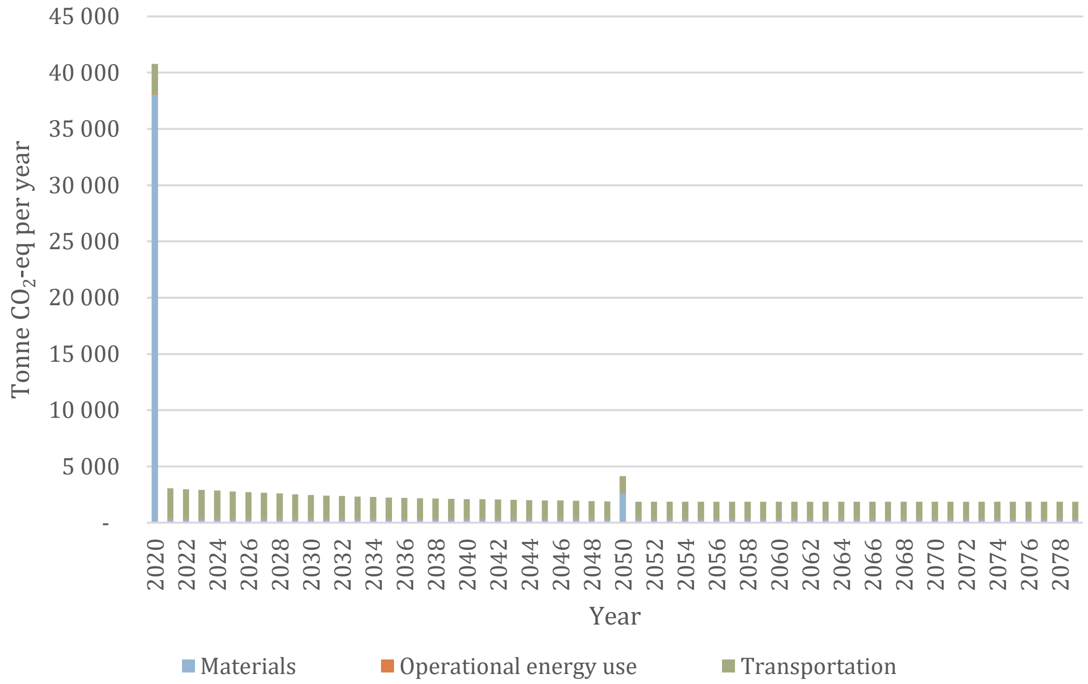


Figure 4.6 Total emissions by year, distributed by the three main categories for case Ydalir

What becomes clear is that the single most decisive emission happens in year one. This is when all the buildings are erected. Module B4, refurbishment of buildings, is equally divided between each separate year of the analysis period, and replacement of solar panels is set to happen after 30 years. The previously mentioned small share of emissions stemming from operational energy use can hardly be seen in Figure 4.6. Huge emissions from materials in year one and a slightly noticeable decrease in emissions from transportation each year are essentially the only takeaways from Figure 4.6. Still, one important thing to remember, looking at the results in this graph, is that the point in time for emissions is decisive. An emission happening today has a greater effect on the climate than an emission happening in 30 years. Since most of the emissions from area development happen in year one, key actions need to happen from the very start of a project.

The presentation of the emissions in Figure 4.6 has difficulties in showing the change in emissions from year to year because of the high peak of emissions happening in year 1. By excluding building materials (A1-A3 and A5) from the graph, this will become clearer. Together with some further division of the main categories, this is shown in Figure 4.7. The further division of main categories makes it possible to see the negative emissions caused by local energy production as well.

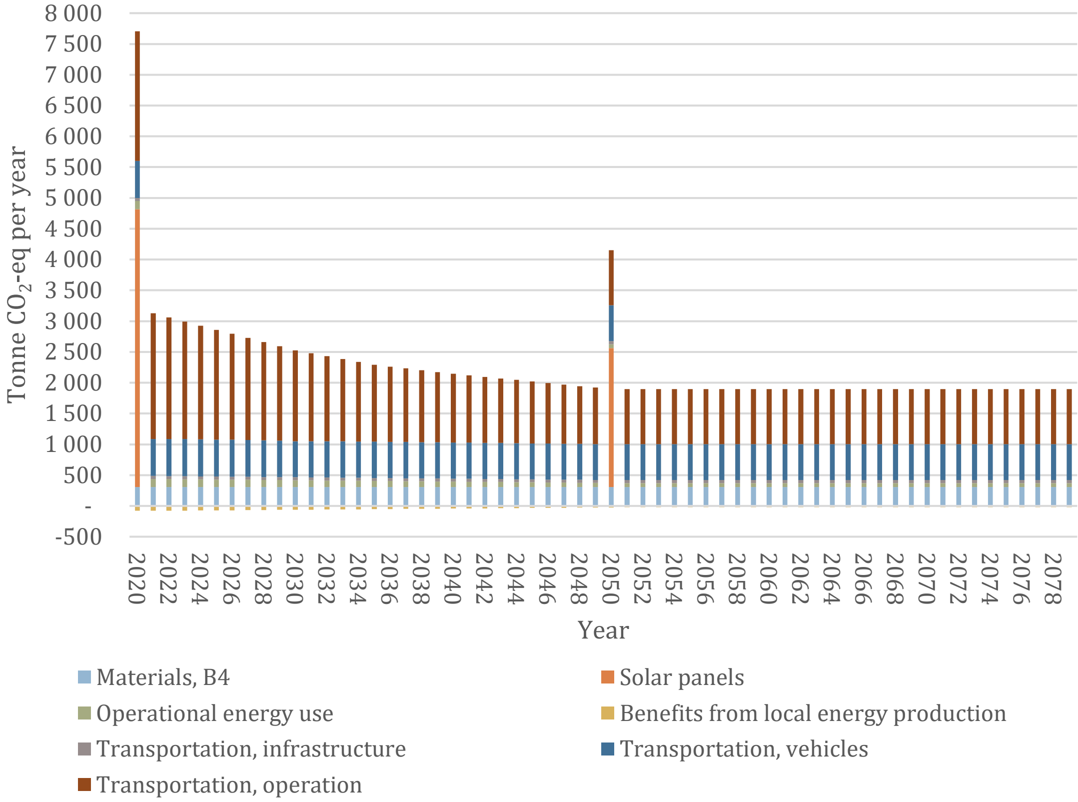


Figure 4.7 Total emissions by year and subcategories for case Ydalir. Materials of module A1-A3 and A5 loss/assembly for buildings are left out

In Figure 4.7, it is easier to see the change in emissions from year to year. The decrease is as a result of more and more cars running on electricity each year, in combination with the emissions intensity from grid electricity decreasing each year. This is also the reason for operation of vehicles being the category showing the most considerable decrease in emissions. Emissions from producing cars also reduce during the analysis period. However, since more and more cars are electric, which are more CO_2-intensive than petroleum cars to produce, the emissions from the production allocated to each kilometre driven stay almost constant. There are no changes in the graph from the year 2050 and beyond since no improvements in technology or emission intensities are implemented into OmrådeLCA from this year. For the emissions intensity, this makes sense since the electricity mix is assumed to almost be zero in year 2050. For the composition of the vehicle fleet, however, a continuation of the trend towards more electric cars could be expected, also after year 2050.

Operation of vehicles, together with the production of vehicles, are the two largest contributors to emissions every year. Even after year 2050, when more people are using electric cars, transportation is by far the main contributor to emissions. This shows that changing the vehicle stock to one based more on electric vehicles is probably not enough to reach a zero emission neighbourhood target. Road infrastructure allocated to the driving of vehicles produces annual emissions that are almost invisible in the graph; compared to driving vehicles and producing them, this source is insignificant.

Benefits from local energy production in the graph include both solar panels and CHP production. However, since the CHP units cause slightly more emissions than they replace, grid electricity and district heating, it is not entirely correct to call it a benefit. Whether they become a benefit is determined by the emission intensity of the district heating and grid electricity they replace. Because of this, the solar panels are the sole reason for the slight benefit, or negative emissions, from local energy production shown in Figure 4.7.

4.1.2. Sensitivity analyses

The results of sensitivity analyses of key parameters, the electricity mix, the location of the development area, static versus dynamic LCA approach, allocation of transportation and allocation of electricity use and production are shown in this chapter.

The result of a sensitivity analysis of some key parameters can be seen in Figure 4.8, where the resulting total emissions from the analysis compared to the assessment of case Ydalir are shown. Each parameter has in turn been altered by a 25% increase. A sensitivity analysis like this can be used to address the critical parameters of a study. It can show which parameters change the most with a change in input data, and it can help display where actions to reduce emissions should be carried out first.

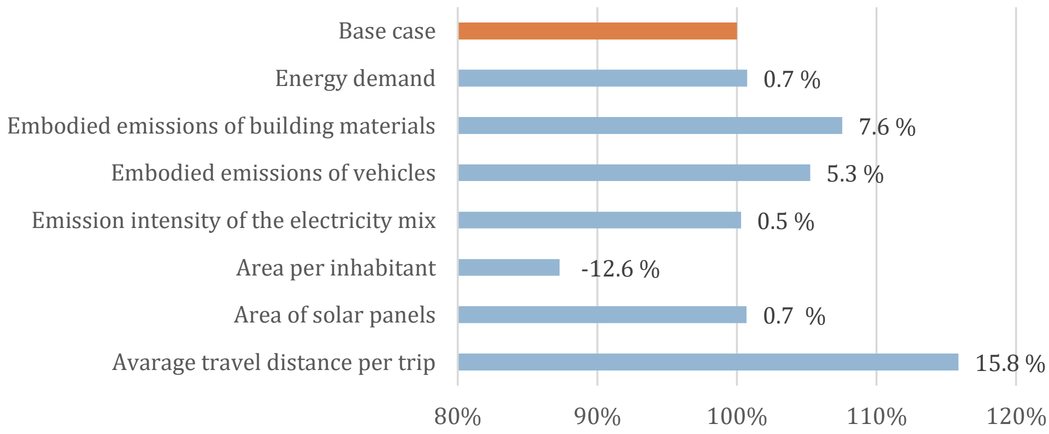


Figure 4.8 Sensitivity analysis of key parameters of case Ydalir

The most decisive parameter, the average distance travelled per trip, has an increase in emissions of 15.8%. The fact that by increasing this one parameter by 25%, total emissions increase by as much as 15.8%, underlines the significance of this parameter. Furthermore, it underscores the importance of performing thorough analyses of transportation when conducting an LCA on the area/neighbourhood scale. Borgnes (2018) also found in her study travel distance to be one of the most decisive parameters.

The decrease in emissions shown in Figure 4.8 when increasing the area per inhabitant (performed in OmrådeLCA by multiplying the area per inhabitant of Ydalir with the given increase in area per inhabitant, 25% in this case) is due to the resulting lower total amount of inhabitants of Ydalir, leading to diminished total transportation demand. This can lead to the misinterpretation that fewer people per square metre is better in regards to emissions. If the functional unit was not total emissions from the neighbourhood, but emissions per inhabitant, the result would be the opposite, an increase in emissions.

Changes in embodied emissions in building materials also have a quite significant impact on total emissions, increasing by 7.6%. Almost as significant is the embodied emissions of vehicles, increasing total emissions by 5.3%.

The three factors having the least impact are all related to operational energy use: energy demand, the emission intensity of electricity, and the area covered by solar panels. This has to do with the already low emissions associated with operational energy use because of the use of a high building standard, combined with the low emission intensity of the Norwegian electricity mix. Furthermore, as mentioned before, the electricity produced by solar panels does not compensate for the emissions caused by the materials in the solar panels, as seen by a 25% increase in amounts of solar panels resulting in 0.7% more emissions.

When comparing the results of the sensitivity analysis with Lausselet et al. (2018) study, which examined which four factors were beneficial for the overall emissions of a ZEN if they were reduced, both similarities and differences appear. Two of them, building floor area per inhabitant and passenger car travel distance, are also shown in the sensitivity analysis of case Ydalir to be two of the most decisive parameters in OmrådeLCA. However, for energy use in buildings and carbon intensity of the electricity mix, there were no similarities, where these parameters are almost unchanged in the sensitivity analysis. As mentioned previously, this has to do with the high share of solar panels with regard to the change in the electricity mix, and the low emission intensity of the Norwegian electricity mix with regard to the change in energy use in buildings.

Electricity mix

A sensitivity analysis examining the effect of using either of the two electricity mixes of NS 3720 has also been carried out. The outcome of this analysis can be seen in Figure 4.9. The results shown here are the total emissions from case Ydalir split between the categories materials, operational energy use, local energy production and transportation. The total emissions when using the European electricity mix are 6.2% higher than when using the Norwegian electricity mix.

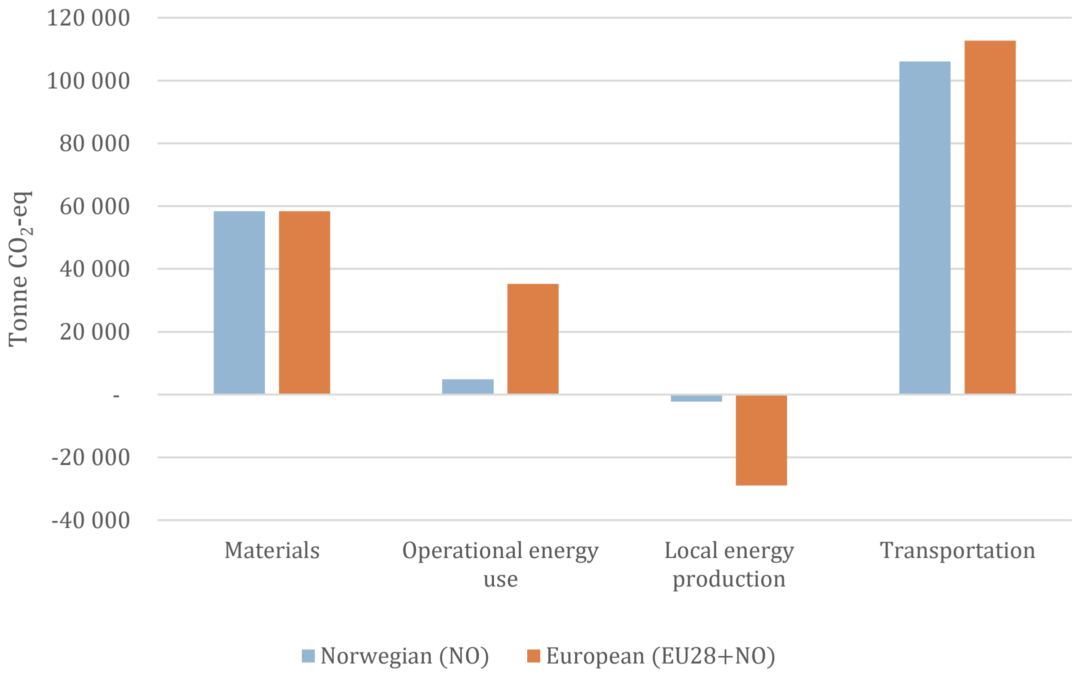


Figure 4.9 Emissions of case Ydalir when using Norwegian or European electricity mix

Emissions from materials are not affected by the change of the electricity mix in the assessment of case Ydalir. The emissions from materials are based on EPDs or key figures that already take into account where the materials are produced, and then the relevant electricity mix. Therefore, a change in the emissions associated with materials because of a change in the electricity mix would not be constructive.

Altering the electricity mix from the Norwegian to the European impacts greatly on emissions associated with operational energy use. As the emission intensity of electricity increases, so do the emissions from operational energy use. However, the same applies to the emissions mitigated by the solar panels. By increasing emission intensity, the solar panels compensate for an increased amount of emissions. The effect of increased compensation by solar panels and increased emissions from operational energy use to a certain degree offset each other.

Emissions associated with transportation are also increased by changing to the European electricity mix. This is due to the increasing share of electric vehicles in the Norwegian vehicle stock in the years to come. The increase that results from altering the electricity mix, however, is not that large. This is because most of the emissions related to transportation are not affected by the electricity mix, as with building materials. This applies to vehicle production and infrastructure, together with the fact that a considerable part of the vehicle fleet in the assessment still runs on petroleum fuel despite the increase of electric vehicles as seen in Appendix A.5, and therefore is not affected by the electricity mix. However, those vehicles in the assessment that do run on electricity are profoundly affected by the electricity mix and are the sole reason for the difference in emissions from transportation for the two electricity mixes seen in Figure 4.9.

Different locations

Travel data vary significantly between different locations, and it can be challenging to assess which dataset most accurately corresponds to the location of a specific project or alternative location. OmrådeLCA, therefore, includes the possibility of comparing results for different choices regarding the travel data selected. Figure 4.10 illustrates the extent to which emissions calculations related to transportation vary data in the Ydalir assessment, depending on the travel survey selected, using travel datasets for the Oslo and Akershus areas as examples.

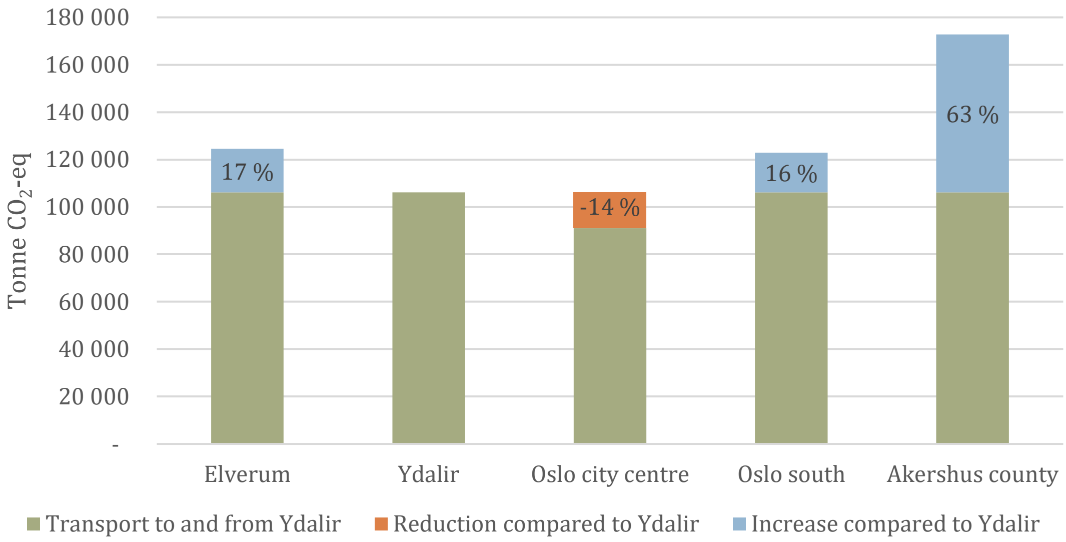
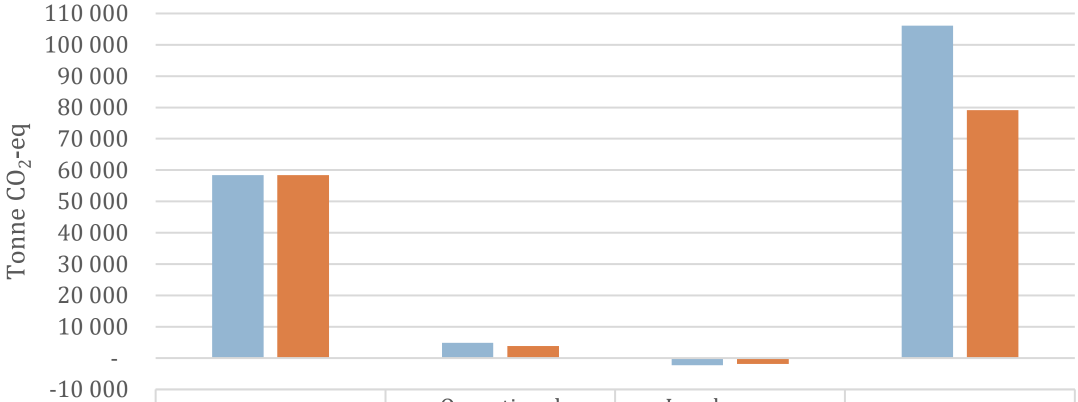


Figure 4.10 Transportation emissions using different travel data sets for case Ydalir

Emissions vary from a 15% decrease if Oslo city centre is chosen to a 63% increase if Akershus county is chosen for comparison with the Ydalir travel survey data. This is a significant difference, demonstrating how important it is to do thorough analyses of transportation. Bastos et al. (2016) found the same significant differences in emissions from transportation relating to the location of buildings in their study, in which they found transportation related emissions to be 350% higher for a suburban house compared to a city apartment.

