BACHELOR THESIS

# Case study on improving the environmental sustainability in construction processes for Alma Tomingas project

Author: Enriko Armand Kalk

Student number: S-2320355

BSc Civil Engineering

FACULTY OF ENGINEERING TECHNOLOGY

**EXAMINATION COMMITEE**

Dr K. Vink (Karina)

**External supervisor**

Brit Põldaru

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# 1. Abstract

Main construction contractor companies' highest priority is efficiency and speed of construction while ensuring the safety of the construction site's processes. Environmental health and sustainability are not yet the main goals for construction companies although the construction industry's operations make up to 28% of global $CO_2$ emissions. However, the emissions and environmental impact of the construction phase are often discarded and considered negligible for some existing research (Bilec, 2006).

Research about construction processes and their environmental impact is rudimentary, contractor companies do not store data about the used machines and vehicles and how much emissions they generate, and not all electricity usage is recorded. Here we show that fuel-based vehicles and machines produce the largest emissions from the construction processes and the electricity production for on-site maintenance electricity consumption generates the most emissions. From the construction processes, fuel-based machines and vehicles produced 88% (127.000 kg $CO_2$ equivalents) of the construction processes' emissions, but the electricity production for the amount of electricity consumed during the whole project makes up to 70% of total emissions (598.000 kg $CO_2$ equivalents). To make the construction processes more environmentally sustainable, the fuel-based machines and vehicles should be changed into electricity-based ones. There are no electrical construction vehicles available on the current construction machinery market for all construction works, only small excavators. To make the construction processes more environmentally sustainable from the main contractor's perspective, the company should invest in buying their electricity from a renewable energy source to reduce the total emissions generated for a construction project.

The results of this study show how large environmental impact construction processes have and that is done by creating a life cycle assessment (LCA), which is the method to measure the environmental impacts associated with a given product or process, in this case, the construction project Alma Tomingas. Each vehicle and machine and its fuel consumption and work duration on the construction project are measured and translated into emissions generated by each process. The diesel-based machines and vehicles' direct $CO_2$ emissions are calculated and for electricity-based machines, the amount of electricity required to produce is translated to kilograms of $CO_2$ equivalents by the GaBi software.

# 2. Introduction

## 2.1 Background

The main task of contractor companies is to manage and administer the construction process, prioritising the efficiency and speed of construction while ensuring the safety of the overall construction site processes. The highest priority of contractor companies is to aspire for optimal revenue, which is achieved with successful management. Environmental health and sustainability are not yet the main goals for construction companies, although the construction industry is producing nearly 40% of global greenhouse gases, where building materials and construction make up to 11% and building operations up to 28% of the global $CO_2$ emissions (GlobalABC, 2018). The construction industry has a significant role in global emissions, but what could be changed to improve this situation? The Intergovernmental Panel on Climate Change (IPCC) has emphasised environmental health and sustainability in different sectors, including construction. Recent technological developments enable construction to modernise zero-energy buildings, thus making them more attainable. (Intergovernmental Panel on Climate Change, 2022). Various efforts to increase the energy efficiency of buildings have been implemented, conforming to a near zero-energy standard being one of them (Sustainable Governance Indicators, 2020). With advancements like these, the construction industry can become more sustainable in the energy section and reduce $CO_2$ emissions in general.

Currently, construction companies tend to manage their projects in a traditional non-sustainable way. Many countries overlook sustainable development and do not support Sustainable Development Goals (SDG) by not adopting the SDG agendas, but how can this situation improve? Many countries supporting SDGs have created policies toward more environmentally friendly construction solutions. Estonia has been ranked $9^{th}$ in an international comparison regarding environmental policies as it supports the EU goals of achieving climate neutrality by 2050 (Sustainable Governance Indicators, 2020). Estonia has already created programs for a more sustainable construction sector, aiming for higher energy-efficient housing and better cost-efficient living environments to improve the consumption capacity of people in Estonia (Ministry of Economic Affairs and Communications, 2020). With technology advancing, sustainable alternatives are becoming cheaper and more attainable, making traditional ways more expensive and forcing countries to change the regime to more sustainable construction. Therefore, it is up to construction companies to implement and adopt more sustainable solutions to support the environmental policies and goals on the local level. On the national scale, countries must create policies and regulations to force traditional ways out of business, thus changing the regime.

