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SINTEF NOTES 29

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## Preface

This report has been written within the pre-project "Utslippsfrie byggeplasser"funded by Regionale Forskningsfond Hovedstaden (RFFHSTAD). The report is quality assured by Christofer Skaar and Christofer Venås from SINTEF Building and Infrastructure. The author gratefully acknowledges the support from RFFHSTAD, Flemming Idsøe from Omsorgsbygg and Pablo Gonzalez, Erlend Salberg and Ola Holmestad from SKANSKA.

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## Abstract

This report summarises the life cycle assessment methodology used to calculate the GHG emissions from a case study considered under "Utslippsfrie byggeplasser forprosjekt". The greenhouse gas emissions (GHG emissions) of Lia barnehage were calculated based on the Life Cycle Assessment (LCA) methodology. The aim was to analyse and document construction phase emissions. A functional unit of 1 $m^2$ of heated floor area over an estimated building lifetime of 60 years is considered. The total heated floor area is 1600$m^2$. Construction site activities considered include transport of building materials, construction machinery, energy use, temporary works, waste management and person transport. The environmental performance is calculated in terms of GHG emissions weighted as carbon dioxide equivalents ($CO_{2eq}$) according to the IPCC GWP 100-year method.

The GHG construction emission results are 1,19 $kgCO_{2eq}/m^2/yr$, 1970 $kgCO_{2eq}/yr$, 72 $kgCO_{2eq}/m^2$ over a 60-year lifetime and 114 413 $kgCO_{2eq}$ in total. The largest contributor to GHG emissions from the construction site is transport of building materials (46% or 0.55 $kgCO_{2eq}/m^2/yr$). This is followed by construction machinery (34% or 0.40 $kgCO_{2eq}/m^2/yr$), person transport (10% or 0.11 $kgCO_{2eq}/m^2/yr$), construction waste (7% or 0.08 $kgCO_{2eq}/m^2/yr$), energy use (3% or 0.04 $kgCO_{2eq}/m^2/yr$), and temporary works (1% or 0.01 $kgCO_{2eq}/m^2/yr$). In Lia barnehage, use of biodiesel in construction machineries was considered as one emission reduction measure. During the construction period, biodiesel was used in all machineries except the Crane. A Sensitivity analysis was performed to evaluate the emission reduction from construction machinery fuel use considering four potential alternative fuel scenarios. One worst case scenario (use of diesel only) and three best case scenarios (use of biodiesel only and electricity only for two different emission factors for electricity) are considered. The results show that the use of biodiesel in Lia barnehage in place of diesel for excavators, loaders, drills and vibroplate machineries enabled to reduce the emission from the construction site by 13%. The GHG emission from the construction site would have been further reduced by 4% if biodiesel was also used for the cranes and by up to 13 % (using the Norwegian ZEB centre emission factor for electricity) to 27% (using the Ecoinvent v.3.1 database, system model "*Electricity, low voltage {NO}| market for | Alloc Rec, S*" emission factor for electricity) if electricity was used as fuel source for all machineries.

Experiences from data collection show that the quality of the inventory and background data source used can greatly affect GHG construction emission calculations. It is recommended to develop a construction site life cycle inventory database with emission factors for common construction site activities. The laborious process of data collection in this study, has also highlighted the importance of using data collection sheet at the early project phase to simplify the construction site data collection process, and improve data quality and transparency. This study also highlighted the importance of performing LCA at the early design phase to evaluate, plan and compare GHG emission reduction measures. Including the cradle to grave LCA of the building using different indicators will enable to avoid problem shifting from one life cycle stage and/or environmental indicator to another. A sensitivity analysis is one method used to evaluate impact of emission reduction measures and their sensitivity to variation and uncertainty factors in LCA. It is recommended to develop a methodology to incorporate sensitivity analysis to evaluate emission reduction measures, inventory and emission data quality. The results from this study may be used in future Norwegian construction projects as a reference, to help measure, evaluate and compare the environmental performance of construction activities. Further study is required to collect case studies of different building typologies to gain experience in evaluating and minimising the potential environmental impacts from other types of construction sites.

# Contents

# 1. Introduction

In response to the first legally binding global climate agreement signed in Paris in 2015 (COP21), Norway initiated goals to reduce greenhouse gas (GHG) emissions by at least 40% compared to 1990 levels by 2030 [1]. Oslo municipality launched the 'Green Shift' with a goal to reduce GHG emissions by 50% by 2020 and by 95 percent by 2030, compared with 1990 levels [2].

The Norwegian construction industry is responsible for approximately 1.2% of national GHG emissions during the construction phase. Of these construction phase emissions, about 5% arise from the heating and drying of buildings (ca. 30,600 tCO2eq) whilst the remainder originate from transportation and operation of machinery [3]. The report from Oslo Municipality's Climate and Energy Strategy shows that the transport sector is responsible for 61% of total greenhouse gas emissions from Oslo [2]. Of these transport emissions, 30% arise from construction machinery, 39% from private cars (including transport of construction workers to and from construction sites), 15 % from lorries and 10% from vans (including transport of construction products to and from construction sites). In addition, 19% of total greenhouse gas emissions come from waste, 17% from buildings and 3% from the energy sector. Of these emissions, a share is used for waste management, heating, drying and energy use at construction sites. Therefore, construction sites activities and the transport sector are identified as important areas for achieving GHG emission reduction.

Research related to fossil free and emission free construction site activities is developing rapidly, and Oslo municipality has a great need to incorporate more feasible requirements than those that are possible to ask today. Emission-free construction sites pre-project (Utslippsfrie byggeplasser forprosjekt), which was funded by the Regional Research Fund (RFFHSTAD) in March 2017, aims on identifying drivers and barriers as well as challenges and opportunities that affect today's procurement practices, with particular focus on fossil and emission-free construction sites. The objective is to prepare a guidance to how to set measurable emission reduction goals and define requirements used to measure the achievements in the various phases of the construction process. The project focuses on four selected themes: processes, optimisation, energy use and GHG emissions using LCA methodology. The study is based on a review of theory, evaluation of existing practice and previous and ongoing research. The project incorporates experiences from findings in the project using case study, Lia kindergarten (here in referred as Lia barnehage).