Static versus Dynamic LCA approach

A comparison of resulting emissions when using a static and a dynamic LCA approach can be seen in Figure 4.11. The total resulting emissions when using the static approach is 19.8% higher than when using the dynamic approach.



	Materials	Operational energy use	Local energy production	Transportation
Static	58 376	4 884	-2 293	106 120
Dynamic	58 376	3 868	-1 890	79 164

Static Dynamic

Figure 4.11 Comparison of resulting emissions when using a static and dynamic LCA approach

A dynamic approach considers when emissions are occurring, in difference to a static approach. Emissions happening today are of greater importance than those happening in the future. The benefit of using a dynamic approach is the possibility to do assessment showing the effect of temporal variations of emissions. Emissions from the refurbishment of materials, module B4 happening in the future, are however not affected using a dynamic or static approach in OmrådeLCA. Therefore, materials have the same amount of emissions for both approaches.

Emissions coming from operational energy use get reduced when shifting approach. The same goes for emissions mitigated by local energy production. The reductions are because the significance of the emissions from operational energy use, and electricity or heat replaced by local energy production, both decreases by time. As for the change in the electricity mix previously elaborated in this chapter, these two, operational energy use and local energy production, to a certain degree offset each other. Both have increased significance when using a static approach and decreased significance when using a dynamic approach.

Transportation is the module having the most considerable difference in emissions when shifting between the approaches. This is because emissions from transportation are happening through the whole calculation period. Infrastructure and vehicle materials are ascribed to each kilometre driven, resulting in these two elements being given a dynamic factor according to when the operation of the vehicle is happening, not when the road is built, or the car produced. This might be a weakness of the dynamic approach in OmrådeLCA.

Allocation of transportation

All transportation of users of the development area in calculation in OmrådeLCA are allocated to the development area. This means that the trip, of a user of the area, both to and from a destination is allocated to the area. This is also how calculations should be performed according to NS 3720. However, if one chooses to allocate transportation between the start and endpoint of a trip, i.e. the trip to work is allocated to the residence, while the trip back again is allocated to the workplace, the resulting emissions are decreased. A comparison of emissions of case Ydalir by allocating either all transportation to Ydalir, or half to Ydalir and half to the end destination, can be seen in Figure 4.12.

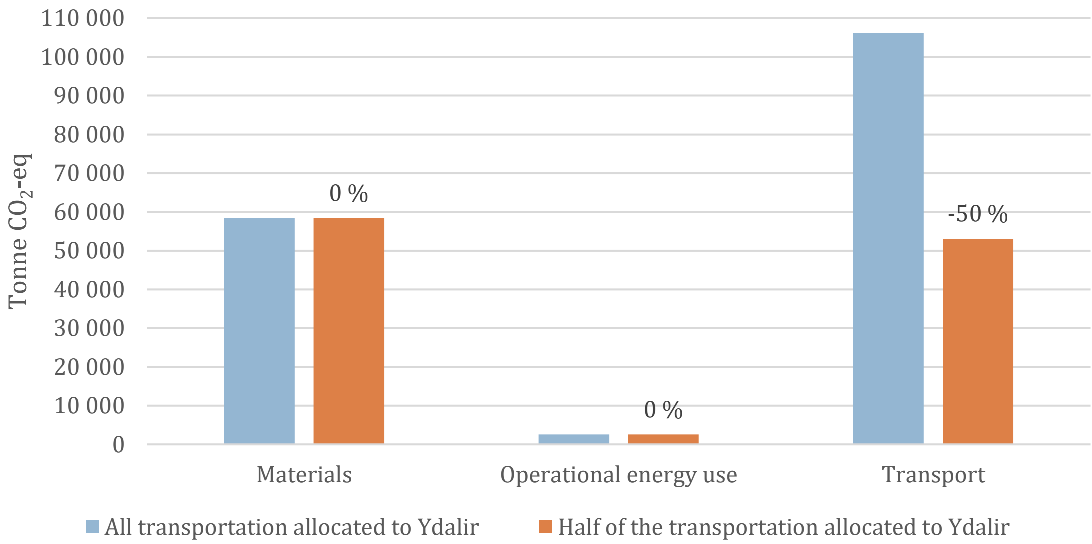


Figure 4.12 Emissions of case Ydalir with either all or half of the transportation allocated to Ydalir

Emissions from transportation are halved since all parameters applying for calculation of transportation related emissions are affected by the amount of distance travelled. As can be seen in Figure 4.12, no other emissions than transportation related emissions are affected by the change in allocation method.

Symmetrical versus asymmetrical allocation of electricity use and production
The standard way of allocating emissions of use and production of electricity is by a symmetrical allocation, where both use and production are given the same emission intensity. An alternative approach is an asymmetrical allocation. Here it is assumed different emission intensities for use and production. A comparison of a symmetrical and an asymmetrical allocation approach used in case Ydalir can be seen in Figure 4.13.

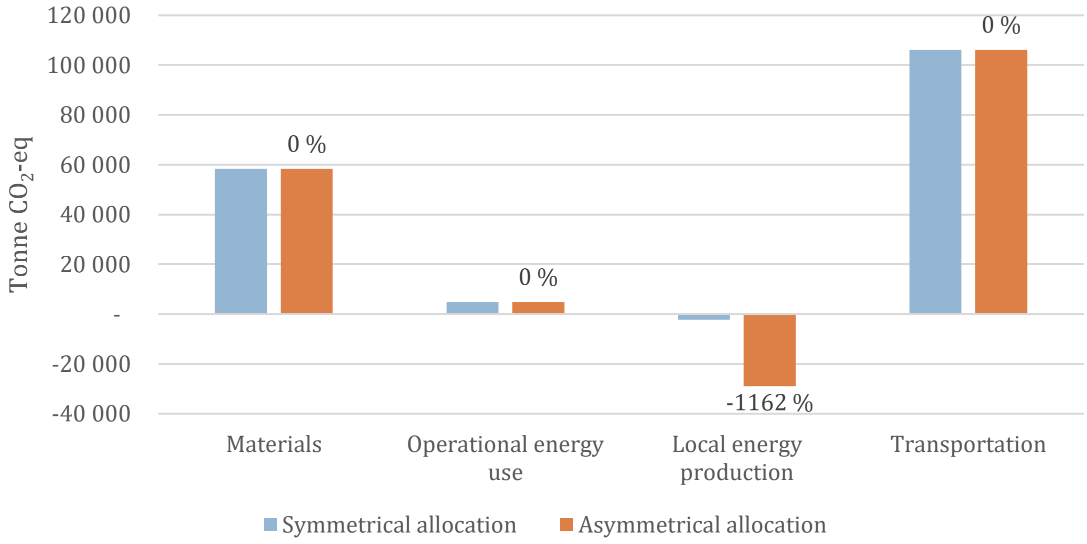


Figure 4.13 Symmetrical versus asymmetrical allocation of energy use and production for case Ydalir

Here, the buildings and electric cars belonging to Ydalir are using Norwegian electricity, while the electricity produced by the CHP units and the solar panels of Ydalir are replacing European electricity. Material related emissions are not affected by this change in allocation. The same goes for operational energy use and transportation. This is because, for both allocation approaches, emission intensities according to the Norwegian electricity mix is chosen for electricity consumption. However, the asymmetrical approach assumes emission intensities according to the European electricity mix for local electricity production, causing a significant difference for local energy production.

Stating that electricity used by the cars and buildings is Norwegian, while the electricity produced by solar panels and the CHP units are replacing European electricity, can be a far-fetched approach. However, from a political point of view, it is stated that emissions shall be reduced. To do so, it is desirable to build high energy-efficient buildings, produce local energy and driving electric cars. To calculate the effect these actions have, it is, therefore, to some degree justifiable to do calculations of the marginal changes by saying electricity used in buildings and electric cars are Norwegian, while locally produced electricity replaces European electricity, to show the effects of the marginal changes.

An alternative approach to symmetrical or asymmetrical allocation is a dynamic model as suggested by Peuportier and Roux (2016) and Lausselet et al. (2019). A dynamic model considers the temporal variation of electricity production and consumption in buildings, resulting in fluctuating emission intensity during the day and year. The use of a dynamic model would be an approach towards a consequential LCA, considering when the electricity is used will affect the background demand of electricity, and then also the emissions intensity of it. A dynamic model can address issues for emissions intensities regarding when energy is used and produced. This is highly relevant for solar panels producing most of its energy during summertime when the energy demand for buildings is at its lowest.

4.1.3. Comparing with a reference scenario

One of the key features of OmrådeLCA is the ability to draw comparisons with a reference development. This makes it easier to evaluate the environmental performance of the Ydalir development. One of the key performance indicators in FME ZEN is a reduction in GHG emissions compared with a reference development, where the KPI is given as a percentage reduction towards the reference. When comparing with a reference, it is possible to understand what the resulting emissions would have been if the development of the given area had not happened, and then see if the development performs better or worse compared to this.

The emissions from the reference development (a description of the reference scenario is given in Chapter 3.3.2.2) and the resulting emissions from case Ydalir can be seen in Figure 4.14. The overall emissions, 167 087 tonnes CO_2-eq, of Ydalir, are 16% lower than in the reference development, 197 767 tonnes CO_2-eq.

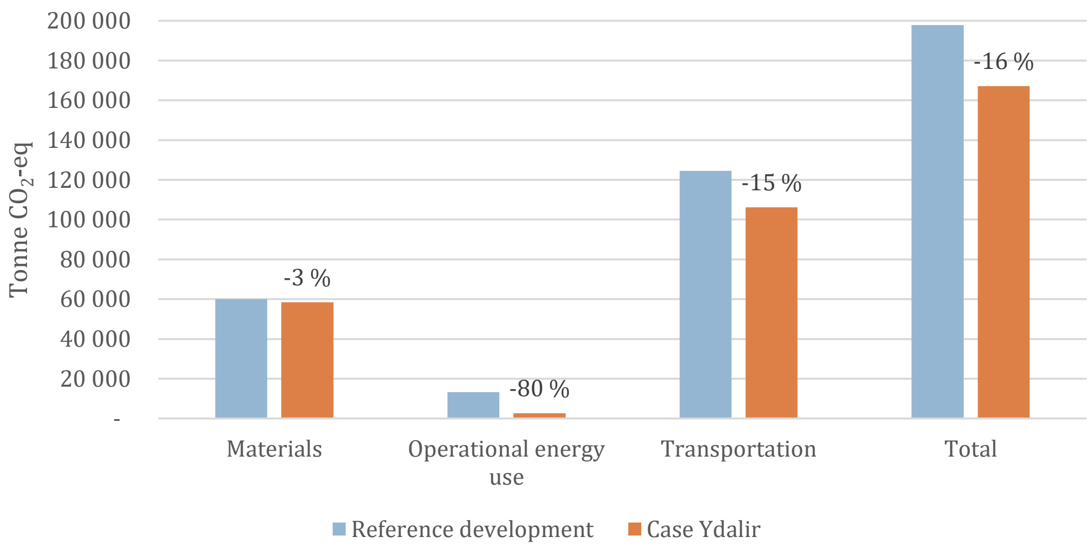


Figure 4.14 Comparison of total emissions calculated for case Ydalir and a reference development

Emissions from building materials are almost identical in both cases. This is even though the emission intensity per square metre used for the ZEB/Passive House at Ydalir is 26.8% higher than in the reference development, where the TEK 17 standard is assumed for the buildings. The reason calculated emissions are lower is the higher area efficiency in case Ydalir, which means that fewer square metres are required to accommodate the same number of inhabitants as in the reference development, where the number of inhabitants per square metre follows the development pattern of Elverum municipality.

The use of solar panels and improved building standard at Ydalir reduces emissions from operational energy use by 80% compared to the reference development. However, since operational energy use accounts for only a small part (6.7% for the reference development) of the total emissions, this does not significantly affect the overall result. The impact of solar panels is also diminished because of the low associated emissions per kWh from the Norwegian electricity mix causing more emissions from materials than gained during energy production, compared to just using electricity from the grid. As mentioned in the explanation of the reference scenario in Chapter 3.3.2.2, the resulting emissions from operational energy use would likely have been higher if district heating had been used as the heat source instead of electricity. This would have resulted in a more significant difference between case Ydalir and the reference scenario. Because of the regulation stating that new building projects must connect to the district heating system in Elverum, a certain percentage of the buildings should probably have been assigned to the district heating system in the assessment in OmrådeLCA, even though it could be argued that the building mass is quite scattered in Elverum, making it uncertain whether new buildings will in fact be attached to the district heating system.

The intention is that the adoption of better building standards, with more embodied emissions, as planned at Ydalir, will pay off in reduced energy costs and reduced emissions during the use phase. However, the emission reductions during the use phase have less of an effect when the emission intensity from the electricity mix is as low as the Norwegian mix. If the comparison of the two developments is performed based on a more CO_2-intensive electricity mix such as the European one, the difference between the two becomes more evident. Emissions from the use phase go from an 80% decrease compared to the reference development, to a 93% decrease when shifting from the Norwegian to the European electricity mix. In terms of total emissions, the reduction goes from a 16% decrease to 39% decrease, showing how important the choice of the electricity mix is.

The reduction in emissions from transportation of 15% must be regarded as a conservative estimate. As mentioned in the description of Ydalir in Chapter 3.3.1, several ambitious measures to reduce travel by car, and travel in general, are planned at Ydalir. However, due to the lack of travel survey data to model the planned effects, conservative estimates have been used. The only measure that has been included is reduced parking options, but not the measures regarding infrastructure for walking, biking or public transportation. It is, therefore, reasonable to assume that the actual reductions in emissions from transportation will be higher than the 15% shown in Figure 4.14.

The overall reduction in emissions of 16% must be said to be an unsatisfactory reduction, considering the fact that Ydalir is a ZEN, a highly ambitious area development. However, there are several mitigating circumstances, such as conservative choices taken with respect to travel survey data and material emissions for the ZEBs, together with the previously mentioned reduced effect on several measures from using a Norwegian electricity mix.

Comparing the two development scenarios according to total emissions, it is still evident that the Ydalir development is the best. However, if the functional unit is altered from total emissions to one per square metre and year as in Figure 4.15, this conclusion is no longer valid.

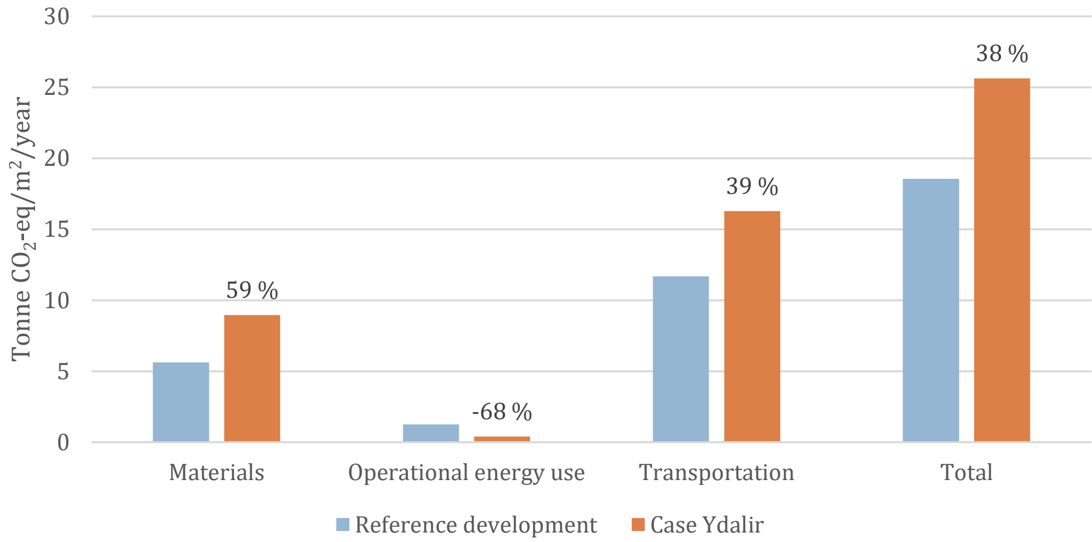


Figure 4.15 Comparison of case Ydalir with a reference development using a spatial functional unit

Using a spatial functional unit, the Ydalir development emits 38% more than the reference development, leading to the misinterpretation that the Ydalir development is a lot worse than the reference development, which is a traditional one. The reason for this change is that more square metres are required in the reference development to obtain the necessary functional mix of buildings because of a much lower density of inhabitants per square metre than compared to case Ydalir. If results per square metre are compared, the reference development performs better, but when the objective is to provide the same amount of housing and educational facilities, a spatial functional unit is not favourable. It is, therefore, vital to think through how results should be presented. Furthermore, this is an argument for not using a spatial functional unit.

A functional unit per capita, as shown in Figure 4.16, is a better way of presenting the results.

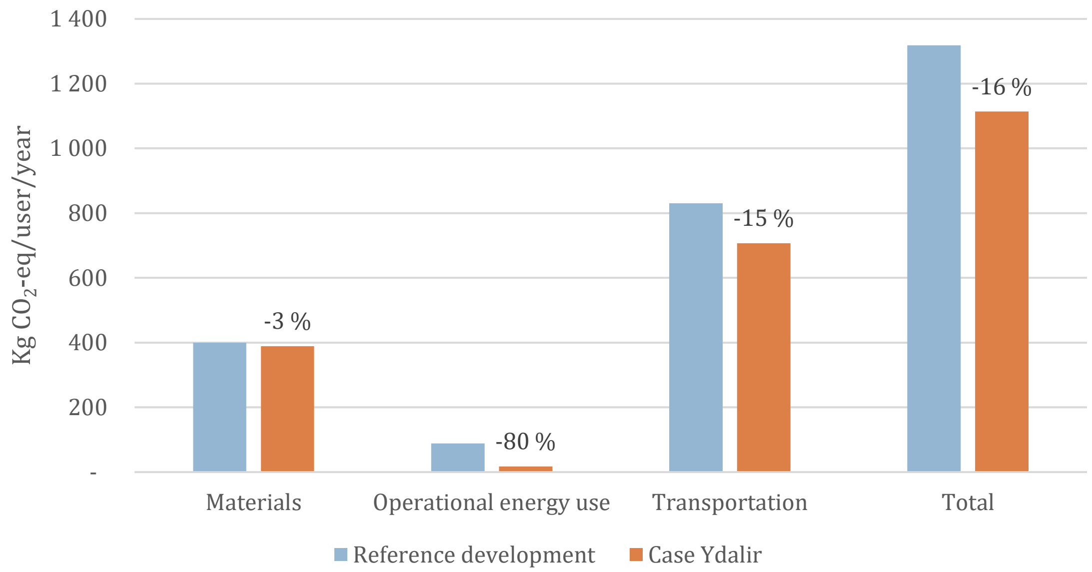


Figure 4.16 Comparison of case Ydalir with a reference development using a per capita functional unit

A per capita functional unit gives the same relative differences between the two developments as shown in Figure 4.14 because both have the same number of inhabitants. Lausselet et al. (2018) also argue for the use of a primary functional unit 'per neighbourhood' and a secondary functional unit 'per person' when conducting LCA on a neighbourhood scale, rather than a functional unit 'per square metre'. Users and employees of the kindergarten and school are not included in Figure 4.16, just inhabitants.