This report summarises the output from construction phase LCA study performed under the pre-project. To follow, Chapter 2 outlines the goal and scope of the LCA study including the description of system boundary considered in the study. Chapter 3 describes the inventory and background data source for the construction site activities within the system boundary. Chapter 4 summarizes the lessons learnt from the GHG construction emissions calculation and evaluation of Lia barnehage.

# 2. Goal and scope of the LCA study

The goal of the LCA study is to analyse and document the construction phase emissions from Lia barnehage building. A functional unit of 1 $m^2$ of heated floor area over an estimated building lifetime of 60 years is considered. The total heated floor area is 1600 $m^2$. The environmental performance is calculated in terms of GHG emissions calculated as carbon dioxide equivalents ($CO_{2eq}$) according to the IPCC GWP 100-year method [4].

The system boundary considered in this study is shown in Figure 1. The construction site activities considered harmonise EN 15804 [5], EN 15978 [6] and include person transport as outlined in prNS 3720 [7]. The calculations are performed using actual data collected onsite during the construction period, from 10th April 2017 until 27th November 2017 (166 days). Appendix A includes a selection of photographs from the construction process.

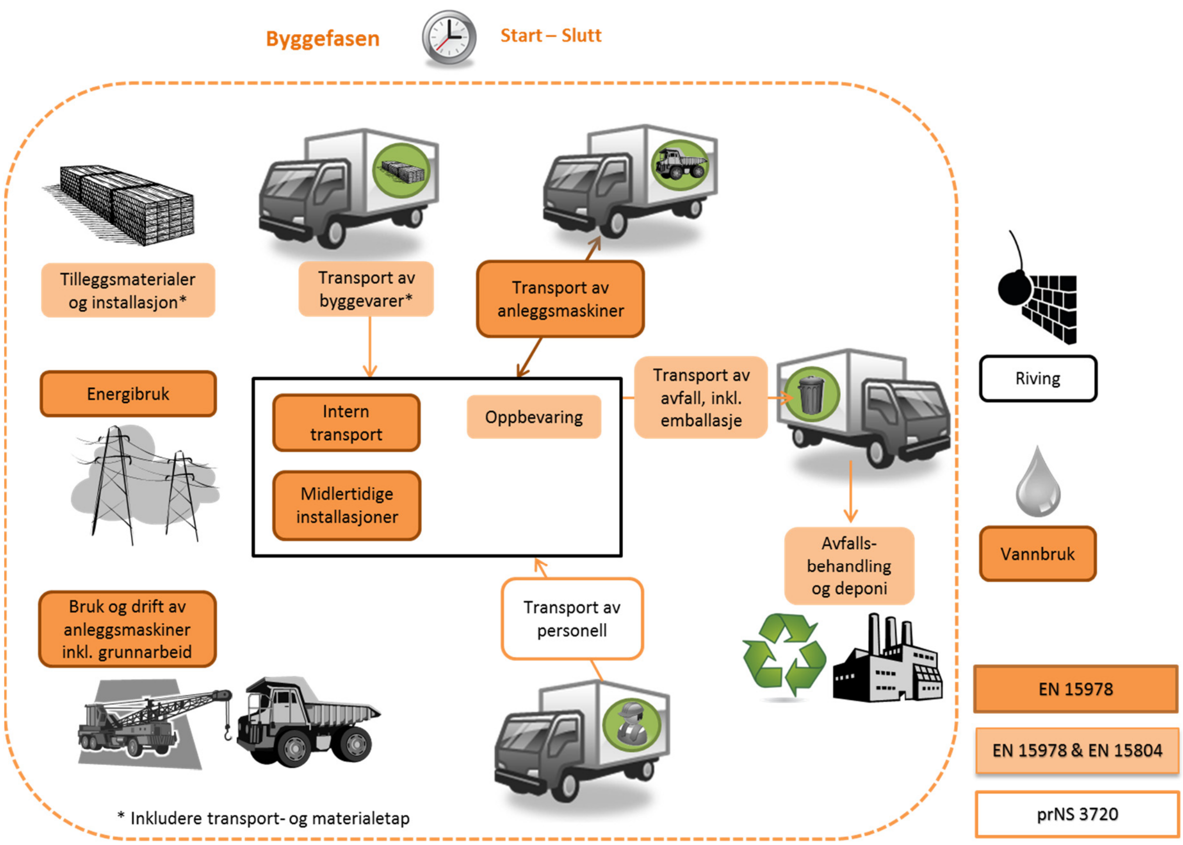


Figure 1. Construction site activities considered in the study.

Activities considered include transport of building materials, construction machinery, energy use, temporary works, waste management and person transport (see Figure 1). Any demolition works belong to the previous life cycle of the existing building, and any cleaning services or water use during the construction period are not accounted for in both phases. In Figure 1, orange text boxes denote construction activities included in the system boundaries described by EN 15978 and EN 15804; orange text boxes with a brown frame denote construction activities included in the system boundary described in EN 15978 only; the white text box with an orange frame denotes construction activity included in prNS 3720 only; and the white text box with a black frame denotes demolition activity not included in the system boundaries of EN 15978, EN 15804 or prNS 3720.

## 3. Inventory and data sources

The GHG emission calculations from the construction phase are performed using actual data collection during construction period. Actual, detailed inventory data were collected through invoices, building site reports, product data sheets and through waste report waste plan filled out by Skanska. The construction inventory was structured according to the construction activity posts identified in EN 15978, EN 15804 and prNS 3720. The main construction activities considered summarised into the following seven categories (Figure 1): i) transport of building materials ii) use of construction machinery, iii) energy use, iv) temporary works, v) construction waste, and vi) person transport. Detailed description of the construction site activities is given in Chapter 2.1-Chapter 2.6.

### 3.1 Transport of building materials

The building material inventory summarised in Table 1 and has been used to ascertain how much of each building material is transported to the construction site. The weight of the materials and transport distance is collected from bills collected from the construction site. The location of factories and construction site is taken into consideration to ascertain the actual transport distances travelled by the building material. The emission factor for the transportation mode has been obtained from ecoinvent v3.1 [8]. Due to lack of data related to transport mode, >32t EURO 3 class truck or lorry 16-32t EURO3| has been used as default truck. It has been assumed that any auxiliary materials required for the installation of the product (e.g. sealing tapes and screws) are transported together with the building material. This measure has been implemented to avoid any double counting of material transportation. The energy use from hand tools (e.g. drills) used during installation is excluded due to lack of data. It would be useful to perform a sensitivity analysis in order to evaluate the contribution of this products in further studies. The heavy equipment such as loaders, diggers and excavators necessary to install the various building assemblies is reported under construction machinery. It is acknowledged that the emission from transport of main materials, not all materials, have been collected due to lack of data.

Table 1. Main building components and materials used in the Lia barnehage.

| **Building Parts** | **Building materials** |
|---|---|
| Groundwork and foundations | Steel reinforced, cast in-situ strip foundations with low carbon concrete, 100mm EPS insulation and a damp proof membrane. |
| 21 Groundworks and foundations | Steel reinforced from Celsa; In-situ concrete B35M40/MF40 low carbon A from Betong Øst; EPS insulation from Jackon |
| 22 Bæresystemer | Stålsøyler (1941,8 kg; Stålfabrikken), stålbjelker hattprofil (9510,7 kg, Stålfabrikken), K-virke (3179,9 kg; Kjeldstad), stålbjelker HEB (6657,5 kg, Stålfabrikken) |
| 23 Outer walls | Wooden cladding 956 $m^2$ fra Møre royal; Doors 2,34 $m^2$*9=21,1 $m^2$ fra Nordan; Insulation 635 $m^2$ from Rockwool; Windows 175$m^2$ fra Nordan; Vapour barrier 774 $m^2$ from Tommen Gram; Plasterboards 774 $m^2$ from Norgips; OSB 774 $m^2$ from Fritzøe-Engros |
| 24 Inner walls | Plasterboards 3416 $m^2$ from Norgips; OSB 3416 $m^2$ from Fritzøe-Engros; Ceramic tiles 696 $m^2$; Door 2,2 $m^2$*77 stk=169,4 $m^2$ fra Nordan; Glass front 69 $m^2$ fra Nordan; steel profiled inner walls 8,65 $m^2$; stud work wood 17,8 $m^2$ from Kjeldstad |
| 24 Slabs | **Slab on ground**: Reinforced concrete (Celsa), In-situ concrete (B30M40/MF40 low carbon A; Betong Øst), EPS Insulation (Jackon)<br><br>**Floors:** Hollow core conrete element HD200 847 $m^2$=170$m^3$ from Spenncon; Insulation 20 mm mineral wool 768 $m^2$=15,36 $m^3$ from Rockwool; Intergral cast 80 mm= 768 $m^2$ fra betong Øst; suspended ceiling 70mm=550 $m^2$ fra rockwool; vinyl 3mm=847 $m^2$ |
| 26 Roof | Steel 7668 kg from Skanska stålfabrikken; Rockwool "Steinull i kompakttak 820 $m^2$=250 mm=20,53 $m^3$*81,2 kg=1665kg; Foiletekking 820 $m^2$/2,9=283 kg fra Sika; OSB 820 $m^2$*4,6 kg=3772 kg fra Fritzoe-Engros |
| 28 Stairs | **Stairs**: Precast concrete 2,72 $m^3$*2400 kg=6528 kg from Betong Øst; Steel 8663 kg-(Nøkkelpros. Jotne ankers. Leveringspros.Tibnor); Wooden stairs 4,4 $m^3$=432kg/ $m^3$=1900,8 kg from Kjeldstad<br>Kebony pine clad steps and steel railings. |
| Technical equipment | PV, Water-based heating system, stainless steel ventilation channels, LED lighting. |

### 3.2 Construction machinery

The construction machinery includes both mobile and stationary machinery used during construction. A visual overview of the different types of construction machinery can be found in Appendix B. The GHG emissions associated with construction machinery include the production of machinery, transport of machinery to the construction site, and combustion of fossil fuels during operation (Table 2). The weight of the construction machinery has been collected from technical specifications. It is estimated that the construction machinery has a service life of 5 years. The onsite duration, service hours and fuel consumption of construction machinery is collected by the contactor. The GHG emission factor (2.26 $kgCO_{2eq}/kg$) for *Industrial machinery, heavy, unspecified, at plant RER / kg* has been selected as a default from ecoinvent v3.1, since there is a distinct lack of construction machinery included in life cycle inventory databases. The construction machinery, except the crane, has been transported from a construction park, located 55km from the construction site, providing an average roundtrip distance of 110km with an assumed transportation mode of >32t EURO 3 class truck, whereby the GHG emission factor for *Transport, freight, lorry >32 metric ton, EURO3 [RER] | Alloc Rec, U* was chosen as default from ecoinvent v3.1. All construction machinery consume biodiesel, apart from the crane, which consumes diesel. The well-to-wheel emission factors for diesel (3.24 $kgCO_{2eq}$/litre), and biodiesel (1.92 $kgCO_{2eq}$/litre) are used [9, 10]. The GHG effect of biodiesel is highly debatable, which is recommended to be evaluated in further studies.