4.1.4. Reaching the goal of being a Zero Emission Neighbourhood

The effort of testing if Ydalir can be a ZEN is presented here. This involves the physical and technical changes of Ydalir explained in Chapter 3.3.2.3. Some of the measures or changes might be a bit optimistic, but for it to be possible to reach zero emission, they are implemented. The result of the improvements of Ydalir is shown in Figure 4.17 and Figure 4.18, resulting in an almost halving of the total emissions. Here, emission intensities according to the European electricity mix has been used for both case Ydalir and this improvement case, to show the effect of solar panels. The improvements involve the use of lowered emission intensities of buildings, use of recycled materials, more solar panels and reduced transportation distances.

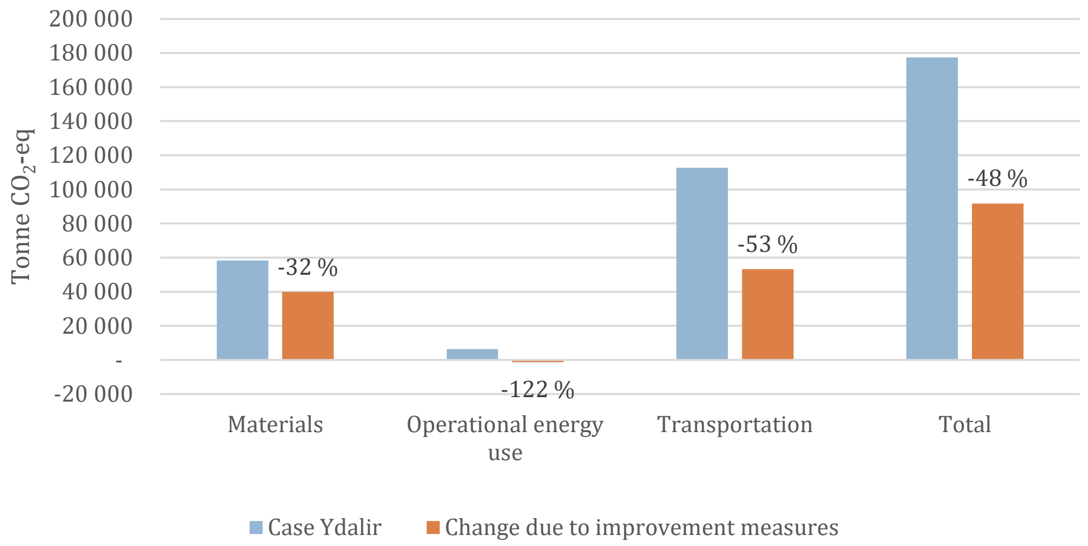


Figure 4.17 Case Ydalir compared to changes due to improvement measures of case Ydalir in an effort of reaching a ZEN target

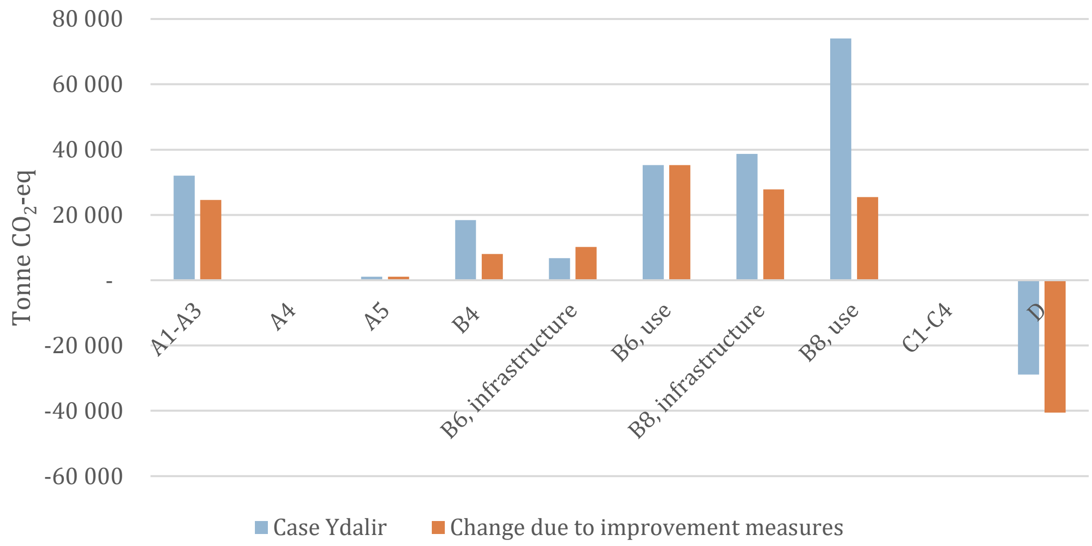


Figure 4.18 Case Ydalir compared to changes due to improvement measures of case Ydalir in an effort of reaching a ZEN target, expressed according to the modules of NS 3720

Emissions from materials are the same as in the assessment with the ZEN-tool, using estimates of the actual buildings that are going to be built at Ydalir. Because of reusing old materials at Ydalir, or using the materials at the end of life of Ydalir in other projects, 20% negative emissions are ascribed to module D, compared to emissions of module A1-A3 of building materials. The benefit of producing local energy is also ascribed to module D.

The solar panels are, in addition to producing more electricity, also causing more emissions for the material module due to more materials needed for the solar panels, which can be seen for module B6, infrastructure. Such a large amount of solar panels will in summertime generate a large surplus of energy from Ydalir. If the local electricity grid can manage this demand because of a large export of electricity from the solar panels, is something that needs to be assessed before the instalment of such an amount of solar panels happens.

For transportation, it is assumed a 50% reduction in travel length. This because the results of a comparison of a reference scenario and the school and kindergarten of Ydalir performed by FutureBuilt showed a reduction of this scale. The 50% reduction used in this improved case Ydalir, is compared to the Elverum travel survey data, not the revised travel survey data for Ydalir used in the assessment of case Ydalir. It is assumed that the reference scenario developed in the FutureBuilt study, which the 50% reduction is towards, is more likely to be similar to the Elverum travel survey data than the Ydalir. That is why the travel survey data of Elverum with a 50% reduction in travel length is used. A 50% reduction in travel length will result in a 50% reduction in emissions. The 50% reduction in travel length seems like a high estimate but is still used since this is an actual assessment of how emissions caused by travelling are for Ydalir. The ultra-low emission path of TØI have also been selected, meaning that a faster change towards using electric cars than what they assume in their trend path will happen. By using the European electricity mix, the emissions from transportation are higher than if using the Norwegian electricity mix.

It is clear that the improvement suggested here do not get Ydalir to the target of a zero emission neighbourhood. If methodological changes also were performed, as the ones in the sensitivity chapter, would Ydalir then become a zero emission neighbourhood? In Figure 4.19 and Figure 4.20, the results of combining both the improvements mentioned above, together with the asymmetrical allocation of emissions from electricity and allocation of transportation between the start and end point of a trip, both explained in Chapter 4.1.2, are shown. The total decrease in emissions from case Ydalir is 86%. These are results of turning premises to benefit Ydalir in an effort of reaching the zero emission target. This is not the way OmrådeLCA normally do assessments of area development.

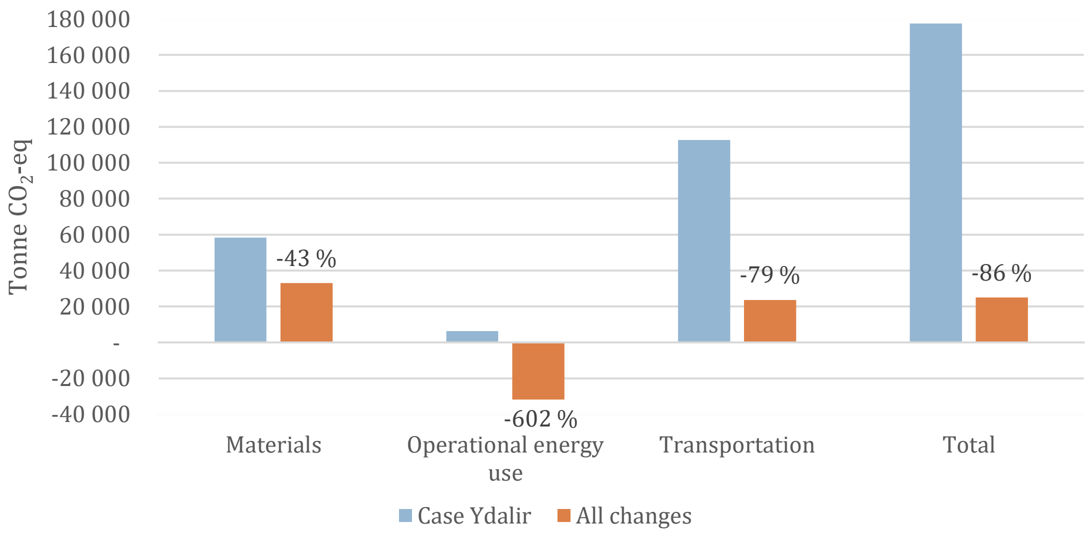


Figure 4.19 Case Ydalir compared to both changes in assessment method and improvement measures in an effort of reaching a ZEN target

The total emissions are considerably reduced but are still not reaching zero emissions. Looking at the results in Figure 4.20, it becomes evident that the two most contributing modules are materials for buildings and materials for vehicles.

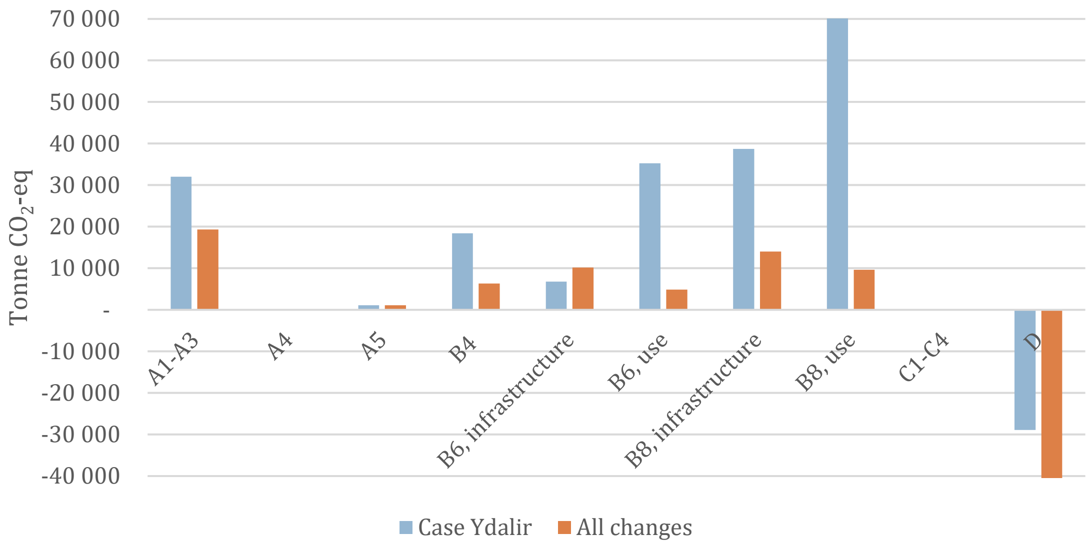


Figure 4.20 Case Ydalir compared to both changes in assessment method and improvement measures in an effort of reaching a ZEN

Emission from materials are already low, and reaching even lower emission intensities for the buildings will be hard. For the materials from vehicles, the emission intensities cannot be lowered by the decision makers of Ydalir. What they can do is using measures causing even less transportation happening by vehicles. All technological development or lowering of emission intensities of OmrådeLCA are ended at year 2050. If this development had continued, the emissions would have decreased even more. Also, the calculation period is set to 60 years. In the studies examined by Lotteau et al. (2015), the lifetime ranges from 50 to 100 years. If the lifetime of the buildings, and then the calculation period in OmrådeLCA were increased, as several of the studies investigated by Lotteau et al. (2015), the resulting emissions would have decreased, because of more time for the solar panels to compensate for the same amount of emissions from buildings even when the solar panels need to be replaced one or two more times because of their lifetime of 30 years.

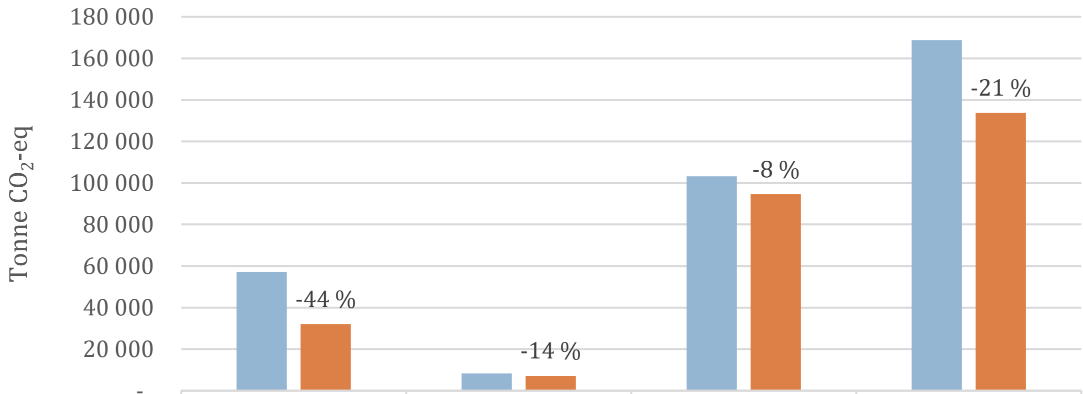
In a further effort of reaching the target of zero emissions, the amount of solar panels has been increased until the target of zero emissions is reached. The result is an increase of 4.4 times as much solar panels as originally planned for Ydalir. This amount of solar panels result in need of 79.2 m^2 of solar panels per housing unit, or a total amount of 79 200 m^2 of solar panels for the whole of Ydalir. This will for sure have implications on the electricity grid. Also, if there will be enough space to install that amount of solar panels at Ydalir is highly uncertain, together with the solar panels being expensive. The row houses might have enough space. The apartments, on the other hand, will probably not. To achieve this amount of solar panels, buildings should be made so that roofs can be used for solar panels and the largest facades should be faced towards south so solar panels at the facades also can be used. Further, solar panels should be mounted on other surfaces as well, like parking garages, sheds, storage rooms and any other available area.

4.2. Comparison of tools

This section presents a comparison of the projected emissions from the assessment of Ydalir according to the two tools, OmrådeLCA and the ZEN-tool. This includes a discussion of what is included in the calculations for each of the tools. The section concludes with a short discussion about the methodological differences in approach between the two tools.

4.2.1. Greenhouse gas emission calculations

As part of this thesis, the emissions that result from the OmrådeLCA assessment of Ydalir have been compared with the results from an assessment of the same case, Ydalir, using the ZEN-tool made by NTNU. The results from the OmrådeLCA and ZEN-tool assessments of Ydalir, explained in Chapter 3.3.3, can be seen in Figure 4.21, according to the main categories: materials (including materials for local energy production); operational energy use; and transportation. In the comparison, the same elements are included for both tools. The total emissions assessed in the ZEN-tool constitute 133 683 tonnes CO_2-eq while in OmrådeLCA they constitute 168 794 tonnes CO_2-eq.



	Materials	Operational energy use	Transportation	Total
OmrådeLCA	57 256	8 302	103 237	168 794
ZEN-tool	32 065	7 110	94 508	133 683

Figure 4.21 Comparison of projected emissions from Ydalir assessed using OmrådeLCA and the ZEN-tool

The two tools do not originally display results in the same way, so this aggregated presentation has been made to compare the results more easily. Furthermore, Figure 4.21 shows the results of an assessment where the same elements are included in both tools, as explained in Chapter 3.3.3. However, there are some system boundary variations between the tools in this respect. The ZEN-tool includes local infrastructure, meaning roads, sidewalks and outside parking lots. This is a strength of the ZEN-tool compared to OmrådeLCA. However, as emissions from infrastructure included in the ZEN-tool account for only 6.8% of total emissions in the assessment of Ydalir, this cannot be considered a very significant weakness of OmrådeLCA. Additionally, the ZEN-tool also includes emissions from local district heating infrastructure, constituting 0.6% of total emissions. OmrådeLCA, including generic data for

Module A5 emissions from loss/assembly at the construction site, and road infrastructure allocated to driving vehicles in the OmrådeLCA assessment, gives an additional 2.4% of emissions that are not included in the comparison.

The difference in calculated emissions from materials is mainly due to quite significant differences in emission intensities per square metre for the buildings used in the two tools. OmrådeLCA, intended for use in an early planning phase, uses key figures for emissions per square metre for the given building category and building standard. The ZEN-tool, on the other hand, uses specific data from LCAs of the planned buildings at Ydalir. The resulting emission intensities per square metre in the ZEN-tool are lower than corresponding calculations for other ZEB buildings. The ZEN-tool, using actual numbers, gives more precise calculations of emissions from materials for this specific case. However, which building components the two assessments include and not differ. E.g. windows are left out of the assessment of the school at Ydalir in the ZEN-tool assessment. Unfortunately, it has not been possible to make a complete comparison of which building components the two tools do and do not include. This can have a significant impact on the resulting emission intensities used in the two tools. The results, giving a 44% decrease in emissions from materials assessed with the ZEN-tool compared to OmrådeLCA, show that the use of average values in OmrådeLCA can render the results unspecific. However, using an additional reduction/increase in the emission intensity in OmrådeLCA in cases where the emission intensity is estimated to be lower or higher than the average, can make OmrådeLCA's results much more accurate.

As stated in the description of the Ydalir development in Chapter 3.3.1, several actions are planned to reduce building related emissions. However, since no specific value is given for these actions, for instance, a percentage reduction, a conservative approach using traditional emission intensities for ZEB buildings was used in OmrådeLCA. The emission intensities used in the ZEN-tool could also, of course, have been used in the OmrådeLCA assessment, but since this comparison was conducted in part to see how OmrådeLCA relates to results given by an assessment on a much later phase of a project, generic emission intensities were used.

The two tools give quite similar answers regarding emissions from operational energy use. Both tools calculate energy demand according to the Passive House standard. The calculations of emissions from local energy production are quite similar too. They both assign net negative emissions to electricity produced with solar panels (due to replacement of grid electricity) and assume that CHP units replace district heating or grid electricity. The difference in the results lies in some small variation in the data used for emission intensities and in production data for solar panels, together with some differences in how estimations and allocations have been performed for the on-site energy production by the CHP units. The difference (14%) in the results regarding emissions from operational energy use between the two tools also has less of a significance given the small share of the total emissions coming from operational energy use (4.9% in the OmrådeLCA assessment of Ydalir, and 5.3% in the ZEN-tool assessment).

Although calculations of transportation demand are based on the same transportation survey data and estimations of the composition of the vehicle fleet in both tools, there are still some differences (8%) in the results for transportation emissions. This is caused by differences in the background data on emissions from vehicle production and direct emissions from vehicle operation. It is hard to conclude on which one of the two tools use the best estimates for emissions from the production and use of vehicles.