Table 2. Summary of the construction machinery inventory data

| Machinery | Amount (pcs) | Weight (kg) | Production of machinery | | | | Machinery energy use on site | | | Transport of Machinery to site | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RSL (days) | Duration on site(days) | Utilization (%) | Emission factor ($kgCO_{2eq}/kg$) | Energy use | Amount (litre) | Emission factor for fuel used (kgCO2eq/liter) | Transport distance (km) | No of trips | Mode of transport | Emission factor for mode of transport (kgCO2eq/kgkm) |
| CATERPILLAR 320EL Hydraulic Excavator | 1 | 21 500 | 1 825 | 33 | 0,6 | 2,26 | Biodiesel - HVO100 | 11760,9 | 1,92 | 55 | 2 | Lastebil, >32t, EURO3 | 0,0000895 |
| HITACHI Zaxis 210LC Excavator | 1 | 20 115 | 1 825 | 142 | 0,6 | 2,26 | Biodiesel - HVO100 | | | 55 | 2 | | |
| GIANT V6004 HL-3, 3-01 Loader | 1 | 3 400 | 1 825 | 44 | 0,6 | 2,26 | Biodiesel - HVO100 | | | 55 | 2 | | |
| GIANT V6004T X-TRA Loader | 1 | 3 300 | 1 825 | 67 | 0,6 | 2,26 | Biodiesel - HVO100 | | | 55 | 2 | | |
| Commando DC130Ri Dril | 1 | 3 250 | 1 825 | 80 | 0,6 | 2,26 | Biodiesel - HVO100 | | | 55 | 2 | | |
| Dynapac LF80A vibroplate | 1 | 78 | 1 825 | 30 | 0,6 | 2,26 | Biodiesel - HVO100 | | | 55 | 2 | | |
| 90 tonn AT Crane | 1 | 9 000 | 1 825 | 21 | 0,6 | 2,26 | Diesel | 11690,9 | 3,24 | 22 | 2 | Lastebil, >32t, EURO3 | 0,0000895 |
| 45 tonn kranbil | 1 | 4 500 | 1 825 | 0,8 | 0,6 | 2,26 | Diesel | | | 22 | 2 | | |

## 3.3 Energy use

Energy use consists of onsite energy use for heating, cooling, ventilation, drying and lighting during the construction period. According to SKANSKA, all the energy used from the start of construction (10th April 2017) until the end (27th November 2017) is electricity, which has been supplied directly from the electricity grid (Table 3). GHG emission factors from the ZEB research centre have been used for electricity from the grid (0.132 $kgCO_2eq/kWh$).

Table 3. Summary of energy use inventory data

| Energy use | Amount (kWh) | Emission factor ($kgCO_{2eq}/kWh$) |
|---|---|---|
| Electricity from the grid | 27700 | 0.132 |

## 3.4 Temporary works

Temporary works provide access, protection, support and services to construction workers, and aid the construction process. The temporary works include, amongst other things; construction offices, lighting, security fences, diesel tank, hand tools, safety clothing, health and safety information boards, pallets, waste containers, provisional makeshift timber stairs and scaffolding. Due to lack of data the emission calculations are carried out for just some of the temporary works shown in Table 4. Appendix C includes a selection of photographs for temporary works from the construction process. GHG emission calculations associated with the temporary works consider the production and transportation of temporary works to the construction site.

Table 4. Summary of temporary work inventory data

| Temporary work | Duration on site (days) | Production of temporary works | | | | | Transport of temporary work to site | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Amount | Unit | Weight (kg) | Service life (days) | Emission factor ($kgCO_{2eq}$/unit) | Distance | Transport mode | Emission factor for mode of transport ($kgCO_{2eq}$/kgkm) |
| *Security fence - galvanised steel (LxH: 3,5x2 m)* | *183* | *960* | *m2* | *3,14* | *21900* | *4,81* | *14* | *Lastebil, >32t, EURO3* | *0,0000846* |
| *Aluminium rammestillas* | 66 | 900 | m2 | *1,30* | *21900* | *4,6* | *14* | *Lastebil, >32t, EURO3* | *0,0000846* |
| *10' storage container (2991 x 2438 x 2591m)* | 122 | 5 | pcs | *680* | *21900* | *4,81* | *7,6* | *Lastebil, >32t, EURO3* | *0,0000846* |
| *HMS-container 8' (2991 x 2438 x 2591mm)* | 121 | 1 | pc | *1350* | *21900* | *269* | *14* | *Lastebil, >32t, EURO3* | *0,0000846* |
| Modular 4 offices | 100 | 4 | pcs | *3150* | *18250* | *269* | *14* | *Lastebil, >32t, EURO3* | *0,0000846* |
| Modular 3 dinning rooms | 100 | 3 | pcs | *3000* | *18250* | *269* | *14* | *Lastebil, >32t, EURO3* | *0,0000846* |
| Modular 3 changing rooms | 100 | 3 | pcs | *3800* | *18250* | *269* | *14* | *Lastebil, >32t, EURO3* | *0,0000846* |
| *Dieseltank rund (1000 ltr.)* | 129 | 1 | pc | *190* | *21900* | *4,81* | 102 | *Lastebil, >32t, EURO3* | *0,0000846* |
| *Dieseltank vera 1050L ADR (1000 ltr.)* | 129 | 1 | pc | *530* | *21900* | *4,81* | 102 | *Lastebil, >32t, EURO3* | *0,0000846* |

The material inventory for temporary works has been collected via observations at the construction site. The weight and service life time data of temporary works are collected from product specifications. The transported from and to the construction site is calculated using an average roundtrip distance and an assumed transportation mode of >32t EURO 3 class truck, whereby the GHG emission factor for *Transport, freight, lorry >32 metric ton, EURO3 [RER] | Alloc Rec, U* was chosen as a default from Ecoinvent v3.1.

### 3.5 Construction waste

The construction waste includes material losses during the construction process, including packaging and the additional production and transportation processes to compensate for the loss of wasted products, and the processing of all waste up to an end-of-waste state or disposal of final residues. It was difficult to get data for the production and transport of additional materials used to replace wasted materials during the construction process. Thus, it has been assumed that additional materials are transported together with building materials whilst all inputs related to the additional materials production processes to compensate for the loss of wastage of products is excluded. The GHG emission calculations associated with the construction waste consider the transport of waste to the treatment plant, waste processing (recycling or incineration) and waste disposal. Table 5 summarises the construction waste inventory data.

Table 5. Summary of construction waste inventory data

| Construction waste | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Construction Waste | | | *Tansport of construction waste to waste processing site* | | | *Construction waste processing* | | | | | |
| | | | | | | *Waste processing* | | | | *Waste disposal* | |
| Type | Amount | Unit | Distance (km) | Transport Mode | Emission factor for transport mode (kgCO2eq/kgkm) | Waste to recycling (%) | Emission factor for recycling (kgCO2eq/kg) | Waste to incineration (%) | Emission factor for incineration (kgCO2eq/kg) | Waste to landfill (%) | Emission factor for landfill (kgCO2eq/kg) |
| Untreated wood | *28140* | *kg* | 50 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,0069 | 0,0000 | 0,9916 | 0,0100 | 0,0014 | 0,0054 |
| Paper, cardboard and carton | 3840 | *kg* | 50 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,9504 | 0,0000 | 0,0476 | 0,0300 | 0,0020 | 0,0054 |
| Glass | 0 | *kg* | 0 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,6741 | 0,0000 | 0,0000 | 0,0000 | 0,3258 | 0,0054 |
| Iron and other metals | 3980 | *kg* | 50 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,9997 | 0,0000 | 0,0000 | 0,0000 | 0,0002 | 0,0054 |
| Gypsum based materials | 8900 | *kg* | 50 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,6784 | 0,0000 | 0,0000 | 0,0000 | 0,3216 | 0,0054 |
| Plastic | 1040 | *kg* | 50 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,7925 | 0,0000 | 0,0876 | 2,5700 | 0,1199 | 0,0054 |
| Concrete, brick, Leca andother heavy building materials | 0 | *kg* | 0 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,7713 | 0,0000 | 0,0000 | 0,0000 | 0,2287 | 0,0054 |
| Electronic waste | 0 | *kg* | 0 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,7664 | 0,0000 | 0,1216 | 0,0000 | 0,1120 | 0,0054 |
| Mixed waste | 10480 | *kg* | 50 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,0005 | 0,0000 | 0,9572 | 0,5200 | 0,0422 | 0,0054 |
| Hazardous or special waste | 1040 | *kg* | 50 | Lastebil, 16 - 32t, EURO3 | 0,000169 | 0,2246 | 0,0000 | 0,2205 | 2,6800 | 0,5549 | 0,0054 |
| Total sorted construction waste | *49 340* | *kg* | | | | | | | | | |
| Total construction waste | *59 820* | *kg* | | | | | | | | | |
| Sorteringsgrad | 82,5 | % | | | | | | | | | |

Data on the total amount and type of onsite construction waste generated have been collected from the final waste report obtained from waste treatment facilities. The amount of materials going to the various treatment processes (recycling or incineration) and final disposal are based on waste treatment data from Statistics Norway [11]. The transport of waste for treatment is based on an assumption that it is 50 km from the building site to the nearest recycling and incineration facility, and 50 km to the nearest landfill. The GHG emission factor from ecoinvent v3.1 process for *Transport, freight, lorry 16-32 metric ton, EURO3| Alloc Rec* is chosen as a default.

### 3.6 Person transport

Person transport includes the one-way transport of construction professionals to the construction site. This includes transport of construction site workers, including construction equipment operators, electricians, plumbers, carpenters, floorers, roofers, painters, ventilation and PV installers. Data on the number of trips, people per trip, and distance travelled are collected by Skanska. There is an assumption that all person transport is based on diesel fuel. An emission factor of 0.24 $kgCO_{2eq}$/person.km is used for the percentage of journey that takes place under 50km/hour, whilst an emission factor of 0.16 $kgCO_{2eq}$/person.km is used for the percentage of journey that takes place over 50km/hour. These emission factors are based on a well-to-wheel analysis [12]. Table 6 summarises the person transport inventory data.