4.2.2. Methodology

The main difference in methodology between the two tools relates to their intended use at different project phases. OmrådeLCA is an early phase tool, meaning that generic data are used more extensively, with the opportunity of replacing these with specific data when available, while the ZEN-tool relies mostly on specific data. By using the "early phase" approach of OmrådeLCA, the results displayed in Figure 4.21, show that by using generic data, OmrådeLCA can give quite representative results compared with the results of the ZEN-tool using mostly case-specific data. This accuracy demonstrates the value of using OmrådeLCA in the early phase of a project. Also, OmrådeLCA can be used in the later phases of a project, like the ZEN-tool, and provide results that are just as reliable. It simply requires changing the generic data in OmrådeLCA to case-specific data.

OmrådeLCA possesses several features that the ZEN-tool does not. OmrådeLCA includes opportunities to account for emissions from more building components than the ZEN-tool, together with emissions related to materials for soil stabilization and change in land-use. However, as the case-specific data needed to apply these features in case Ydalir were not available, the potential impact of these additional features was not quantified. OmrådeLCA, made to be applicable to various kinds of developments, also provides greater flexibility in adapting model parameters than the ZEN-tool, which is a more case-specific tool.

Another key difference in the methodology of the two tools is the possibility in OmrådeLCA to compare results with a reference scenario or several other alternatives using the same functional mix of built area. This makes it possible to find not only the alternative with lowest associated emissions for a given area but also the alternative causing the lowest amount of emissions for a given function, e.g. 10 000 inhabitants. Advantages and opportunities that come with the system expansion approach of OmrådeLCA will more thoroughly be discussed in Chapter 4.3.1.

4.3. Strengths and weaknesses of OmrådeLCA

This chapter includes a four-part discussion of the strengths and weaknesses of OmrådeLCA. Part one explains the strengths and advantages of OmrådeLCA with a particular focus on the system expansion approach. Part two elaborates on some limitations. Part three take up some thoughts and reflections made while working with OmrådeLCA and preparing results. Part four examines how the revised version of OmrådeLCA performs in the light of some of the criticism and feedback of the original version of OmrådeLCA provided by Asplan Viak and provides suggestions for further improvements of the tool.

4.3.1. Advantages

OmrådeLCA is a tool used to assess GHG emissions at an early phase of a project. The scenarios the tool investigates are often not planned in detail. Sometimes it has not even been decided if the development are going to go ahead. This puts some limitations on the level of detail the answers from OmrådeLCA can provide, given the data available. However, if case-specific data is available, this can easily be entered into OmrådeLCA. Whether the data is generic or case-specific, there are many things that OmrådeLCA can do and give answers to. A brief discussion of some of these features follows before a more comprehensive discussion of OmrådeLCA's system expansion approach.

The overall purpose of OmrådeLCA is to compare different developments in an area with respect to the amount of GHG they emit for the three categories: materials, operational energy use, and transportation. There are several parameters to choose from that have different options and preferences with respect to background data. This applies to the electricity mix, district heating mixes, allocation/non-allocation of waste heat, dynamic or static calculation approach, building standards, trend paths for the vehicle fleet, composition of residential buildings, travel survey data, and more.

Results can be presented as overall, per square metre, and per capita emissions, and are given according to the different modules specified in NS 3720, as well as split among the different building categories considered. Results can also be shown as annual emissions. Furthermore, OmrådeLCA shows results of sensitivity analyses of key parameters, the location of a project regarding transportation related emissions, the location of a project regarding residential composition, the density of inhabitants, and the electricity mix. Using OmrådeLCA, it is, for example, possible to assess how different densities of residents per area affect emissions and how the location of building mass in a central or less central location affects emissions. A new feature is the possibility of answering which energy solutions are the best for emissions, by including both embodied and mitigated emissions from local energy production.

Another feature of OmrådeLCA is the possibility of indicating if rehabilitation or demolition and rebuilding is the best solution for emissions, given the ability of OmrådeLCA to do calculations for both demolition and refurbishment of buildings.

Emissions calculations are time-dependent in OmrådeLCA, meaning that the start year and analysis period will affect the amount of emissions. Giving the project a starting date in the future will result in reduced emissions since most of the emission intensities within OmrådeLCA are lowered each year, either because of changes in user habits, policy or technology.

The possibility in OmrådeLCA of showing results by different functional units is a strength, substantiated by Wiik et al. (2018b), which confirmed the importance of different functional units. Likewise, Norman et al. (2006) found that the choice of the functional unit when comparing different cases is highly important because of significant variations in emissions per functional unit. The same is shown in Chapter 4.1.3 where the Ydalir development goes from being 16% better than the reference development to be 38% worse when shifting from a per capita, or absolute, to a spatial functional unit. Some studies suggest combining three types of functional units (spatial, per capita and absolute) to overcome the difficulties in defining a unique functional unit. FME ZEN and Lausselet et al. (2018) also suggests the use of a functional unit per capita and suggests that if open areas are a part of the assessment, these should have a spatial functional unit. These conclusions underpin one of the strengths of OmrådeLCA - the ability to present results in all three functional units: absolute, per capita, and per square metre.

Two of the most essential features of OmrådeLCA, as mentioned previously, are the system expansion approach and the ability to use the tool in early phases of development. Several LCAs using the system expansion approach have been found during work on this thesis. However, none have been found for the assessment of areas, neighbourhoods, or even buildings. Therefore, OmrådeLCA might be the first tool to use this approach. The system expansion approach and the early phase of applicability of OmrådeLCA will now be discussed.

In a later part of the construction phase, where a zoning plan has often been approved, a GHG calculation is meant to help achieve emissions that are as low as possible for the planned area. Earlier in the planning process, when OmrådeLCA is intended to be used before the zoning plan is approved, and when it is not known what type and size of buildings will be built on the area, there are other answers required of the GHG assessment. It is then often desirable to be able to compare different options for the area and determine how these impact GHG accounting. OmrådeLCA's system expansion approach can be used to do so. Since there is only one alternative development for Ydalir, it has not been possible to show in practice how this works in the Ydalir assessment.

In a traditional comparison of different development scenarios for an area, a comparison based on the total, per square metre, or per capita emissions of the development can be made. This will result in finding the best development with respect to emissions for that given area. The comparison will not consider the effect these development scenarios have on the surroundings on a broader scale. By scaling each scenario to fulfil the same functional mix of buildings, OmrådeLCA can compare how a development scenario affects the development of new buildings in other places. More holistic answers can be given to the question which development of an area has the least contribution to greenhouse gas emissions.

The system expansion feature of OmrådeLCA has to some degree been used at Ydalir in the development of a reference development. In essence, the question has been asked, 'if Ydalir had not been developed, what would have happened instead?' The result, discussed in Chapter 4.1.3, shows that 16% more emissions would have been the case. By comparing with a reference, or comparing different solutions in OmrådeLCA, it can become evident in an early phase of a project if the planned development is doing better than traditional development, or which development scenario should be chosen if mitigating GHG emissions is the main objective. FME ZEN, which features a comparison of the development to a base case or reference as a key performance indicator, indicates both the usefulness and advantage of OmrådeLCA in doing the same.

The newly added features allowing the calculation of emissions from both land-use change and from materials used in soil stabilisation, have developed OmrådeLCA so that it can achieve more complete results, and also brought it closer to achieving a full consequential approach.

OmrådeLCA does not yet have a full consequential life cycle approach. As stated in Chapter 3.1, a consequential LCA includes the changes happening in the background because of what is happening in the foreground. It could be argued that whatever is happening in one development in an area, will not affect background processes like the electricity mix, the percentage of electric cars, or the demand for timber in construction. However, this can be the case for marginal technologies or products. For example, if an increased demand for concrete is put on the supplier of concrete, resulting in the supplier delivering European instead of Norwegian concrete, this will affect the background system. Therefore, it is more accurate to say that OmrådeLCA takes an attributional approach with a system expansion that is closing in on a full consequential approach.

4.3.2. Limitations and weaknesses

As already partly discussed, OmrådeLCA has some limitations and deficiencies. These, and others will now be examined.

OmrådeLCA operates on the basis of several assumptions and uses some simplifications. Not including emissions from deconstruction at the end of life of buildings is one of these. In the upgraded version of OmrådeLCA, these modules are included in the calculations. However, generic data for emission intensities for these modules need to be found and installed in the tool to obtain emission results. However, Lotteau et al. (2015) found the deconstruction phase to be relatively insignificant.

OmrådeLCA does not include calculations of neighbourhood outdoor spaces and area infrastructure, such as roads and parking spaces. Borgnes (2018) found these two categories constituted 2.3% of the total in her study; the Ydalir assessment with the ZEN-tool returned 6.8%. These are relatively low contributions and do not significantly affect the quality of assessments made using OmrådeLCA. Also, as discussed in 4.2.1, OmrådeLCA is intended to be used at an early stage where information on the size and amount of such infrastructure will rarely be available. In addition, if it was to be included in OmrådeLCA, it must also be accounted for in the alternative location of the built area in order to fulfil the functional mix, which will be challenging to estimate with sufficient accuracy.

Emissions from transportation are only included for the building categories 'offices' and 'residential buildings'. This is a limitation further discussed in Chapter 4.3.3.

Travel surveys are calculations of yesterday's travel patterns, not future travel patterns, which is required for OmrådeLCA's calculations. This is not only a limitation for OmrådeLCA, but also for any tool trying to do an assessment of the future. The ZEN-tool, using the same travel survey data, has the same limitations. One uncertainty regarding transportation is technological development, both regarding the types of transportation and emissions from these. Scenarios for these uncertainties are included in OmrådeLCA. Also, every calculation of anything in the future relies on assumptions. Therefore, OmrådeLCA uses several development patterns for the composition of the vehicle fleet to show the results of different scenarios for the future.

Usually, an assessment of an area has a calculation period of 60 years in OmrådeLCA. For technology development or improvements of values regarding emission intensities, these all stop at the year 2050, just halfway through the calculations. This is a limitation that causes the resulting emissions calculated in OmrådeLCA to be higher than they would have been if progress had gone on beyond the year 2050.

4.3.3. Reflections on the use of OmrådeLCA

There are several essential aspects of performing an LCA of an area that becomes clear when looking at the results obtained with OmrådeLCA, both in the specific case of Ydalir, but also more generally. An elaboration of these follows.

As of now, emissions from transportation in OmrådeLCA are only calculated for the two building categories, residential and offices. However, the tool has been developed so it is ready to calculate emissions from all building categories. The problem lies in the gathering of data for distance and means of transportation for each building category. The travel survey data used in OmrådeLCA for transportation of inhabitants apply to the total transportation impacts of one person per day. Thus, transportation to and from buildings, e.g. kindergarten and school, and all other building categories for that matter is already accounted for. In this way, if transportation from other building categories is included, there will be double counting of emissions from transportation. E.g., the trip to and from work will be allocated to the dwelling, resulting in no emissions allocated to the workplace. If those who do an LCA of the workplace use the same calculation method, they will allocate all transportation to the workplace, and none to the dwelling, resulting in double counting.

In the case of Ydalir, only transportation from inhabitants is calculated, and no transportation is associated with the kindergarten and school for people outside Ydalir. However, this extra emission constitutes a small amount of the total emissions for Ydalir, since the kindergarten and school constitute a small part of the total number of square metres at Ydalir. It can also be argued that since all transportation for each inhabitant of Ydalir is already accounted for, including transportation to work, kindergarten, school and more, there should be no need to add transportation calculations for the school and kindergarten. However, if there were no dwellings in Ydalir, only a school and kindergarten, should no emissions from transportation for these building categories at Ydalir be included?

A possible solution to the double counting issue and the question of including other building types could be to allocate emissions equally between the start- and end point of a trip, which is an option within OmrådeLCA. In other words, halve the emissions and then avoid double counting. However, then there is a need for data both regarding travel distances and means of transportation for each building category. This might, to some degree, be possible to obtain from the travel survey data used. The travel survey data differentiate between different kinds of trips, e.g. work related, school, care and procurement. Whether it is possible to split up the travel survey data into the different building categories of OmrådeLCA is, on the other hand, hard to say. NS 3720 states that emissions shall not be allocated between the start and end point of a trip.

When performing an LCA of GHG emissions, some factors and assumptions chosen are more critical for the resulting emissions than others. For OmrådeLCA this especially applies to where the alternative location of buildings will be. This because of the significant variations in emissions depending on the choice of locations or travel survey data, as seen in Figure

4.10, varying from a 15% reduction to a 63% increase from case Ydalir in emissions from transportation. As transportation is the most critical contributor to overall emissions from a neighbourhood assessment, it becomes clear that the location and travel survey data assumptions are vital. In the specific case of Ydalir, where travel survey data of an average city of the size of Elverum were used as a basis, and then adapted in accordance with a study on the effect of changes in parking availability, would it have been better to use travel survey data from another area? For instance, would the results have been more correct using travel survey data from Oslo city centre, assuming that all the measures planned at Ydalir will result in the transportation of people in a manner similar to that found in a city centre like Oslo?

Another assumption regarding the location of the alternative development area is the change in share of different dwelling types because of another development pattern for this area. In an assessment using OmrådeLCA of Landbrukskvartalet, in Oslo city, Asplan Viak was criticised because of this use of different housing compositions for different areas. In this case, Asplan Viak compared three different development scenarios against a reference scenario, which was continued use of Landbrukskvartalet as it is today. The critique of this assessment was that all the different scenarios should have had the same types of dwellings and the number of square metres both inside Landbrukskvartalet and for the alternative location. The answer to this critique was that one of the assumptions for the calculations is that when a square metre of a dwelling gets cheaper, as it does further away from the city, the consumer buys more square metres of dwelling, resulting in more square metres per inhabitant in a more rural area than in a more urban area. Thus, when one buys an apartment in the city centre, it is more expensive than outside the centre, resulting in fewer square metres of apartment bought. Also, it is assumed that a buyer of a dwelling substitutes smaller housing near a workplace in the city centre with larger housing outside the city centre and more considerable transportation costs.

The decision about which emission intensity for electricity consumption to use in an assessment has considerable influence on how significant emissions will be from both operational energy use and transportation. There is no straightforward way of answering which emission intensity to use. Following NS 3720, one should provide results for two consumption mixes, e.g. Norwegian and European, which was the approach taken in this thesis. However, for this thesis, as shown in the sensitivity analysis of the electricity mix in Chapter 4.1.2, the emissions do not vary as much as perhaps predicted. The reason, as mentioned in the same chapter, is because of the large amount of local energy produced by solar panels replacing grid electricity. If the emission intensity of the electricity increases, so does the amount of emissions mitigated by the solar panels.

Some aspects will always provide reductions in emissions in OmrådeLCA. One such important factor is that the development scenarios usually only consist of apartments, while in order to fulfil the functional mix in the reference scenario, the area for the alternative development consists of a combination of apartments, row houses and single-unit dwellings.

Since the row houses and single-unit dwellings both have more square metres per resident than apartments, the total area of accommodation in the reference scenario will always be higher than that in the development scenario. The total amount of energy and materials needed decreases for every square metre not being built; therefore, this will be a factor that always turns out positively for the development scenario(s).

Another factor that generally results in reductions in emissions compared to a reference is area development close to the city centre due to reduced transportation distances for inhabitants. This, together with the previously mentioned effect of higher prices per square metre closer to a city centre, results in less square metre per inhabitant. An essential aspect of densification not considered is the change in the quality of life, or any other quality aspects that densification can affect. In an OmrådeLCA assessment, qualitative differences in scenarios other than GHG emissions are not investigated, because this is not the purpose of OmrådeLCA.

4.3.4. Revised versus original version

Some of the criticisms of the original version of OmrådeLCA concerned how results were presented. The revised version of OmrådeLCA presents results in a variety of ways and shows all choices and assumptions in one place for ease of use and interpretation. As the revised version of OmrådeLCA has not yet been used in any projects, there is no feedback on how it performs in relation to the earlier criticisms. It is still likely that by providing a transparent presentation of a variety of results and a straightforward and understandable presentation of what has been done within the tool, the revised version performs better than previously.

Regarding the other suggestions for improvements to OmrådeLCA, stated in Chapter 3.2.2, covering the thesis prior to this thesis, all have been implemented. The modular structure of NS 3720 has been implemented both in how calculations are performed and how results are displayed. To improve and raise the quality of the tool a number of measures have been taken: the inclusion of more energy infrastructure; the improvement of data for transportation; and evaluation of underlying data, particularly for materials. All of these measures help to improve the revised version of OmrådeLCA. The same goes for the inclusion of emissions caused both by the change of land-use and by materials in soil stabilisation.

To verify and demonstrate the effects of the improvements to the original version of OmrådeLCA, it would have been beneficial to show a comparison of results from Ydalir with the original and revised versions of OmrådeLCA. However, as explained in the Methodology chapter, the original versions of OmrådeLCA were developed for one specific project, and then further developed to be applicable for three more projects. This resulted in OmrådeLCA being case-specific for each of the projects. The original version of the tool needed the audit work done in this thesis to make it possible to use the tool more generally in different kinds of projects, e.g. in a project like Ydalir. This is due to the need to have the flexibility to choose different energy solutions and calculate material emissions according to different building standards and more. This is the reason for not being able to show a comparison of results between the original and revised versions of OmrådeLCA.

The strength of the revised version of OmrådeLCA, as in the original version, lies in its ability to be used in the early assessment phase of a project. It can, at the very start of a project answer which solutions or scenarios are the best regarding emissions, not only by comparing different solutions but also when they are all fulfilling the same functional mix. The revised version of OmrådeLCA can now perform assessments of developments at a much later phase than it previously could, as it allows greater possibilities for entering case-specific data, such as several different local energy systems or a modular structure for materials and more. The revised version still has some limitations, especially regarding transportation calculations for building categories other than residential and offices.

4.4. Strengths and weaknesses of this thesis

Both the improvements of OmrådeLCA and the evaluation of OmrådeLCA are discussed in this chapter. How OmrådeLCA performs as a tool is not discussed here, as it is discussed in previous chapters.

One of the key strengths of this thesis has been the comparison with another tool, designed to be used at a much later project phase. It has also been possible to perform an assessment of the same case that was assessed using this alternative tool, where details and data related to the analysis and area have been available. By comparing the results and methodology of different tools, OmrådeLCA can be improved in a better way, and more reliable results obtained. The comparison also makes it easier to verify that the calculations within OmrådeLCA are correct. The ability to draw comparisons with another tool has made it possible to improve and evaluate OmrådeLCA more thoroughly and profoundly than would otherwise have been possible.

Another strength of this thesis is the close connection to the standard 'Method for greenhouse gas calculations for buildings', NS 3720 (Standard Norge, 2018), which has always been considered whenever improvements or choices have been taken. This has resulted in the structure of the tool following the modular structure of the standard. It has also resulted in a number of other features following the standard: electricity emission intensities, scenarios, allocations of transportation, district heating, and many other features.

In revising the tool, it has been possible to continually make changes to assumptions and data, to reveal both errors and insufficiencies. In this way, it has been possible to improve them, limit the sources of error in the tool, and improve the reliability of the results.

One uncertainty in this thesis is the literature investigated. First, this field of study, environmental assessment of neighbourhoods, is quite new and immature. Therefore, there have not been many studies carried out, resulting in difficulties in finding relevant literature. Second, the literature carried out is very distinctive and diverse. Because of the complexity and lack of frameworks for performing an LCA of a neighbourhood, different studies approach the LCA of neighbourhoods in quite different ways. There is a lack of consistency in system boundaries, as well as goal and scope. This makes it hard to compare the literature, but also the results of OmrådeLCA with the literature.

The database used for estimating emissions from materials, used for both the separating of the combined modules A1-A3 + B4 into two, and the comparison of TEK 10 and ZEB, is not that large. This results in few buildings to compare with, leading to uncertainties in the estimates for the separation of modules and comparison of the building standards. However, the database and the belonging tool is a good way of making these comparisons because of the opportunity to include the same building components and assumptions for both building categories in a comparison. The database will grow larger in time, and will, therefore, diminish the uncertainty about the emissions estimated for buildings in OmrådeLCA.