Table 6. Summary of person transport inventory data

| Enterprenør og location | Dato | Kjøretøytype | Antall turer | Antall personer | Antall bil | Kjørelengde (km) |
|---|---|---|---|---|---|---|
| *Skanska Husfabrikken - leilighet Seljeveien Oslo* | *13.06.17-01.10.17* | *Bil <1.4l, EURO 4* | *57* | *7* | *3* | *14* |
| Park og Anlegg - Lillestrøm | 03.05.17-27.11.17 | *Bil 1.4-2l, EURO 4* | 149 | 3 | 2 | 10 |
| Spenncon -Hamar- hotell oslo | 26.06.17-10.07.17 | *Bil <1.4l, EURO 4* | 11 | 2 | 1 | 6 |
| Lett-Tak - hotell Olavsgård | 10.07.17-13.07.17 | *Bil <1.4l, EURO 4* | 4 | 3 | 1 | 15 |
| Follo Tak og vedlikehold - Ski | 17.07.17-16.09.17 | *Bil <1.4l, EURO 4* | 45 | 2 | 1 | 36 |
| Nordic Crane- HOTELL | 19.06.17-13.07.17 | *Bil <1.4l, EURO 4* | 19 | 1 | 1 | 12 |
| Hæhre Gulvstøp- ASKER | 10.07.17-20-07-17 | *Bil <1.4l, EURO 4* | 9 | 3 | 2 | 22 |
| Rørpartner- Oslo | 05.06.17-27.11.17 | *Bil <1.4l, EURO 4* | 126 | 4 | 2 | 8 |
| Kreativ Elektro- Ski | 05.06.17-27.11.17 | *Bil <1.4l, EURO 4* | 126 | 4 | 2 | 22 |
| Ing. Oddbjørn Hagen- Jessheim | 14.08.17-27.11.17 | *Bil <1.4l, EURO 4* | 76 | 2 | 1 | 31 |
| Regnbuen malermester - Alnabru Oslo | 21.08.17-27.11.17 | *Bil <1.4l, EURO 4* | 71 | 4 | 2 | 5 |
| Firesafe - Lillestrøm | 11.09.17-27.11.17 | *Bil <1.4l, EURO 4* | 56 | 1 | 1 | 8 |
| Acusto himling - Skanska Oslo | 15.09.17-27.11.17 | *Bil <1.4l, EURO 4* | 52 | 2 | 1 | 15 |
| Marbre, innvendig tømmer- Jessheim | 10.07.17-31.10.17 | *Bil <1.4l, EURO 4* | 82 | 4 | 2 | 31 |
| Lås og beslag - Oslo | 02.10.17-27.11.17 | *Bil <1.4l, EURO 4* | 41 | 2 | 1 | 15 |
| Bille, innvendig møbler- hotell Olavsgård | 23.10.17-27.11.17 | *Bil <1.4l, EURO 4* | 26 | 2 | 1 | 6 |
| Otis heis- Oslo | 09.10.17-20.10.17 | *Bil <1.4l, EURO 4* | 31 | 2 | 1 | 15 |
| Jotne, stål + trapper - Sarpsborg | 19.09.17-20.10.17 | *Bil <1.4l, EURO 4* | 24 | 2 | 1 | 92 |

# 4 Results and discussions

## 4.1 GHG emission results

The GHG construction emission results are 1.19 kg CO2eq/m2/yr, 1970 kg CO2eq/yr, 72 kgCO2eq/m2 over a 60-year lifetime and 114 413 kgCO2eq in total (Table 7).

Table 7. GHG emissions from construction site activities

| Construction site activities | $kgCO_{2eq}$ | $kgCO_{2eq}/yr$ | $kgCO_{2eq}/m^2$ | $kgCO_{2eq}/m^2/yr$ |
|---|---|---|---|---|
| Transport of building materials | 52 863 | 881 | 33 | 0,55 |
| Person transport | 10 887 | 181 | 6,8 | 0,11 |
| Machinery | 38 728 | 645 | 24,2 | 0,40 |
| Energy use | 3 656 | 61 | 2,3 | 0,04 |
| Waste | 7 495 | 125 | 4,7 | 0,08 |
| Temporary work | 785 | 13 | 0,5 | 0,01 |
| **Total** | **114 413** | **1 907** | **72** | **1,19** |

The largest contributor to GHG emissions from the construction site is transport of building materials (46% or 0.55 kgCO2eq/m2/yr). This is followed by construction machinery (34% or 0.40 $kgCO_{2e}q/m^2/yr$), person transport (10% or 0.11 $kgCO_{2eq}/m^2/yr$), construction waste (7% or 0.08 kgCO2eq/m2/yr), energy use (3% or 0.04 kgCO2eq/m2/yr), and temporary works (1% or 0.01 kgCO2eq/m2/yr) (Figure 2).

The transport of prefabricated wall construction to site represents 93% of the total emission from transport of the building materials considered. Here it is acknowledged that the transport data for all materials was not included in the analysis.

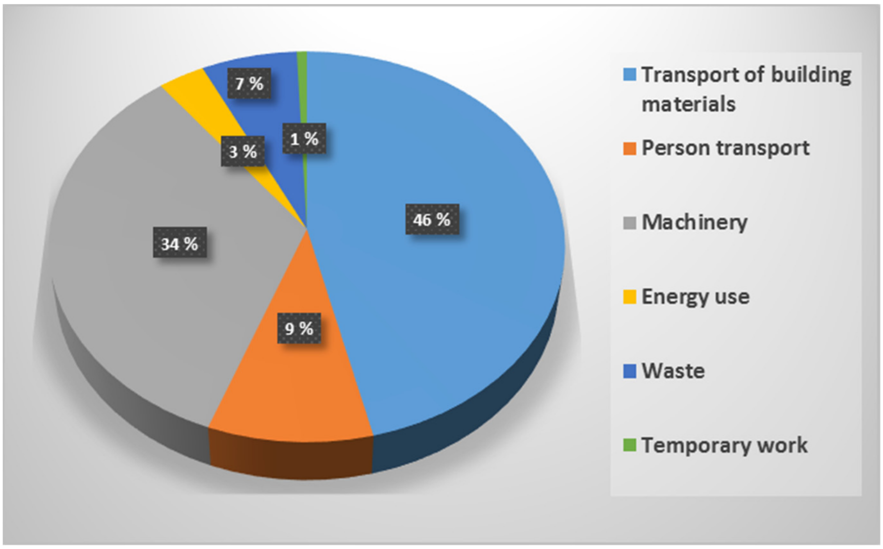

Figure 2. GHG emission results from Lia barnehage construction site activities

Figure 3 shows a breakdown of embodied emissions from construction machinery. Of these emissions, the largest contributor to $CO_{2eq}$ emissions is from the fuel use of construction machinery (90% or 0.36 kgCO2eq/m2/yr) followed by emissions from the production of construction machinery (8% or 0.03 kgCO2eq/m2/yr). Emissions from the transport of construction machinery are 1% or 0.006 kgCO2eq/m2/yr.