The most decisive weakness in the revised version of OmrådeLCA lies in the calculations of emissions from transportation. The tool is prepared for including calculations of emissions from all building categories, but as of now only includes these for inhabitants and workers at offices. The reason is that the travel survey data within the tool applies to all travel by a person on an average day, making it hard to divide between all the building categories. These problems are applicable to the ZEN-tool as well, showing the difficulties in solving these problems. For the use of OmrådeLCA in the case of Ydalir, this is not a significant uncertainty given the fact that Ydalir consists mostly of residences. Still, the lack of emissions from transportation generated by the school and kindergarten is a weakness of this thesis.

There are also considerable uncertainties in the development of the travel survey data for Ydalir. Since the measures planned at Ydalir will in all likelihood cause a reduction in the use of cars, an adjustment to the travel survey data of Elverum had to be performed. The uncertainty lies in how this adjustment was performed. A report from TØI (Christiansen et al., 2015) that deals with distribution effects because of reduced parking availabilities in cities or districts were used as the basis for the adjustment of the travel survey data. It is uncertain if the effects of this report, which applies to cities, are also representative of a more rural area such as Elverum. In addition, several of the other measures planned at Ydalir were left out of the adjustment of the travel survey data because of struggles finding literature stating the effect of these measures. If they were included, all the different effects could not have been added together because one measure likely would have had an impact on the effect of other measures. A possible solution for this, and a way of assessing the total transportation emissions of inhabitants, users and workers at Ydalir together with some of the planned measures is a regression analysis of transportation. This is a time- and data-consuming measure that was suggested by representatives of TØI. Because of this uncertainty surrounding the adjustment of the travel survey data, a conservative approach has been used, causing the resulting emission calculations to likely be higher than they actually will be.

4.5. Recommendations for further work

The recommendations for further work are split into three parts. The first part deals with the further development of OmrådeLCA. The second part concerns Ydalir and what should be done to achieve a zero emissions target. The last part concerns general recommendations and policy implications.

OmrådeLCA

As of now, the calculations for an entire development in OmrådeLCA start at one given year. It is not possible to allow the development of the area to happen over time in several construction phases. To develop OmrådeLCA further, the possibility of allowing the development to be staged over several construction phases could be implemented. This will, however, be a very time-consuming implementation. For now, it is possible to just run OmrådeLCA one time for each construction phase, changing the start year for the development each time, and then add up all the results.

A similar improvement is to make it possible to have a scenario within OmrådeLCA that keeps a given area as it is today, but then allows the implementation of a refurbishment/upgrading of the buildings of this area at a given year in the future. This would make it possible to compare demolishing and then building new, with keeping it as it is today, but where a refurbishment is needed because of the degradation of the old buildings. A possible solution, if using OmrådeLCA as it is today, is letting B4 be a part of the refurbishment scenario, and then letting these emissions happen at a given year.

Not all modules or aspects within OmrådeLCA take into account improvements that come with time, for instance, due to technological improvements. This applies to both direct and indirect emission intensities of public transportation and the development of the vehicle fleet after the year 2050. It also applies to emissions from module B4 of materials. The emission intensities of module B4 are estimated based on how technology and production are today. It is reasonable to believe that the emission intensities of B4 will fall in the future when these emissions are occurring. Therefore, the possibility of choosing an improved emission intensity of B4 could be implemented within OmrådeLCA.

The new key report from TØI containing national travel survey data for 2018 will be finished during 2019. This report is likely to publish results in the same way as the previous report that was used to inform OmrådeLCA. Given this, either of the following should be performed: dividing the results of the current travel survey data into the different building types; or devising a new way of calculating means of transportation and daily travel length for each building category. This will help OmrådeLCA include more of the emissions caused by a neighbourhood. The first suggestion of splitting the results of the current travel survey data or from the forthcoming report coming seems like the best solution.

Ydalir

The results in this assessment of Ydalir clearly show that it will not become a ZEN according to the definition of a ZEN given in this report. Therefore, it is recommended that the developers of Ydalir should look further into measures to reduce emissions. Possible actions are mentioned in Chapter 3.3.2.3. Also, to get a better assessment of the emissions from transportation at Ydalir, it is suggested that a regression analysis should be undertaken of the transportation, where consultation with TØI would be beneficial.

General

To improve the strength of the functional unit per capita, a thorough evaluation of what the definition of a user is should be carried out. Should the inhabitant of an apartment have the same importance as the worker in an office, or a child going to school? A definition of a user should be defined for all building categories, so it is possible to add all users together and find an aggregated per capita value.

The FME ZEN obtained a good understanding of emissions from buildings and energy infrastructure from the previous FME ZEB. What has become apparent during the assessment of Ydalir in this thesis is that transportation is both the most significant contributor to emissions and also an element that it is hard to assess. Therefore, FME ZEN, and also consultants, should put their primary focus on lowering emissions from transportation and finding the best possible means of assessing the emissions caused by transportation. Lowering the emissions from transportation is challenging because choices taken in construction projects do not have a direct impact on transportation, beyond parking capacity. But showing how much impact transportation has can perhaps provide a stronger rationale for tightening access to parking.

5. Conclusion

OmrådeLCA is a tool used to assess greenhouse gas (GHG) emissions of area development in an early planning phase of building projects. The tool uses a system expansion approach to create a reference for assessing the GHG performance of alternative development scenarios for an area. OmrådeLCA distinguishes between GHG emissions from the use of building materials, operational energy use and transportation.

OmrådeLCA has, in this thesis, been revised from its original version, and used to assess the GHG performance of the Zero Emission Neighbourhood (ZEN) Ydalir, located right outside Elverum city, Norway. The results found that GHG emissions from transportation contribute to 64% of total GHG emissions, while building materials and operational energy use account for 35% and 2%, respectively. The sensitivity analyses performed show that parameters related to transportation have the greatest impact on results. This underscores the importance of conducting thorough analyses of factors affecting transportation in order to achieve representative results.

The results show that Ydalir faces substantial challenges in achieving the definition of a zero emission neighbourhood used in this thesis. Considerable efforts must be made towards reducing the GHG emissions from transportation, in addition to establish local energy production that can compensate for GHG emission from materials and transportation, as well as operational energy use. This is a challenge not only faced by Ydalir, but all areas, neighbourhoods or buildings trying to reach a net zero emission target over its lifecycle.

The resemblance of results and methodological choices from the literature reviewed in this thesis and OmrådeLCA, support the strength of results and methodology of OmrådeLCA. The same applies to the approach OmrådeLCA takes towards using methods and parameters from the national standard NS 3720.

The ZEN-tool, also used to assess Ydalir, yields results similar to OmrådeLCA for the different modules, even though the ZEN-tool is intended for a much later phase of a project than OmrådeLCA, and uses project-specific data to a much greater extent. The difference in calculated total emissions for the two tools is 21%, where the ZEN-tool yields the lowest values, mainly due to the fact that emission intensities used for materials in buildings in the ZEN-tool assessment are much lower than values used for zero emission buildings (ZEB) in the OmrådeLCA assessment. This shows that OmrådeLCA can yield results that are representative for the specific project assessed, even though the assessment is performed in an early planning phase.

One of the essential features of OmrådeLCA is the system expansion approach where different development scenarios are scaled, so each scenario fulfils the same functional mix of buildings. In doing so, OmrådeLCA can compare how a development scenario affects the development of new buildings in other areas. More holistic answers can be given for which development of an area that has the least contribution to GHG emissions.

Using the system expansion approach in OmrådeLCA, it is possible to understand what the resulting emissions would become if the development of the given area would not have happened. Then it is possible to see if the development performs better or worse compared to this reference. For the Ydalir assessment, this reference scenario follows traditional development patterns and is set to be placed in an average location within Elverum municipality. The total calculated emissions for case Ydalir are 16% lower than the reference's GHG emissions. This shows that even though Ydalir is a highly ambitious development project when it comes to GHG emissions, the resulting reductions compared to a traditional development, are not especially significant. This is partly due to conservative estimates for lowered transportation needs by cars, but also decreased reductions in emissions due to the use of a Norwegian electricity mix. By using a Norwegian electricity mix, the effects of reduced electricity demand and more local electricity production are not that significant due to a low associated emission intensity of the Norwegian electricity mix. When shifting to a European electricity mix, the difference in the resulting GHG emissions between the reference and case Ydalir increases from 16% to 39%.

Several improvements have been implemented in the revision of the original version of OmrådeLCA. Including, among other measures, calculating emissions from materials per module according to NS 3720, calculating all emissions on a per year basis, showing more results, more transparently, and implementing functionality for performing sensitivity analyses. Compared to the original version, the revised version of OmrådeLCA provides more transparent results and more features and alternatives for the user to choose among. The new improvements will ease the use and increase the range of application of OmrådeLCA. There are still a lot of measures and calculations OmrådeLCA can benefit from implementing. On the basis of the work in this thesis, specific recommendations are offered, especially concerning further developing the calculations of transportation distances and modes for all the building categories, which are a part of OmrådeLCA. This will likely imply a thorough examination of the new national travel survey, expected released during the summer/fall of 2019.

References

ASKER MUNICIPALITY 2017. Standard rom- og funksjonsprogram for skoleanlegg - 2017.

BASTOS, J., BATTERMAN, S. A. & FREIRE, F. 2016. Significance of mobility in the life-cycle assessment of buildings. *Building Research & Information,* 44**,** 376-393.

BORG, A. & FUGLSETH, M. 2018a. Klimagassberegninger områdeutvikling hopsfossen.

BORG, A. & FUGLSETH, M. 2018b. Utslippsberegninger hopsfossen. *In:* VIAK, A. (ed.).

BORGNES, V. 2018. *Scenario assessment in lca for zero emission neighbourhoods.* master thesis, Norwegian University of Science and Technology.

BRANDER, M. 2012. Summary paper | substitution: A problem with current life cycle assessment standards, . *In:* ECOMETRICA (ed.). Ecometrica.

BUGGE, J. T. n.d. *One click lca* [Online]. Available: https://www.symetri.no/produkter-og-loesninger/produkter/one-click-lca/ [Accessed 29.05. 2019].

BUGGE, L. & JØRGENSEN, P. F. 2017. Konseptutredning energi. *Masterplan del 1 Vedlegg 3.*

CHRISTIANSEN, P., ENGEBRETSEN, Ø. & HANSSEN, J. U. 2015. Parkeringstilbud ved bolig og arbeidsplass.

CIRAIG. 2016. *Wat is dynco2* [Online]. Available: http://www.ciraig.org/en/dynco2.php [Accessed 24.11. 2018].

CONSEQUENTIAL-LCA. 2015. *Why and when?* [Online]. Available: https://consequential-lca.org/clca/why-and-when/ [Accessed 01.12. 2018].

CONSEQUENTIAL-LCA. 2017. *The functional unit* [Online]. Available: https://consequential-lca.org/clca/the-functional-unit/ [Accessed 20.11. 2018].

CONTEXT AS 2017a. Ydalir barnehage klimagassberegning.

CONTEXT AS 2017b. Ydalir skole klimagassberegning.

CONTEXT AS 2018a. Klimagassregnskap ydalir barnehage.

CONTEXT AS 2018b. Klimagassregnskap ydalir skole.

DAHLSTRØM, O. 2018a. Energisystem.

DAHLSTRØM, O. 2018b. Information about data for solar panels. *In:* EMAIL CORRESPONDENCE (ed.).

DAHLSTRØM, O. 2018c. Klimagassberegninger laksevågneset. *In:* VIAK, A. (ed.).

DAHLSTRØM, O. 11.03.2019 2019. *RE: Information on soil stabilisation.* Type to EMAIL CORRESPONDENCE.

DAHLSTRØM, O. & SOLLI, C. 2018. Klimagassberegning av utviklingsscenarioer.

DAHLSTRØM, O., SØRNES, K., ERIKSEN, S. T. & HERTWICH, E. G. 2012. Life cycle assessment of a single-family residence built to either conventional- or passive house standard *Energy and Buildings,* 54**,** 470-479.

DIREKTORATET FOR BYGGKVALITET. 2011. *Byggteknisk forskrift (tek10)* [Online]. Available: https://dibk.no/byggeregler/tek/ [Accessed 29.05. 2019].

DIREKTORATET FOR BYGGKVALITET. 2017. *Byggteknisk forskrift (tek17)* [Online]. Available: https://dibk.no/byggereglene/byggteknisk-forskrift-tek17/ [Accessed 04.05. 2019].

ECOINVENT. n.d.-a. *Ecoinvent version 3.5* [Online]. Available: https://www.ecoinvent.org/ [Accessed 19.12. 2018].

ECOINVENT. n.d.-b. *Ecoinvent version 3.5* [Online]. Available: https://www.ecoinvent.org/ [Accessed 24.11. 2018].

ELVERUM TOMTESELSKAP AS 2017. Konseptutredning ydalir – sluttrapport til enova.

ELVERUM VEKST 2017a. Ydalir masterplan del 1 - versjon 2.

ELVERUM VEKST 2017b. Ydalir masterplan del 2 - ambisjoner og krav.

EPD-NORGE.NO. *Hva er epd?* [Online]. Available: https://www.epd-norge.no/hva-er-en-epd/ [Accessed 21.12. 2018].

EUROPEAN COMMISSION JOINT RESEARCH CENTRE INSTITUTE FOR ENVIRONMENT AND SUSTAINABILITY 2010. International reference life cycle data system (ilcd) handbook.

EUROPEAN ENVIRONMENT AGENCY 2018. *Trends and projections in europe 2018, tracking progress towards europe's climate and energy targets.*

FRØYEN, Y. K. 2019. Information on transportation and effects of different measures. *In:* EMAIL CORRESPONDENCE (ed.).

FUFA, S. M., SCHLANBUSCH, R. D., SØRNES, K., INMAN, M. & ANDRESEN, I. 2016. A norwegian zeb definition guideline. *ZEB Project report no 29.*

FUGLSETH, M. 2019. Bygglca.

FUTUREBUILT. 2016. *Om oss* [Online]. Available: https://www.futurebuilt.no/Om-oss [Accessed 24.11. 2018].

HAMMERVOLD, J. 2015. Metode for beregning av co2-utslipp knyttet til arealbeslag ved vegbygging.

HERFRAY, G. 2011. *Contribution à l'évaluation des impacts environnementaux des quartiers.* École Nationale Supérieure des Mines de Paris.

HERFRAY, G., VORGER, E. & PEUPORTIER, B. 2011. Life cycle assessment applied to urban settlements and urban morphology studies.

HJORTHOL, R., ENGEBRETSEN, Ø. & UTENG, T. P. 2014. Den nasjonale reisevaneundersøkelsen 2013/14 - nøkkelrapport.

HOFSTAD, K. 2018. *Norsk standard* [Online]. Available: https://snl.no/Norsk_Standard [Accessed 10.11. 2018].

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION 2006a. Environmental management - life cycle assessment - principles and framework (iso 14040:2006).

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION 2006b. Iso 14044:2006, environmental management -- life cycle assessment -- requirements and guidelines.

KENTON, W. 2018. *Input-output analysis* [Online]. Available: https://www.investopedia.com/terms/i/input-output-analysis.asp [Accessed 15.12. 2018].

KRISTJANSDOTTIR, T. F., HOULIHAN-WIBERG, A., ANDRESEN, I., GEORGES, L., HEEREN, N., GOOD, C. S. & BRATTEBØB, H. 2018. Is a net life cycle balance for energy and materials achievable for a zero emission single-family building in norway? *Energy and Buildings,* 168**,** 457.469.

LARSEN, H. N., BORG, A. & TØNNESEN, J. 2018. Energi og miljø - fagutredning.

LAUSSELET, C., BORGNES, V. & BRATTEBØ, H. 2018. Life-cycle assessment methodology to assess zero, emission neighbourhood concept.

LAUSSELET, C., ELLINGSEN, L. A. W., STRØMMAN, A. & BRATTEBØ, H. 2019. A life-cycle assessment model for zero emission neighborhoods, in a review process in the journal of industrial ecology *ZEN report,* 12.

LEVASSEUR, A., LESAGE, P., MARGNI, M., DESCHÊNES, L. & SAMSON, R. 2010. Considering time in lca: Dynamic lca and its application to global warming impact assessments. *Environmental Science & Technology,* 44**,** 3169-3174.

LIEN, K. M. 2013. Co2 emissions from biofuels and district heating in zero emission buildings (zeb).

LIEN, K. M. 04.04.2019 2018. *RE: Information on calcuations of co2 emissions from chp.* Type to PERSONAL CONTACT.

LILLEBERG, A. 01.04.2019 2019. *RE: Information about volter chp units.* Type to EMAIL CORRESPONDENCE.

LOISEAU, E., JUNQUA, G., ROUX, P. & BELLON-MAUREL, V. 2012. Environmental assessment of a territory: An overview of existing tools and methods. *Journal of Environmental Management,* 112**,** 213-225.

LOTTEAU, M., LOUBET, P., POUSSE, M., DUFRASNES, E. & SONNEMANN, G. 2015. Critical review of life cycle assessment (lca) for the built environment at the neighborhood scale. *Building and Environment,* 93**,** 165-178.

LOVDATA 2004. Forskrift om vedtekt til plbl, elverum.

NHP. n.d. *Om nhp* [Online]. Available: http://www.byggemiljo.no/om-nhp-nettverket-2/ [Accessed 10.06. 2019].

NORCONSULT INFORMASJONSSYSTEMER AS. n.d. *Norsk prisbok* [Online]. Available: http://www.norskprisbok.no/WhatIsNP.aspx [Accessed 02.06. 2019].

NORMAN, J., MACLEAN, H. & KENNEDY, C. 2006. Comparing high and low residential density: Life-cycle analysis of energy use and greenhouse gas emissions. *Journal of Urban Planning and Development,* 132.

NORSK FJERNVARME. 2018. *Norsk fjernvarme* [Online]. Available: https://www.fjernkontrollen.no/ [Accessed 06.03. 2019].

NSB-KONSERNET 2015. Årsrapport 2015, vilje til å lykkes.

OTTERLEI, E. T. 2014. Klimaregnskap for fjernvarme

PEUPORTIER, B. & ROUX, C. 2016. Eco-design of urban sttlements using lca. *Conference: LCA [avniR] Conf. 2013*.

RESCH, E. & ANDRESEN, I. 2018. A database tool for systematic analysis of embodied emissions in buildings and neighbourhoods. *Buildings*.

RUTER 2016. Årsrapport 2016.

SELVIG, E., ENLID, E. & ARGE, N. 2014. Regneregler for klimagassberegninger i future built, bygg og områder.

SKULLESTAD, J. L. 2018. Emission intensities for reference buildings gathered from klimagassregnskap.

SOLID WORKS. n.d. *Appendix b - a deeper look at the lca process* [Online]. Available: http://www.solidworks.com/sustainability/sustainable-design-guide/lca-detailed-overview.htm [Accessed 20.11. 2018].

SOLLI, C., NORDBY, A. S., DAHLSTRØM, O., IVERSEN, M. S. & FUGLSETH, M. 2016. Byggematerialer, tid og klima.

STANDARD NORGE 2006. Miljøstyring, livsløpsvurderinger, prinsipper og rammeverk. *In:* NORGE, S. (ed.) *NS-EN ISO 14040:2006.*

STANDARD NORGE 2011. Sustainability of construction, assessment of environmental performane of buildings, calculation method. *In:* NORGE, S. (ed.) *NS-EN 15978:2011.*

STANDARD NORGE 2018. Metode for klimagassberegninger for bygninger. *In:* NORGE, S. (ed.) *NS 3720:2018.*

STATISTISK SENTRALBYRÅ. 2013. *Folke-og boligtellingen, boliger (oppført), 19. November 2011* [Online]. Available: https://www.ssb.no/befolkning/statistikker/fobbolig/hvert-10-aar/2013-02-26 [Accessed 02.03. 2019].

STATISTISK SENTRALBYRÅ. 2019. *Boliger, etter bygningstype og bruksareal (k) 2007 - 2019* [Online]. Available: https://www.ssb.no/statbank/table/06513/ [Accessed 02.02. 2019].

STATSBYGG AND CIVITAS 2012. Klimagassregnskap.No/versjon 4.

STEPHAN, A., CRAWFORD, R. H. & MYTTENAERE, K. 2013. Multi-scale life cycle energy analysis of a low-density suburban neighbourhood in melbourne, australia. *Building and Environment,* 68**,** 35-49.

STRØMMAN, A. H. 2010. Methodological essentials of life cycle assessment.

SYTATSBYGG. n.d. *Om oss* [Online]. Available: https://www.statsbygg.no/Om-Statsbygg/ [Accessed 30.05. 2019].

TEGN_3. n.d. *Tegn_3* [Online]. Available: https://www.tegn3.no/ [Accessed 05.06. 2019].

THE NORWEGIAN EPD FOUNDATION. n.d. *Epd-norge.No* [Online]. Available: https://www.epd-norge.no/?lang=no_NO [Accessed 29.05. 2019].

THE RESEARCH CENTRE ON ZERO EMISSION BUILDINGS. n.d. *Om zeb* [Online]. Available: https://www.zeb.no/index.php/no/om-zeb/about-the-zeb-centre [Accessed 01.12. 2018].

TØI. n.d. *Transportøkonomisk institutt (tøi)* [Online]. Available: https://www.toi.no/om-toi/category6.html [Accessed 20.12. 2018].

VOLTER 2018. Datasheet volter 40 indorr.

WIIK, M. K., FUFA, S. M., KRISTJANSDOTTIR, T. & ANDRESEN, I. 2018a. Lessons learnt from embodied ghg emission calculations in zero emission buildings (zebs) from the norwegian zeb research centre. *Energy and Buildings*.

WIIK, M. K., FUFA, S. M., KROGSTIE, J., AHLERS, D., WYCKMANS, A., DRISCOLL, P., BRATTEBØ, H. & GUSTAVSEN, A. 2018b. Zero emission neighbourhoods in smart cities: Definition, key performance indicators and assessment criteria: Version 1.0.

YTTERSIAN, V. L. 2018. Assessment of the use of 'områdelca' in view of the zeb and zen concepts.

ZEB. 2018. *Zebs definisjoner* [Online]. Available: https://www.zeb.no/index.php/no/om-zeb/zeb-definisjoner [Accessed 19.12. 2018].

ZEN. 2017. *What is the zen research centre?* [Online]. Available: https://fmezen.no/about-us/ [Accessed 15.11. 2018].

ZEN RESEARCH CENTRE. *Sustainable neighbourhoods with zero greenhouse gas emissions* [Online]. Available: https://fmezen.no/ [Accessed 26.04. 2019].

Appendix

A. OmrådeLCA

A.1. Equations of OmrådeLCA

In this appendix are the main equations used in OmrådeLCA presented together with some of their sub equations. These show the calculation principles of OmrådeLCA, but do not represent all the equations and calculations performed in OmrådeLCA. CO_2 is used as a shortening for CO_2-equivalents in the equations. The same goes for greenhouse gas (GHG) emissions shortened to emissions.

Materials

These calculations are for the whole calculation period.

Main equation:

$$E_m = \sum_{b=1}^{n} \left(\left(\left(e_{module_{(A1-A3+B4)_b}} \cdot f_m \right) + e_{module_{(B,C)_b}} \right) \cdot A_b \right) + E_l$$

E_m: Emissions from materials $g\ CO_2$

b: Building category

e_{module}: Emission intensity of a module $g\ CO_2/m^2$

For module B4, the calculation is normally set to 60 years

A: Area of building category m^2

E_l: Emissions from materials for local energy production $g\ CO_2$

f_m: Emission intensity factor of the buildings chosen compared to TEK 10

$$E_l = e_{sp} \cdot A_{sp} + E_{ol}$$

e_{sp}: Emission intensity of solar panels installed, including replacement over calculation period $g\ CO_2/m^2$

A_{sp}: Area of solar panels installed inside system boundary m^2

E_{ol}: Total emissions over calculation period from other local energy production systems installed inside system boundary $g\ CO_2$

Operational energy use

These calculations are for each year of the calculation period.

Main equation:

$$E_{eu} = \sum_{b=1}^{n} \left(\left(\sum_{d=1}^{n} NE_d \cdot \eta_d \cdot e_d \right) \cdot A_b \right) + P_{lp} \cdot (e_{lp} - e_{re})$$

E_{eu}: Emissions from operational energy use $g\ CO_2$

NE: Net energy demand $kW\text{h/m}^2$

d: Different energy sources to provide heat, cooling and direct electricity

η: Efficiency (system efficiency)

e_d: Specific emission intensity for heat, cooling or direct electricity source d $g\ CO_2/kWh$

P_{lp}: Local energy produced kWh

e_{lp}: Emission intensity of locally produced energy (only fuel or energy needed to produce the energy) $g\ CO_2/kWh$

e_{re}: Emission intensity of replaced (non-local) energy $g\ CO_2/kWh$

$$\eta_d = \eta_{em} \cdot \eta_{dis} \cdot \eta_{pr}$$

η_{em}: Regulation efficiency

η_{dis}: Distribution efficiency

η_{pr}: Production efficiency

$$P_{lp} = p_{sp} \cdot A_{sp} + P_{ol}$$

p_{sp}: Specific energy produced from solar panels kWh/m^2

P_{ol}: Energy production from other local energy kWh

Transportation

These calculations are for each year of the calculation period

Main equation:

$$E_t = \sum_{y=1}^{n} \left(D_y \cdot N_i \cdot \left(s_{p_y} \cdot e_{p_y} + s_{c_y} \cdot e_{c_y} \right) \right)$$

E_t: Emissions from transportation $g\ CO_2$

y: Year

D: Total distance travelled by each person per day *km*

N_i: Number of inhabitants/users/employees

s_{p_y}: Share of transportation happening by public transportation

s_{c_y}: Share of transportation happening by cars

e_{p_y}: Emission intensity public transportation $g\ CO_2/pkm$

e_{c_y}: Emission intensity cars $g\ CO_2/pkm$

pkm: person kilometre

$$N_i = \sum_{b=1}^{n} (A_b \cdot n_b)$$

A_b: Area of each building category m^2

n_b: Number of inhabitants/users/employees per square metre of a building category

$$e_{k_y} = \sum_{k=1}^{n} \left((e_d + e_{id}) \cdot s_k \right)$$

$$e_{c_y} = \sum_{c=1}^{n} \left((e_d + e_{id}) \cdot s_c \right)$$

e_d: Direct emissions, *tank-to-wheel* $g\ CO_2/pkm$

e_{id}: Indirect emissions, *well-to-tank* $g\ CO_2/pkm$

s_k: Share of different public transportation

s_c: Share of different powertrain of cars

Change of land-use

$$E_{col} = e_{la} \cdot A_r$$

E_{col}: Emissions from change of land-use	$g\ CO_2$
e_{la}: Emission intensity of land replaced	$g\ CO_2/m^2$
A_r: Replaced area	m^2

Soil stabilisation

$$E_{st} = (M_{cs} \cdot e_{cs} + M_b \cdot e_b) \cdot l_{br} \cdot A_{fb}$$

E_{st}: Emissions from soil stabilisation	$g\ CO_2$
M_{cs}: Amount of construction steel	$kg/(m^2 \cdot m)$
e_{cs}: Emission intensity construction steel	$g\ CO_2/kg$
M_b: Amount of concrete	$m^3/(m^2 \cdot m)$
e_b: Emission intensity concrete	$g\ CO_2/m^3$
l_{br}: Length to bedrock	m
A_{fb}: Footprint of buildings	m^2

A.2. Alternatives, choices and scenarios included in OmrådeLCA

OmrådeLCA has several different alternatives for how to calculate, and choices and scenarios to select from. In Table A.1 most of them are listed. Default values and choices are highlighted. It is possible to overrule and change several of the choices, alternatives or scenarios.

Table A.1 Alternatives, choices and scenarios included in OmrådeLCA (Borg and Fuglseth, 2018a, Dahlstrøm and Solli, 2018, Dahlstrøm, 2018a, Larsen et al., 2018)

	Possible alternatives	**Choice/alternatives/scenarios**
General options	Calculation period	**60 years**
	Start year of calculations	2015-2029 (if a 60-year calculation period is chosen)
	GWP method	**Dynamic**, Static
	Evaluate scenarios combined (fulfilling same functional mix)	**Yes**, No
	Emission intensities electricity	**Norwegian (NO)**, European (EU28 + NO)
	Emission intensities district heating	**Norwegian average**, Hafslund District heating mix 2015, BKK mix 2017, Eidsiva Bioenergy mix 2018
	Emission intensities for electricity as part of the district heating	**Norwegian (NO)**, European (EU28 + NO)
	Allocation of waste heat in district heating mix	**To district heating plant**, to the producer of the waste heat
Development pattern	Regions with development patterns for residential housing	Norway, Akershus, Oslo, Trondheim, Bergen, Elverum
	Building categories with correction for users per square metre depending on where they are located	Residential (apartment, row house, single-unit dwelling)
	Use case-specific values for number of residents per area for existing locations, and locations inside and outside the development area for both dwellings and offices	Yes, No
Materials	Types of buildings (when it comes to material use)	Apartment, Row house, Single-unit dwelling, Shop, Industry, Office, Hotel, Restaurant, Kindergarten, Educating facility, Culture, Other
	Types of building standards (for material use)	**TEK 10**, TEK 17, Passive House/ZEB, can do a percentage change in emissions according to the TEK 10
	Modules that can be included	**A1-A3**, A4, A5 construction phase, **A5 demolition**, **A5 loss/assembly**, **B4**, C1-C4, D
	Emission intensities of each module	Key numbers, percentage of A1-A3, not included
	Modules with key figures for emissions	**A1-A3**, **A5 demolition**, **A5 loss/assembly**, **B4**
	Possibility to change emissions from building materials because of reuse, waste, including of transportation of materials, building materials with less emissions	Yes, but only by as a percentage increase/decrease of the emission intensity of the chosen building standard
	Emissions from rehabilitation of existing buildings	**Yes**, No. If yes, then as a percentage compared to building a new building according to the chosen building standard. 30% is the default value
	Including emission from waste management	Can be, but the default choice does not

	Including negative emissions, benefits, from waste management. By assuming the materials can be reused, recycled or recovered	Can be, but the default choice does not
	Reduction in emissions from solar panels in module B4 compared to new solar panels	**50%**
	Building categories to choose from when demolition of existing buildings is needed	Small dwellings, Larger building complex, commercial/industrial buildings, other buildings
Operational energy use	Energy demand from buildings	Case-specific, According to TEK 10, TEK 17, Low energy house or Passive House
	Energy supply options	Electricity, district heating, district cooling, solar panels, heat pumps, refrigerating machines, local energy productions
Transportation	Technology mix of cars (share of types of cars; electric, gasoline, diesel, hybrid)	As today, TØI trend path, TØI ultra-low emission path
	Travel survey data available	Oslo city centre, Oslo inner city, Oslo west, Oslo east, Oslo south, Asker and Bærum, Oslo municipality, Akershus county, Oslo/Akershus, Bergen centre, different parts of Bergen, Trondheim and Stavanger, Case-specific
	Data sources for emissions form cars	TØI's average assumption and ecoinvent[1], lifecycle values from Lausselet et al. (2019)[2]
	Data sources for emissions from public transportation	Ruter and NSB
	Include emissions from vehicles and road infrastructure	**Yes**, No
	Allocate transportation emissions between start- and endpoint of trip	Yes, **No**
	Include each separate building category in the calculations of emissions from transportation	**Yes**, No
	Number of days per year with travel by users/inhabitants of houses, offices and hotels.	Value can be changed from 0 to 365, but with default values of 365, 230 and 365 respectively
	Parking availability for offices	Free parking/full access, taxed parking by employer, taxed parking by the government, no parking options
	Parking availability for dwellings	Free parking/full access, taxed parking by private company, taxed parking by the government, no parking options
Soil stabilisation	Include soil stabilisation, both for the development area and alternative area	Yes, No
	Depth to bedrock [m]	**10 metres**

Change of land-use	Include change in land-use, both for development area and alternative area	Yes, No
	Type of area being replaced	Forest with high site quality, forest with average site quality, forest with low site quality, agricultural area, bog

[1] Ecoinvent is a lifecycle database (Ecoinvent, n.d.-a).

[2] Calculations made by Lausselet et al. (2019) of emissions from cars from now and into the future of both production and end of life.

A.3. Improvements and implementations in OmrådeLCA

Most of the improvements and changes done in OmrådeLCA are presented here. Some minor improvements and changes have been left for the sake of brevity. The changes are divided into the different topics or sheets of the excel workbook they belong to. However, some general changes will first be explained that applies for several of the sheets and the tool in general. To start with, several things were "tidied up" in the tool. Explanations or improved explanations have been added within the tool to make formulas and calculations comprehensible. Colour-coding has also been added to make the tool more comprehensible. Unnecessary and redundant content have been removed.

Scenarios and choices

To make OmrådeLCA a more straightforward tool to use, all the options (some few exceptions later explained) and choices the user can affect in the tool have been moved to the same sheet. This sheet is systemized so that the same type of choices, e.g. choices concerning emissions from materials, are grouped together. An explanation to each choice and what is affected by it is also added. Area data for different building categories has been moved to this sheet, so it no longer needs to be performed in the "area" sheet. The same goes for the newly added features of OmrådeLCA when it comes to area affected by land-use change and soil stabilisation.

Results

Results are now moved to a separate sheet. The results are gathered from the other sheets and presented here. The modular structure of NS 3720 is displayed, including information on which modules are included in the current calculation according to data put in and choices taken. Next follows results for total emissions, total emissions per building category, emissions per square metre and year, emissions per square metre and year per building category, emissions according to the different modules of NS 3720, emissions from change of land-use, emissions from different energy systems and emissions per capita. All these results are presented for the chosen development scenario along with the most important results for the reference scenario. Explanations to clarify what is included and where it is included in the results are also given.

Sensitivity analyses

A new sheet for sensitivity analyses has been made. The different sensitivity analyses include the result of different production mixes for electricity, different density of inhabitants, different locations for the travel survey data used, dynamic vs. static LCA approach, and finally a sensitivity analysis for different key parameters. All sensitivity analyses apply to the development scenario, not the reference. For each sensitivity analysis, a thorough explanation of how to proceed, how to interpret the results, and what the results include have been included in the sheet. When performing sensitivity analyses, the results displayed in the "result" sheet are also affected. Therefore, "check" boxes that alert in both the "result" and "Scenarios and choices" sheet are implemented, showing if settings in the "sensitivity analysis" sheet are on so that mistakes in the rest of the calculations will not happen.

Annual emissions

A major improvement of OmrådeLCA is the functionality of showing emissions per year of the assessment period, instead of only as an aggregated sum. The emissions per year are shown for operational energy use in buildings, building materials, transportation of inhabitants and as total emissions, a combination of the three. The results are shown for both the reference and the development scenario, as annual and cumulative emissions.

Areas (square metres)

In addition to the relocation of where the number of square metres is installed to the "scenario and choices" sheet, some more efforts have been done. This include the splitting of residential buildings into the three categories single-unit dwellings, row houses and apartments. In addition, a culture buildings category and an option to define a specific building category have been added.

Development pattern

Several new features have been added. These include the possibility to both add a case-specific development pattern (share of different types of residences and sizes) for a region or a custom split between apartments, row houses and single-unit dwellings (how much of the houses are apartments, single-unit dwellings or row houses). Further, it is possible to change the number of square metres per inhabitant from the development pattern if specific information is known. This, however, needs to be done in the "Scenario and choices" sheet.

Change in land-use

A new feature has been added to calculate emissions caused by transformation of land. Emission intensities for permanently changing different kinds of land areas is implemented. The emission intensities are gathered from a report regarding the assessment of CO_2 emissions from land-use change by Hammervold (2015). These intensities are multiplied with the total built area of the different alternatives to get a total amount of emissions. Choices for kind of land area and total built area is set by the user of OmrådeLCA in "Scenario and choices".

Soil stabilisation

This is also a new feature added into OmrådeLCA which calculates the emissions associated with materials used for soil stabilisation of buildings, which is not included in the calculation of emissions from materials. Amounts of steel and concrete per square metre BTA (gross area) and depth to bedrock is used together with emission intensities for steel and concrete. BTA and depth to bedrock needs to be defined in "Scenario and choices".

Emissions from materials

The sheets that deal with emissions from materials have been changed a lot from the original version. The only thing that is unaltered is the calculations of waste treatment in Norway that is used to find emissions from waste associated with waste treatment of demolition, rehabilitation and new buildings.

Emissions are now divided among the different modules of NS 3720 for all the different building categories. Emission intensities per square metre have been collected for reference buildings. These are multiplied with the number of square metres per building category. The emission intensities are for buildings following the TEK 10 building standard, and can be changed with a factor (predetermined percentage difference from TEK 10) depending on the building standard of the case chosen in “Scenarios and choices”.

Emission intensities from materials associated with production and replacement of solar panels are also included here and are multiplied with the amount of solar panels that are chosen in the “Operational energy use” sheets. If there are any emissions from the productions and replacement of any other local energy production than solar panels, this can be added here as well.

Emission intensities

The two emission intensities for electricity production which shall be used according to NS 3720 have been added, in addition to empty cells for a possibility to add custom values. Different emission intensities have also been added for district heating according to different production mixes from Norwegian district heating companies. Several different emission intensities of each production mix have also been made depending on if waste heat is allocated to the district heating plant or not, and if the electricity in the mix is Norwegian or European. In addition, a part has been added with emission intensities used for local production of energy, e.g. CHP. Some values for different energy sources are added, but these likely need to be changed depending on case-specific local energy production.

Operational energy use

The emissions from operational energy use have been changed somewhat from the original version of OmrådeLCA. As before, the net energy demand is calculated according to different building standards, but the calculations of delivered energy demand and emissions from this has changed. A functionality which allows the user to select between different energy sources has been implemented. The user can also define a custom energy source. These energy supplies have been assigned an efficiency that determines the delivered energy demand, and which kind of energy source they each use (electricity or district heating). Further, each of the building locations (alternative location, inside the development plot, refurbished buildings or not refurbished buildings) must be assigned to one or several of these energy supply systems, by the user of OmrådeLCA, and if they are going to cover the heat or electricity demand. In this way is the annual delivered energy demand of each building category found and can be multiplied with the belonging emission intensity to find the annual emissions.

Another function added to this part of OmrådeLCA is the possibility to include local energy production. The amount of energy, electricity or heat, produced each year and the emission intensity needs to be chosen. The energy produced from local production is multiplied with the difference in emission intensity from the local energy production and what it is replacing (the difference is calculated by subtracting the emission intensity of what it replaces from the emission intensity of the local energy production). This results in an amount of annual emissions, either with a negative or positive value/sign, that is added to the total emission each year from operational energy use.

Transportation

Calculations of transportation are mostly conducted in the same way as in the original version of OmrådeLCA. A difference is that it is possible to now include all the building categories in the calculation of emissions from transportation. Number of trips per square metre and year for the different building categories are calculated. This is calculated based on number of inhabitants/employees/users, days of the year/opening days and square metres, depending on the building category. Combined with travel survey data on total travel distance for the different building categories per year split between walking/biking, public transportation and private car. This again is multiplied with emission intensities for each transportation mode. However, travel survey data for other building categories than residence and offices are not included in OmrådeLCA.