The excavators (CATERPILLAR 320EL Hydraulic Excavator, HITACHI Zaxis 210LC Excavator), loaders (GIANT V6004 HL-3, 3-01 Loader, GIANT V6004T X-TRA Loader), drill (Commando DC130Ri Dril) and vibroplate (Dynapac LF80A) machineries, which used biodiesel, contribute 68% of the total emission from construction machinery, whilst the cranes contribute 32% of the total emission from construction machinery. Even if the cranes were driven by diesel, were only used for 21 days during the construction period.

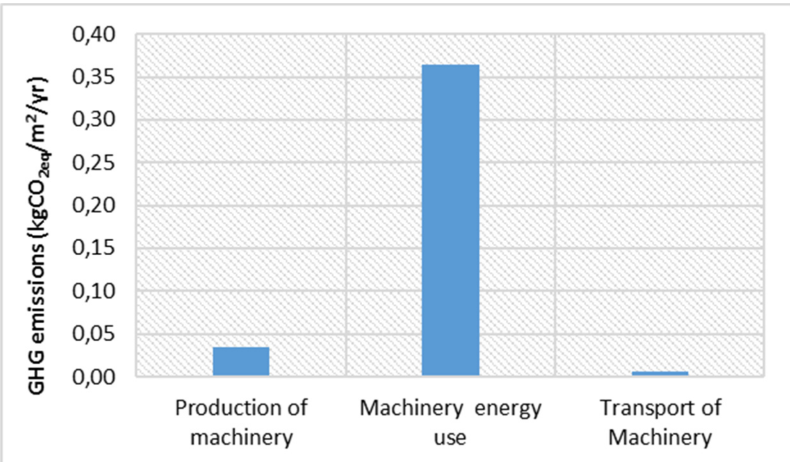

Figure 3. Breakdown of GHG emissions from construction machinery

The largest contributor to GHG emissions in construction waste is mixed waste which represented 71% of the total construction waste emission. This followed by plastic waste (11%), hazardous waste (8%), untreated wood waste (7%), Paper, cardboard and carton (1%), Iron and other metals (1%) and gypsum-based materials (1%) (Table 8).

Table 8. GHG emissions from the construction waste

| Waste | Weight (kg) | Emissions from transport (kgCO2eq) | Emissions from waste processing and disposal (kgCO2eq) | Total emissions from waste (kgCO2eq/) |
|---|---|---|---|---|
| Untreated wood | *28140* | 273,45 | *279,25* | *552,70* |
| Paper, cardboard and carton | 3840 | 37,32 | 5,52 | *42,84* |
| Glass | 0 | 0,00 | 0,00 | *0,00* |
| Iron and other metals | 3980 | 38,68 | 0,00 | *38,68* |
| Gypsum based materials | 8900 | 86,49 | 15,46 | *101,94* |
| Plastic | 3440 | 33,43 | 776,68 | *810,11* |
| Concrete, brick, Leca andother heavy building materials | 0 | 0,00 | 0,00 | *0,00* |
| Electronic waste | 0 | 0,00 | 0,00 | *0,00* |
| Mixed waste | 10480 | 101,84 | 5218,75 | *5320,58* |
| Hazardous or special waste | 1040 | 10,11 | 617,69 | *627,80* |

The emission from energy use is relatively low (3% of the total GHG emission from construction site activities). Including the energy use from

The relative lower emission results from temporary works (1%) is due to the difficulties in collecting specific life cycle inventory data and/or emission factors due to lacking good data sources.

## 4.2 Sensitivity analysis

Sensitivity analyses is performed to test the robustness of the LCA results in relation to the variation of the main input parameters. In particular, these analyses are used to quantify the effect of emission reduction measures on the LCA outcomes resulting from fuel use of the construction machinery. In Lia barnehage, the use of biodiesel was considered as one emission reduction measure. As shown in Table 7 and Figure 2, construction machinery (34%) are the second main GHG emission contributor. From construction machinery, 90% of GHG emission is from fuel used. In this study, a sensitivity analysis is performed to evaluate the emission reduction from construction machinery fuel use considering four potential alternative fuel scenarios (Table 8). One worst case scenario (use of diesel only) and three best case scenarios (use of biodiesel only and electricity only for two different emission factors for electricity) are considered. The actual data from Lia barnehage is used as a base case in the sensitivity analysis.

Table 8. Sensitivity analysis of the energy use in construction machinery

| Scenarios | Description/assumptions | Emission factor ($kgco_{2eq}$/litre) |
|---|---|---|
| Base case scenario | Actual data from Lia barnehage | 3,24 for diesel and 1,92 for biodiesel |
| Scenario 1 | If all machineries use diesel only | 3,24 |
| Scenario 2 | If all machineries use biodiesel only | 1,92 |
| Scenario 3 | If all machineries use electricity only | 1,318 (the Norwegian ZEB centre emission factor for electricity=0,132kg$CO_{2eq}$/kWh[13] =1,318kgCO2eq/litre) |
| Scenario 4 | If all machineries use electricity only | 0,250 (using Ecoinvent v3.1 emission factor for NO elmix=0,025kg$CO_{2eq}$/kWh [8] =0,250 kg$CO_{2eq}$/litre)) |

The results in Figure 4 shows that the use of biodiesel in place of diesel for excavators, loaders, drill and vibroplate machineries reduced the emission from the construction site by 13%.