There have been some changes in the background data used to calculate the transportation emissions. To start with, a function is added so that emissions are calculated from the start year set in the study. This result in lowered total emissions if the study starts in a later year, because of improvement of technology. In addition, the emissions have been split up into direct and indirect emissions so that it is possible to express the annual emissions both with and without infrastructure. Infrastructure emissions include both vehicle production and road, rail and similar infrastructure, and it is possible to choose one or both of them, if wanted. Emissions from production and end of life of both electric, diesel/petrol and hybrid cars have been included in the calculations.

Veileder til OmrådeLCA

Hva er OmrådeLCA?

Dette er en veileder til verktøyet OmrådeLCA, utviklet i Microsoft Excel. Først kommer en kort forklaring av metodikk, før en forklaring av hvordan verktøyet er bygd opp og en forklaring av hvordan det brukes vil bli gitt.

OmrådeLCA er et verktøy laget i Excel for å i en tidlig fase beregne klimagassutslipp fra områdeutvikling, hvor målet med verktøyet er å belyse spørsmålet; hva er den klimamessige beste utviklingen av et gitt område? I verktøyet er det mulig å sammenligne det å fortsette med dagens situasjon for et område, en rehabilitering, eller opptil flere nye utbyggingsforslag av området. OmrådeLCA er bygd opp slik at alle utbyggingsalternativ, og referanse, som sammenlignes skal oppfylle samme funksjon. Dette må enten skje innenfor det gitte området, eller på en gjennomsnittlig plassering i for eksempel Oslo kommune. Samme funksjon innebærer at alle alternativ må kunne huse samme mengde beboere, ansatte eller for eksempel ha samme areal av barnehage eller hotell. OmrådeLCA gjør denne sammenligningen av ulike alternativ ved å se på utslipp fra energibruken i bygg, materialbruk i bygg, og transport av beboere og brukere av området. Utslippene fra hele livsløpet til området inkluderes.

Verktøyet

OmrådeLCA er bygd opp slik at det første arket er det arket der de aller fleste valg gjøres og verdier settes inn. Deretter følger ark for resultater, arealer m.m., utslipp forbundet med materialer, utslipp forbundet med energibruk, og til slutt utslipp forbundet med transport.

De fleste valg og verdier fylles som nevnt inn i arket «Scenarioer og valg». Det er noen få unntak. For valg av energisystemer for ulike lokasjoner, bestemmes dette i arket «Energibruk i bygg». Skal man gjøre spesielle beregninger, legge til nye elementer, eller data for andre lokasjoner enn det som ligger inne i verktøyet, må dette gjøres i respektive ark. Det er valgt å la celler som kan endres på i OmrådeLCA, og hvor valg må/kan tas, eller viktig informasjon er skrevet, å være gule.

Nedenfor følger en forklaring av de ulike arkene i verktøyet, med forklaring av hva som må gjøres, hva som kan gjøres, og hvilke muligheter det er.

Scenarioer og valg

Her følger en overordnet forklaring til de ulike valgene som kan og må gjøres i dette arket. Det ligger også inne en forklaring til de fleste valg i selve OmrådeLCA. Forklaringen her er delt inn i de grupperingene som er i OmrådeLCA.

Arealinnsetting

Her legger man inn hvilke areal som finnes i dag på tomten for referansen, hvilke areal som finnes på tomten i dag som skal rehabiliteres for alternativene, samt hva som skal bygges nytt på tomten for de ulike alternativene.

I arealtabellene er det gjort plass for en egendefinert bygningskategori. Denne må tilegnes utslipp fra materialer i «Utslipp materialer A-D» i tabellene for nøkkeltall som befinner seg fra rad 19-30. I tillegg må denne bygningskategorien tilegnes et energibruk. Dette gjøres i «Energibruk i bygg»-arket. Arealet for å oppnå funksjonell miks av denne bygningskategorien beregnes i «Arealer» i rad 164. Disse arealene må hentes inn i tabellen «Netto energibehov utbyggingsscenario og referanse» i «Energibruk i bygg», og legges til i en av bygningskategoriene som er der. For eksempel er ikke kategorien sykehjem brukt, og kan dermed brukes. Da er det viktig at sykehjem i tabellen «Energibruk i forhold til ulike standarder» ovenfor oppdateres med en energibruk som er lik den energibruken den egendefinerte bygningskategorien har. Om denne egendefinerte bygningskategorien skal inkludere transport, kreves det en god del mer endringer og jobb.

Overordnede variable

Her legges inn nøkkelinformasjon om prosjektet. Startår og beregningsperiode angis. Man velger også om man skal ha en statisk eller dynamisk GWP-metode. Velges dynamisk tilnærming (utslipp teller mer i dag enn i fremtiden) regnes utslipp med en faktor på én for startår, og så en reduksjon fra startåret og til null 100 år etter startåret.

Man velger også her hvilket av utbyggingsalternativene man vil gjøre beregningene for. Det er kun mulig å beregne for et av utbyggingsalternativene av gangen. Det man kan gjøre for å sammenligne alle opp mot hverandre, også referanse, er å velge JA i cellen som spør om alternativ skal vurderes samlet. Dette innebærer at alle utbyggingsalternativene og referansealternativet oppfyller samme funksjon, og ikke bare at det alternativet man har valgt å gjøre beregninger for og referansen skal oppfylle samme funksjon, som er tilfelle om man velger NEI. Resultatarket er bygd opp slik at det er enkelt å gjøre sammenligninger der ved å kopiere over resultater for så å endre på hvilket alternativ man vil sammenligne referansen med.

Videre gjøres det valg for elektrisitetsmiks, hvor begge scenariene i henhold til NS 3720 ligger inne (norsk og europeisk elektrisitetsmiks). Det siste valget her er hvilken fjernvarmemiks som skal brukes. Her ligger det inne noen standard fjernvarmemikser, men det er også mulig å legge til egne i «utslippsfaktor energi». Bruker må også definere hvilken elektrisitetsmiks som skal ligge til grunn for fjernvarmemiksen, samt om gjenvunnet varme fra avfallsforbrenning i fjernvarmemiksen skal tilegnes utslipp eller ikke.

Utbyggingsmønster

Her gjøres det valg for boligsammensetning og tetthet av personer per bolig. Det første valget man gjør er å velge hvilket område/landsdel/kommune som igjen bestemmer hvilket snittareal det er per beboer for de ulike boligtypene for både referansen og utbyggingsalternativet. Det er mulig å legge inn et eget (case-spesifikt) område/landsdel/kommunes boligsammensetning helt til høyre i rad 13-27 i «Utbyggingsmønster». Om man vil ha egendefinerte snittareal per beboer er det mulig å velge dette i de tre neste valgene for utbyggingsmønster i «Scenario og valg». Om man gjør det må tabellen i cellene H41:K46 fylles ut for de områdene man har valgt å ha egendefinerte snittareal for.

Det neste valget man gjør er å velge hvilket område/landsdel/kommune/by som skal avgjøre hvordan fordelingen er mellom ulike typer boliger for den alternative plasseringen av boliger for å oppfylle samme funksjonelle miks for alle alternativ. Det er også mulig å lage en egendefinert fordeling. Dette må i så fall gjøres i tabellen som ligger i radene 88-91 i «Utbyggingsmønster». De to siste valgene går på om man vil at alle boligtyper skal ha det samme antall kvm pr beboer, og da i så fall hvilken boligtypes antall kvm pr beboer som skal brukes.

Materialer

Her gjøres det valg for utslipp knyttet til materialer i bygg. Det første man velger her er hvilken byggestandard bygninger på forskjellige plasseringer (innenfor, utenfor og rehabiliterte) skal følge. Standardtallene som ligger inne er for TEK 10. Det er angitt forhåndsdefinerte prosentvise forskjeller fra TEK10 for ZEB «standarder» som da endrer utslipp fra modulene A1-A3 og B4 om man velger ZEB «standard».

Etter dette følger det en del valg for om man skal inkludere utslipp fra forskjellige prosesser (bygge nytt, rehabilitere og rive) samt mulighet for å legge inn reduksjoner i utslipp fra forskjellige tiltak som ombruk og reduksjon i svinn, og reduksjon i forhold til gitt standard.

Deretter følger valg for hvilke moduler man skal inkludere for utslipp fra materialer. Man kan for de fleste velge om det skal brukes nøkkeltall, verdier som en prosent av A1-A3, eller om de ikke skal inkluderes i det hele tatt. Slik det er nå ligger kun inne nøkkeltall for A1-A3, A5 svinn/montering, A5 riving og B4. Om man velger som en prosent, må denne prosenten legges inn i den påfølgende raden. Om man velger nøkkeltall er det viktig å sjekke i «Utslipp materialer A-D» at disse nøkkeltallene ligger inne for den gitte modulen.

Om noen bygg skal rives, må man velge hvilke type bygg dette er. Bygg som må rives regnes ut ifra eksisterende areal på bygg som er på området, fratrukket det areal av bygg som skal rehabiliteres i det valgte utbyggingsalternativet.

Grunnstabilisering

Her velger man om man skal inkludere grunnstabilisering for utbyggingsområdet, og også for den alternative plasseringen. Videre velges det dybde til grunn. 10 meter er satt som en standard. Om man inkluderer grunnstabilisering, må man også legge inn BTA for de aktuelle områdene i tabellen som er i cellene H48:L53.

Arealbruksendringer
Her velges det om man skal inkludere arealbruksendringer. Om man gjør det må man videre velge hvilken type areal man fortrenger innenfor utbyggingsområdet og ved alternativt område. Til slutt må man legge inn tomtearealet, eller areal man fortrenger, for disse områdene i tabellen som er i cellene H48:L53.

Energibehov
Her velger man hvilken byggestandard energibehovet for referansen og utbyggingsalternativet skal baseres på. Det er mulig å velge et egendefinert energiforbruk. Hvis et egendefinert energiforbruk velges, må verdier for dette legges inn i «energibruk i bygg» arket. Denne innleggingen er videre forklart i forklaringen av «energibruk i bygg» arket senere i veilederen.

Energiforsyning
Energiforsyningsvalg gjøres ikke her, men i «Energibruk i bygg»-arket. Energiforsyningsvalg er forklart i forklaringen av dette arket senere i veilederen. Det eneste valget man tar her er om solceller skal være med i beregningene, og hvor mye utslippene fra disse er redusert med ved utskifting etter 30 år ved endt levetid. 50% er det som er brukt i ZEB-beregninger.

Transport
Her velges det hvilken teknologimiks for personbiler man skal følge. Man kan velge en med samme teknologimiks som i dag, samt trendbane og ultra-lavutslippsbane fra TØI. Disse endrer hvor fort overgangen til mer bruk av elektriske biler skjer. Videre velges hvilket område sin fordeling av kollektivmuligheter man skal ha både innenfor og utenfor utbyggingsområdet, samt om man skal inkludere kjøretøy og infrastruktur. Videre er det mulighet for å inkludere transport for de forskjellige bygningskategoriene. Foreløpig er det kun kontor og bolig som kan inkluderes, ytterligere forklart under «Transport» senere i veilederen.

Det er også mulig å gjøre begrensninger i parkeringsmuligheter, og inkludere ulike bygningskategorier. Det er og mulig å velge om utslippene fra transport skal allokeres kun til byggene på området, eller deles med sluttdestinasjonen også. Deles de med sluttdestinasjonen, halveres transportlengden fra RVUene.

Det siste man velger er hvilket område fra RVUen man skal ha innenfor utbyggingsområdet, og for den generelle plasseringen. Dette påvirker fordelingen mellom gang/sykkel, bil og kollektivt, og i tillegg transportdistansen per dag. Både for fordeling av kollektiv og valg av RVU, kan man legge inn egendefinerte i «Transport» som er ytterligere forklart i forklaringen av dette arket.

Resultater

<u>Her kan man hente ut resultater.</u>
I dette arket finner man samlinger av ulike resultater. Øverst i arket er det lagt inn en sjekkcelle som sier ifra om det er gjort noen valg i «sensitivitetsanalyser» som endrer/påvirker resultatene. Dette fordi det i sensitivitetsanalysene kan gjøres analyser som vil påvirke resultatene i dette arket. Deretter følger en figur som viser hvilke moduler som er inkludert

i analysen, avhengig av valg som er tatt i «Scenarioer og valg», i henhold til NS 3720. Videre er resultater for totale areal, totale utslipp, totale utslipp pr bygg, utslipp pr kvm og år, utslipp pr kvm og år for de ulike byggene, utslipp pr modul i henhold til NS 3720, utslipp fra arealbruksendringer, sammenligning av energisystemer, og til slutt utslipp per bruker vist. Det er for de fleste av disse lagt ved en forklaring av hva disse resultatene inkluderer og ikke. Enkelte steder står det «kopier over ->». Dette er hvis man skal sammenligne flere alternativer. Da må man mellom hver kopiering forandre hvilket alternativ man sammenligner opp mot i «Scenarioer og valg», og velge om «Skal alternativer vurderes samlet» i samme ark.

Sensitivitetsanalyser

Kan gjøre endringer for å få svar fra sensitivitetsanalyser.

I dette arket er det gjort noen sensitivitetsanalyser, samt sammenligninger av resultater med forskjellig valg av parametere. Øverst i arket er det lagt inn en sjekkcelle som sier ifra, av samme grunn som sjekkcellen i «resultater», om det er noen innstillinger i dette arket som er skrudd på som kan påvirke svarene i «Resultater». Resten av arket består av en sammenligning av strømmikser (Norsk og Europeisk forbruksmiks i henhold til NS 3720), ulik tetthet av innbyggere (prosentvis endring), ulik plassering av innbyggere (i henhold til RVUer), samt en sensitivitetsanalyse av ulike parametere. Det står en utfyllende forklaring i arket på hvordan disse fungerer og skal brukes. Det er viktig at ingen innstillinger står på Ja i dette arket hvis det er resultater fra andre ark man ser på eller jobber med.

År for år-utslipp

Trengs ikke å gjøre noe i dette arket.

I dette arket vises utslipp for hvert år av analysen. Beregninger her vises slik verktøyet er nå, med en beregningsperiode på 60 år. Utslippene vises som punktutslipp og som akkumulerte for hvert år for både referansescenarioet og utbyggingsscenarioet. Resultatene er også vist for energibruk, materialer, transport, og som totale, altså summen av de tre.

Areal

Trengs ikke å gjøre noe i dette arket.

Arealene som legges inn i «Scenarioer og valg» kobles til dette arket. Arealene for de videre beregningene endres ettersom hvilket alternativ man vil se på, og om man skal se på alternativene samlet eller ikke. Arealer som skal rives beregnes ut ifra eksisterende bygningsmasse og hvor mye som blir rehabilitert i utbyggingsalternativet. Arealene for alternativ plassering, altså utenfor utbyggingsområdet, blir justert ut ifra utbyggingsmønster som er valgt i «Scenarioer og valg».

Utbyggingsmønster

Her kan man legge inn eget utbyggingsmønster, i tillegg til de som allerede ligger inne. Dette gjøres i felt AY12:BE28. I dette arket beregnes snittareal per bolig for forskjellige boliger, samt andel ulike typer bolig. Dette gjøres for forskjellige lokasjoner. Ulikt utbyggingsmønster fører til at det kan bli forskjell på kvadratmeter som må bygges ut for utbyggingsalternativene og referansen utenfor utbyggingsområdet for å oppfylle samme funksjonelle miks.

Arealbruksendringer

Trengs ikke å gjøre noe i dette arket.
I dette arket beregnes utslipp i forhold til hvilken arealtype som endres.

Grunnstabilisering

Trengs ikke å gjøre noe i dette arket.
I dette arket beregnes utslipp fra grunnstabilisering. Her beregnes det hvor mye som trengs av stål og betong, og da utslippene for disse materialene.

Avfallsbehandling

Trengs ikke å gjøre noe i dette arket.
Her ligger det inne data for avfallsbehandling som brukes for å bestemme utslipp fra riving av eksisterende bygninger, samt avfall fra rehabilitering og nybygg. Dette gjøres for ulike bygningskategorier. Disse linkes opp til neste ark «Utslipp materialer A-D».

Utslipp materialer A-D

Her kan noen tall legges inn.
Dette gjelder tall for utslipp fra materialer til eventuell lokal energiforsyning. Disse legges inn i rutene R7-R12 om det er lokal energiforsyning. Videre i arket ligger det inne nøkkeltall for en del av modulene A-D for ulike bygningskategorier. Det er også mulig å endre på disse tallene om man har spesifikke data. De tallene som ligger inne er for referansebygg fra klimagassregnskap.no som følger standarden TEK 10. Det er lagt inn faktorer for hvor store utslippene fra modulene A1-A3 og B4 for passivhus/ZEB er i forhold til TEK 10. Disse kan tas i bruk ved valg i «Scenarioer og valg». Om man skal bruke egne nøkkeltall må de legges inn per år, regnet ut for å gjelde for en periode på 60 år. I dette arket regnes utslipp fra modulene A-D, og for alle bygningskategoriene som er definert. Utslipp fra materialbruk for solceller inkluderes også i beregningene. Disse er avhengige av arealet på solceller man legger inn i «Energibruk i bygg».

Utslippsfaktorer energi

Her kan man legge inn egne utslippsfaktorer.

I dette arket ligger det inne utslippsfaktorer for forskjellige strømmikser og fjernvarmemikser. Det er også mulig å legge til egne utslippsfaktorer for strøm og fjernvarme.

Helt til høyre i arket må man legge inn utslippsfaktorer om man har lokal energiproduksjon (annet enn PV), som man da definerer i «Energibruk i bygg». Om man legger inn en utslippsfaktor til noe som produserer en annen mengde energi enn den bruker (energi inn er ulik energi ut) må dette korrigeres for i utslippsfaktoren, som forklart spesifikt i dette arket. Er energi inn 1 kWh mens energi ut er 3 kWh må man gange den opprinnelige utslippsfaktoren med (1/3). Har man en CHP-maskin kan det være lurt å allokere utslipp fra denne til enten varme eller strøm. Da legger man inn to lokale energiforsyningsløsninger i «Energibruk i bygg» arket, en for varme og en for strøm, og velger videre hvem av de som tildeles et utslipp og hvem som ikke gjør det. I så fall er det viktig å passe på at utslippsfaktoren tar med i betraktning mengden av fyringsmaterialet som trengs for både varme og strømproduksjonen, siden utslippsfaktoren som legges inn her ganges opp med enten varme eller strømproduksjonen, ikke begge deler.

Energibruk i bygg

Her må man definere energiforsyning.

Eventuell lokal energiproduksjon legges til i rad 4 til 8. Her er det kun de gule feltene man må sette inn noe i. Man må velge hvor mye som produseres per år, samt hva den erstatter (strøm eller fjernvarme), slik at denne energimengden trekkes bort og ikke telles dobbelt. Det siste man må gjøre er å velge utslippsfaktor for denne energiproduksjonen. Denne må legges inn i «Utslippsfaktor energi» som forklart i Utslippsfaktorer energi ovenfor.

Videre må man definere energiforsyning, både for utbyggingsområdet og den alternative plasseringen. Dette gjør man i radene 26-31. Her kan man velge inntil 4 ulike energiforsyninger som skal dekke behovene oppvarming, tappevann, direkte el og kjøling for hver av de ulike plasseringene; nybygg innenfor, rehabilitering utbygging, rehabilitering referanse og utenfor. Først velger man energiforsyning i rad 26, og deretter hvor mye av de nevnte behovene som skal dekkes av denne energiforsyningen, i rad 28-31. Det ligger inne fire typiske/standard energiforsyninger å velge blant. Disse er definert i rad 14-19. Her er det også mulig å definere nye energiforsyninger. Det gjøres da i de gule feltene.