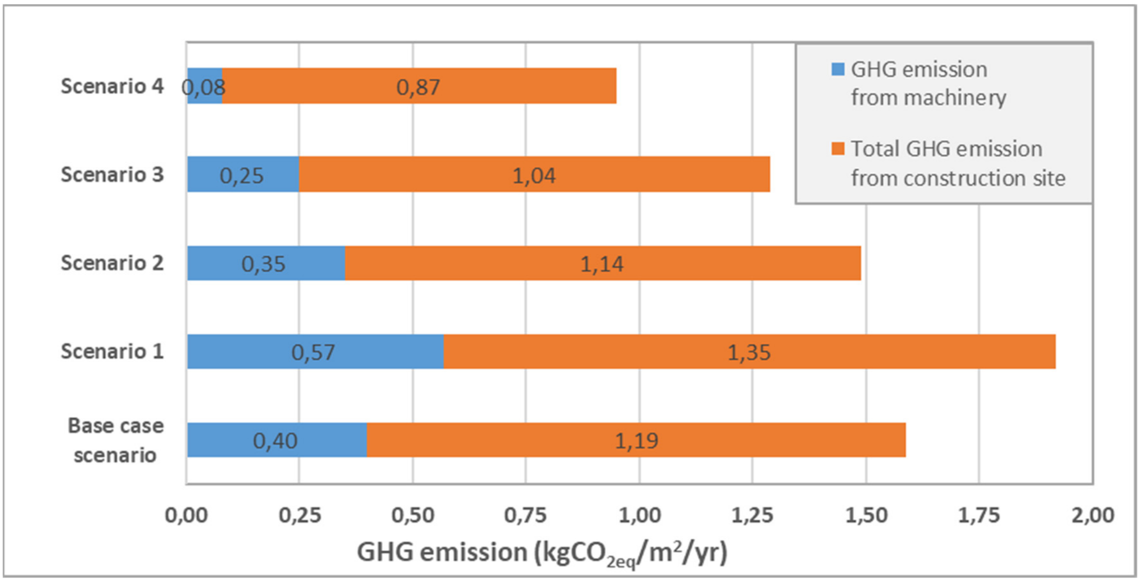

Figure 4. Results from sensitivity analysis

The GHG emission from the construction site would have been further reduced by 4% if biodiesel was also used for the cranes and by up to 13 % (using the Norwegian ZEB centre emission factor for electricity) to 27% (using Ecoinvent database emission factor for electricity) if electricity is used as fuel source for all machineries.

## 4.3 Lessons learnt

In this chapter, some of the lessons learnt from the GHG construction emissions calculation and evaluation of Lia barnehage project are summarized.

***Inventory data***: Experiences from data collection show that the quality of the inventory and background data source used can greatly affect GHG construction emission calculations. It is recommended to develop a construction site life cycle inventory database with emission factors for common construction site activities. The laborious process of data collection in this study, has also highlighted the importance of using data collection sheet at the early project phase to simplify the construction site data collection process, and improve data quality and transparency. It would also be important to develop a system in which the data collection sheet is filled/checked by different stakeholders at different stages of the construction process. Although construction phase activities are typically project specific, the data collection procedure and calculation methodology presented in this work can be used as a reference for performing GHG emission calculations in future construction projects.

***Sensitivity analysis***: A sensitivity analysis is performed to evaluate the impact of emission reduction measures. The use of biodiesel in place of diesel as a fuel source for construction machineries enabled to reduce the GHG emissions from construction site activities by 13%. The results from a sensitivity analysis also show the potential reduction of emission from the construction site up to 27% by using construction machineries driven by electricity. The result from the sensitivity analysis shows the GHG emission reduction achieved through emission reduction measures (use of biofuel in construction machinery) considered in the project. However, it was difficult to perform a sensitivity analysis to evaluate the results from other emission reduction measures due to lack of data. For example, even if transport logistics (e.g. use of prefabricated materials) is mentioned as one measure, which enables to reduce emission, the result from the LCA study shows transport of materials to the construction site as the main GHG emission contributor. It would have been interesting to perform a sensitivity analysis in order to evaluate the results from transport logistics. Thus, it is recommended to develop a methodology to incorporate sensitivity analysis to evaluate emission reduction measures, inventory and emission data quality.

***LCA at early design phase***: Even if emission reduction measures have been considered in the early design phase, the impact of these measures were not evaluated using LCA. Performing LCA in the early design phase would have helped to further evaluate, plan and compare GHG emission reduction measures. The results from the early design phase would have been also used to compare with the results from construction phase. It is therefore recommended to perform LCA at the early design phase.

***Reference projects***: The LCA calculation methodology and emission reduction measures considered in this study can be used as a reference for other projects. Further study is required to collect case studies of different building typologies to gain experience in evaluating and minimising the potential environmental impacts from other types of construction sites.

***Climate budget***: Given the magnitude of the construction phase carbon spike, it is important to evaluate how construction site emission reduction activities can contribute to reaching global, national and regional GHG mitigation goals. For example, Oslo pledges to reduce GHG emissions to 50% below 1990 levels by 2020 and by 95% by 2030. It is important to evaluate how or in what degree the emission reduction measures from construction phase enables Oslo to meet its goals and its contribution to Norway's pledged reductions.

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## Appendix A. Photographs from the construction process

26.06.2017

20.10.2017

04.12.2017

## Appendix B. Photographs of the construction machinery found on site

Crane


HITACHI Zaxis 210LC Gravemaskin


CATERPILLAR 320EL Hydraulic Gravemaskin


GIANT V6004 HL-3, 3-01 Hjullaster


GIANT V6004T X-TRA Hjullaster


Dynapac LF80A Vibroplate

## Appendix C. Photographs of the temporary work found on site


HMS containers


Fuel tanks

Waste containers

Modular offices, dinning and changing rooms

Security fences

# GHG EMISSION CALCULATION FROM CONSTRUCTION PHASE OF LIA BARNEHAGE

This report summarises the construction phase life cycle assessment methodology used to calculate the GHG emissions from a case study (Lia kindergarten) considered under "Utslippsfrie byggeplasser forprosjekt".

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