Resten av arket regner først netto energibehov i henhold til hvilke standarder man har valgt for energibehov for alle de forskjellige bygningskategoriene i utbyggingsscenarioet og referansen, før levert energibehov regnes. Det er mulig å legge inn egen energistandard samt dagens energibruk i de to siste tabellene helt til høyre i arket i radene 37-49.

Utslipp energi

Her trengs det ikke gjøres noe.

Her knyttes energibruken for hver bygningskategori pr år opp mot tilhørende utslippsfaktorer for hver av de opp mot fire energiforsyningsformene som er valgt. Det samme gjøres med den lokale energiproduksjonen som kan velges i «Energibruk i bygg». Resultatene i dette arket er veldig «detaljerte» i den form av at det vises resultater for hver energiforsyning for hver enkelt bygningskategori. Disse er mer aggregerte i neste ark.

Utslipp energi summert

Her trengs det ikke gjøres noe.

Dette arket viser det samme som «Utslipp energi» bare mer aggregert. Her vises det totalt for hver bygningskategori, samt totalt for hvert område (innenfor, utenfor, rehabilitert) for utbyggingsalternativ og referansen.

Antall reiser

Her kan man endre på antall reiser for ulike bygningskategorier.

I dette arket hentes arealer, beboere og ansatte ut fra «Arealer». Disse blir ganget opp med antall dager med transport (for eksempel åpningsdager), personer per kvm og antall reiser pr dag, for å få et tall på hvor mange reiser det er per år for de ulike bygningskategoriene. Faktorer i dette arket er bestemt for å kunne å gjøre disse beregningene, men kan om ønskelig endres. Dette gjøres i den øverste tabellen under «bakgrunnsdata».

Transport

Her kan man legge inn egen RVU og kollektivfordeling.

I dette arket regnes utslippene fra transport, både som totale, pr år, og fordelt på hver bygningskategori ut ifra hvor mange som reiser pr bygningskategori. Beregningene tar utgangspunkt i «RVU», «Antall reiser», «Bil» og «Kollektiv». Om man vil legge inn en egen RVU og/eller egen fordeling av kollektivfordeling gjøres dette helt øverst i arket.

RVU

Her trengs det ikke gjøres noe.

I dette arket ligger RVUer for ulike områder for bolig og kontor inne.

Kollektiv

Her trengs det ikke gjøres noe.

I dette arket regnes utslippsintensiteter pr passasjerkilometer for kollektivtransport. Persontog, T-bane, trikk, bybuss og båt er inkludert, hvor data er hentet fra Ruter og NSB. Utslipp fra transportmiddel og infrastruktur er inkludert.

Bil

Her trengs det ikke gjøres noe.

I dette arket beregnes utslippsintensiteter pr personkilometer for personbiler. Dette gjøres med bakgrunn i bilparkens sammensetning over tid (TØI trendbane eller Ultralavutslippsbane), bensins/diesel/strøm-forbruk fra bilene, samt utslipp forbundet med produksjon av biler og infrastruktur.

Utslipp transport

Her trengs det ikke gjøres noe.

I dette arket ligger det inne data fra TØI for bilparkens bestand og sammensetning, samt forskjellige utslippstall for ulike biler.

M-valg

Her trengs det ikke gjøres noe.

I dette arket ligger det inne valg for de fleste av rullegardinmenyene i resten av verktøyet. I tillegg ligger det inne noen verdier for «Sjekk» av at ulike kriterier er oppfylt.

A.5. Electricity mixes of OmrådeLCA

In Figure A.1 are the emission intensities of the two electricity mixes used in OmrådeLCA shown. These are the Norwegian and European according to NS 3720.

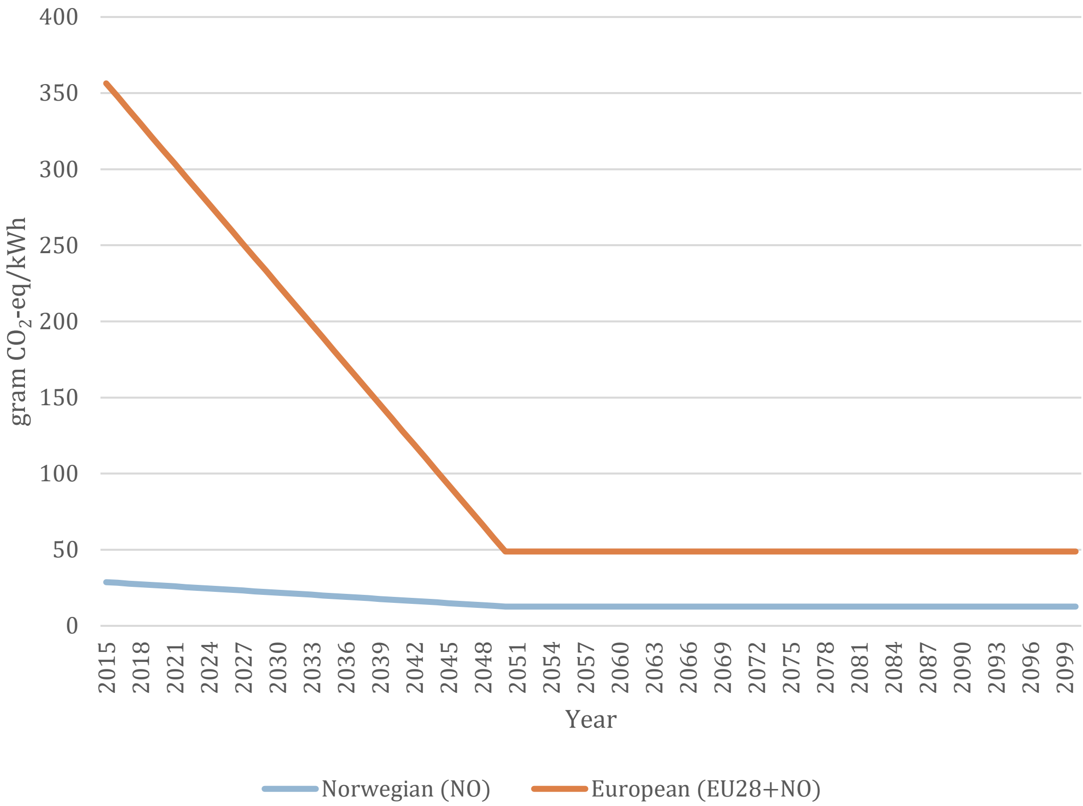


Figure A.1 Electricity mixes of OmrådeLCA

A.6. Composition of vehicle fleet

In Figure A.2 and Figure A.3 are the compositions of the vehicle fleets used for the assessments in OmrådeLCA presented. These are based on the trend path and ultra-low emission path projections of TØI (TØI, n.d.). The small amount of hydrogen cars has been included as electric cars, while hybrid cars are assumed to run 67% of the travelled distance on petrol.

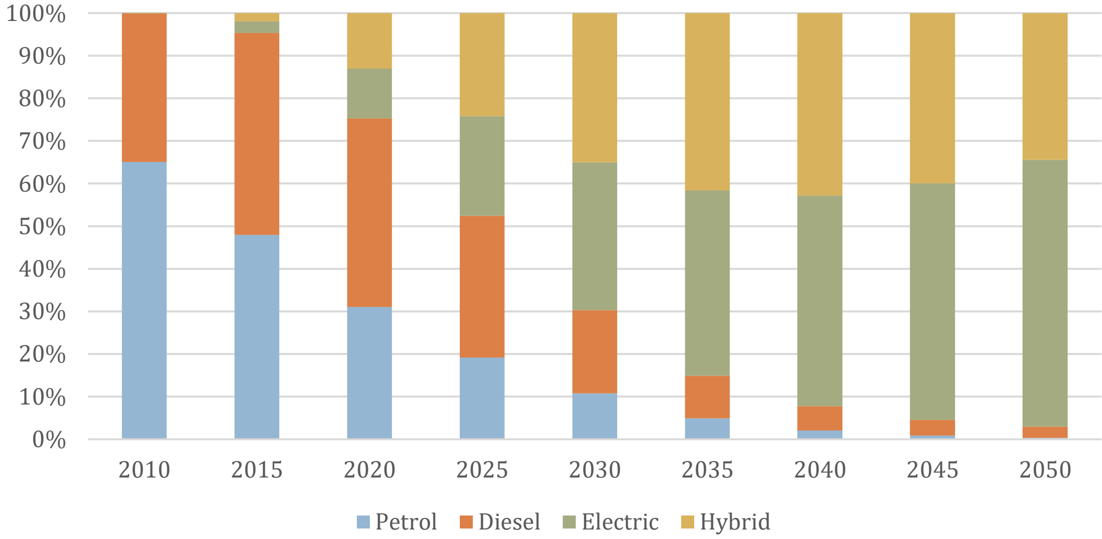


Figure A.2 Trend path of the composition of the vehicle fleet

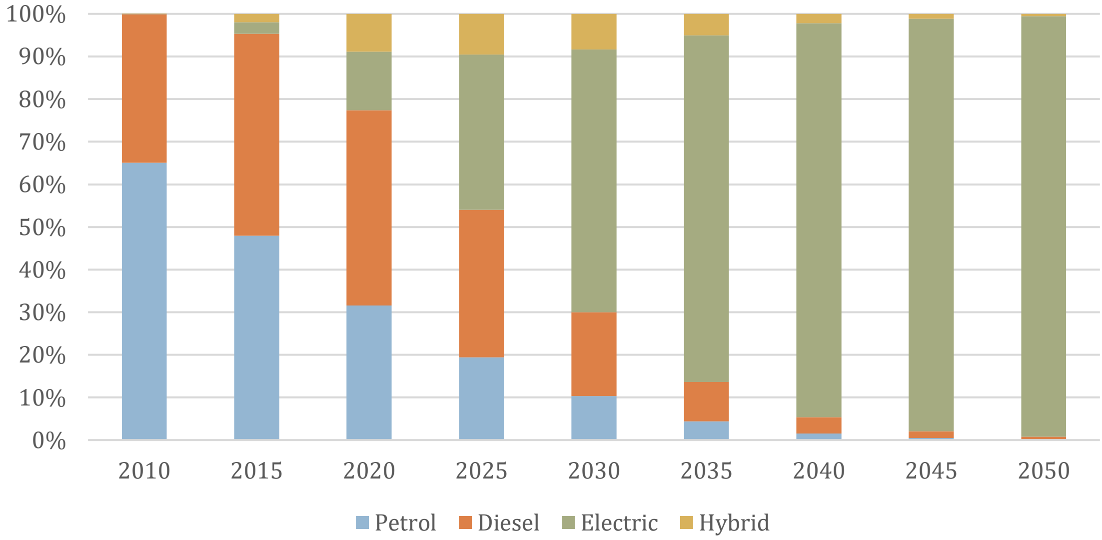


Figure A.3 Ultra-low emission path of the composition of the vehicle fleet

B. Zero Emission Buildings

B.1. ZEB ambition levels

Here follows the ZEB ambition levels given in a report by Fufa et al. (2016).

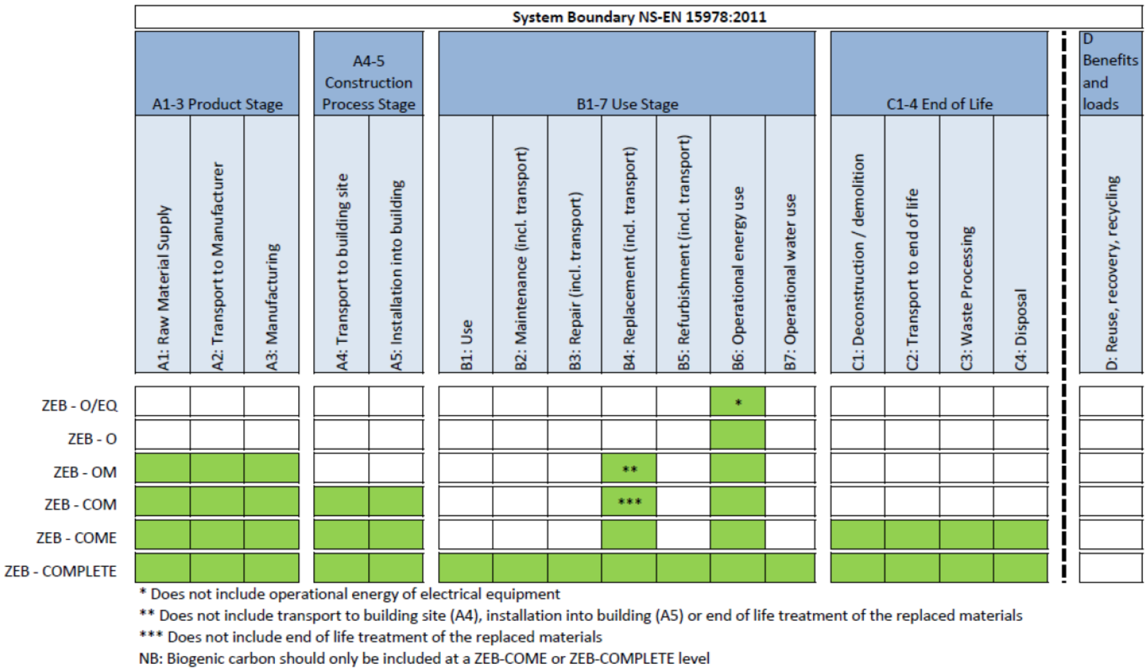


Figure B.1 Description of ZEB ambition levels (Fufa et al., 2016)

The current system boundaries of the ZEB ambition levels, show in Figure B.1, are defined as follows:(Fufa et al., 2016)

ZEB-O÷EQ: Emissions related to all energy use for operation "O", except energy use for equipment and appliances (EQ), shall be compensated for with renewable energy generation. The definition of O÷EQ therefore includes operational energy use, except energy use for equipment and appliances (B6*), as outlined in NS-EN 15978: 2011.

ZEB-O: Emissions related to all operational energy "O" shall be compensated for with renewable energy generation. The O includes all operational energy use (B6), according to NS-EN 15978: 2011.

ZEB-OM: Emissions related to all operational energy "O" plus embodied emissions from materials "M" shall be compensated for with renewable energy generation. The M includes the product phase of materials (A1 – A3) and scenarios for the replacement phase (B4**), according to NS-EN 15978: 2011. Note that B4** in ZEB-OM considers only scenarios related to the production of materials used for replacement. The transport (A4), installation (A5), and end of life processes for replaced materials are not included in B4**. The scope of materials to be included in M for a ZEB-OM ambition level can be found in Figure B.1.

ZEB-COM: This is the same as ZEB-OM, but also takes into account emissions relating to the construction "C" phase. The phases included in C are transportation of materials and products to the building site (A4) and construction installation processes (A5), according to

NS-EN 15978: 2011. Note that B4*** in ZEB-COM is expanded to include the transportation (A4) and installation process (A5) of replaced materials. The end of life processes of replaced materials is not included in B4***. The scope of materials to be included in M for a ZEB-COM ambition level can be found in Figure B.1.

ZEB-COME: This is the same as ZEB-COM, but also takes into account emissions relating to the end of life "E" phase. The end of life phase include deconstruction/demolition (C1), transport (C2), waste processing (C3), and disposal (C4), according to NS-EN15978: 2011. Similarly, the end of life processes of replaced materials in B4 are to be included and taken to an end of waste state.

ZEB-COMPLETE: Emissions related to a complete lifecycle emission analysis have to be compensated for, namely all phases: product stage (A1 - A3), construction process stage (A4 –A5), use stage (B1 – B7), and end of life stage (C1 - C4). If relevant and available, benefits and loads beyond the system boundary (D) can be included as additional information, according to NS-EN15978: 2011.

C. Ydalir

C.1. Calculation of square metres of different kind of dwellings to fulfil the functional mix

This appendix explains the approach for finding the share of different residential buildings and square metres per resident of an area using Elverum municipality as an example. Table C.1 gives the number of different dwelling types and size for the Elverum municipality. These values are gathered from SSB, Statistisk Sentralbyrå (Statistisk Sentralbyrå, 2019).

Table C.1 Number of dwellings in Elverum municipality split into different building types and sizes

Elverum 2018	Single-unit dwellings	Duplexes	Row houses, chain houses and other small houses	Apart-ment buildings	Buildings for shared housing	Other building categories
Under 30 m^2	24	3	4	94	13	17
30-39 m^2	50	3	17	98	24	18
40-49 m^2	77	5	52	245	5	76
50-59 m^2	96	40	63	121	0	15
60-79 m^2	244	122	252	650	39	101
80-99 m^2	340	161	261	279	11	39
100-119 m^2	428	220	87	134	0	24
120-139 m^2	494	135	46	53	0	20
140-159 m^2	658	75	106	8	0	5
160-199 m^2	1 627	65	25	7	0	6
200-249 m^2	1 569	26	7	1	0	10
250-299 m^2	636	7	1	1	1	0
300-349 m^2	255	3	0	0	0	0
350 m^2 or bigger	132	2	1	1	0	0
Unknown	34	0	0	0	0	21
Sum	6 664	867	922	1 692	93	352

In Table C.2 are each number of dwellings from Table C.1 multiplied with the average area of each size interval to find total built area of each dwelling type.

Table C.2 Square metres of different dwelling types in Elverum municipality

Average area	Single-unit dwellings	Duplexes	Row houses, chain houses and other small houses	Apartment buildings	Buildings for shared housing	Other building categories
25	600	75	100	2 350	325	425
35	1 750	105	595	3 430	840	630
45	3 465	225	2 340	11 025	225	3 420
55	5 280	2 200	3 465	6 655	0	825
65	15 860	7 930	16 380	42 250	2 535	6 565
90	30 600	14 490	23 490	25 110	990	3 510
110	47 080	24 200	9 570	14 740	0	2 640
130	64 220	17 550	5 980	6 890	0	2 600
150	98 700	11 250	15 900	1 200	0	750
180	292 860	11 700	4 500	1 260	0	1 080
225	353 025	5 850	1 575	225	0	2 250
275	174 900	1 925	275	275	275	0
325	82 875	975	0	0	0	0
375	49 500	750	375	375	0	0
120	4 080	0	0	0	0	2 520
Sum BRA	1 224 795	99 225	84 545	115 785	5 190	27 215
Weighted average area BRA	183.8	114.4	91.7	68.4	55.8	77.3

Table C.3 gives data on residents per dwelling from SSB (Statistisk Sentralbyrå, 2013) which are multiplied with the weighted area per dwelling from Table C.2 to find the area per resident. Table C.2 is also used to find the share of the different dwelling types, which can be seen in Table C.3. Here, the duplex and row house categories are combined, while buildings for shared housing and other building categories have been left out of the calculations. This is done in order to limit the number of dwelling categories in the calculations.

Table C.3 Area per resident and share of dwelling types for Elverum municipality

	Residents per dwelling	Area per dwelling [BRA]	Area per resident [BRA]	Share of dwelling types
Single-unit dwellings	2.5	183.8	73.5	8%
Duplexes	2.3	114.4	49.8	12%
Row houses, chain houses and other small houses	2.1	91.7	43.7	
Apartment buildings	1.6	68,4	42.8	80%
Other building categories	1.4	55.8	39.9	-

The share of different dwelling types and area per resident are used to find the development pattern of the alternative location, or reference scenario in an assessment with OmrådeLCA, and calculating the needed square metres of dwellings to fulfil the functional mix.

Vidar Lind Yttersian

Greenhouse gas emission assessment using OmrådeLCA: Case study of the Zero Emission Neighbourhood Ydalir

NTNU

Kunnskap for ei betre verd