Energy costs in Europe are rising because of the current sanctions applied on Russia, affecting Europe's natural gas and fuel prices. The total energy demand is increasing because consumption on an individual level has been rising in recent decades; economic growth raises incomes, and the population is growing (Hannah Ritchie, 2020). Electricity consumption in building operations represents approximately 55% of total global electricity consumption (Global Alliance for Buildings and Construction, 2020), but what new measures should be considered for the construction process to become more sustainable? Since the 1980s, sustainable development has become more prevalent within the construction and other industries due to growing awareness of the ecological crisis (Pisani, 2007). Many countries that support a sustainable future have invested in alternative energy sources to reduce their dependence on fossil fuel-based energy sources and become more self-reliant on their energy needs. Since the on-site energy sources are mainly based on diesel, natural gas, and electricity, the fossil fuel price increase in Europe is pointing toward a change in the construction regime. Investing in environmentally friendly and sustainable alternatives like electric-based vehicles/tools and other eco-friendly solutions will become the new regime in the construction industry in the upcoming decades.

## 2.2 Aim of the Study

The current landscape for the construction industry consists of cheap, fast, and profitable projects. In construction, environmental sustainability is usually measured by the final product, how many environmentally sustainable elements are implemented for the building, like renewable energy sources and sustainable materials used for construction. There are multiple kinds of research on environmentally sustainable elements implemented on construction projects to make them "green," but limited research on making the construction process more environmentally sustainable. Each phase in a building's life cycle has environmental impacts, especially the construction phase. Therefore, the aim is to examine construction processes' environmental impact on the energy sector and compare each process's effects to find the environmental effects' bottleneck of the construction phase and make subsequent sustainable recommendations. The proposed research question for this study is "What construction processes have the largest environmental impact in the energy sector, in terms of emissions, and where to improve the sustainability of construction processes."

The environmental impact of the construction industry has been analysed and given more attention in recent years since it is producing a significant fraction of the total global emissions. Measuring the greenery of buildings is becoming a standard for construction as the LEED rating system is more widely used. LEED is a globally recognised symbol of sustainability achievement and leadership, measuring how buildings save money, improve efficiency, lower carbon emissions, and create healthier places for people (USGBC, 2022).

The result of an LCA study is an environmental profile of a product or activity, which gives a score list with environmental effects. The ecological profile shows the largest environmental problems caused by a product created in the LCA model (RIVM, 2018). The LEED rating system has credits in the energy and atmosphere section for the construction industry, like minimum energy performance and optimising energy performance, but not specific for construction processes.

## 2.3 Current Research

One scientific paper, similar to the aim of this study, by Melissa Bilec, performed a hybrid life cycle assessment of construction processes. The author combined the advantages and disadvantages of both LCA approaches: process and input-output methods and did a case study for the construction phase of a parking garage and developed a hybrid LCA for the construction processes (Bilec, 2006).

The research on the environmental health of the construction industry focuses on "green projects" where the resulting infrastructure is constructed of sustainable materials and/or is sustainable throughout its use, rather than measuring the processes involved in construction. Green construction differs from conventional construction because of its underlying principles and use of environmentally-friendly materials and technologies (Mokhlesian, 2014). Some existing research assumed that the impacts of the construction phase could be negligible; others indicated that construction's environmental impacts are underestimated (Bilec, 2006).

## 2.4 Involved Parties

The project this study investigates is conducted in cooperation with a construction contractor, Nordecon Betoon (NOBE), which belongs to the Nordecon Group. NOBE has been providing building contracting services and concrete work since 2000. They are one of the few construction companies in Estonia with their design unit, offering clients more flexible solutions. Their values are trustworthiness, flexibility, and creativity while following quality, environmental, and safety management. In their work, to prevent any potential adverse effects, they monitor and observe compliance with all environmental requirements, cooperating with partners with environmental-conscious worldviews (Nordecon Betoon OÜ, 2019). The project is conducted in cooperation with Nordecon Group.

## 2.5 Study Area


*Figure 1: Alma Tomingas commercial building*

Figure 1: Alma Tomingas commercial building represents the project on which this thesis will be based. The project this study investigates is located in Tallinn, Estonia, in a newly developed urban area called Ülemiste. The building will be a 12-story commercial building with a view of the airport and Ülemiste lake, a spacious design, and a tropical botanical garden through the first four stories. The client of the building has environment-friendly goals, aiming for high environmental sustainability and achieving the LEED Gold certificate as a green building for the Alma Tomingas project (Ülemiste City, 2021).

The project is currently at the stage of finishing works. That includes painting works, plaster works, low current works, construction of indoor ceilings, and installation of glass walls and floor covering works. The construction process started on 11.01.2021. The construction processes, including construction vehicles and machines, ended on 06.01.2022. After that, machines were no longer used, and the finishing works started from the 7$^{th}$ floor (the previous floors were also in progress).

# 3. Methodology

The methodology chapter describes and explains the choices of the chosen approach, research question, methods, simplifications and assumptions, and their reasoning. The choices for how the life cycle assessment is conducted, the dimensions and characteristics are explained, and the simplifications of how the life cycle assessment model is conducted.

## 3.1 Approach

In this report, the life cycle assessment differs from how life cycle assessments are often used. Generally, life cycle assessment represents all five phases of a product's life cycle – resources, transportation, production, operation, and end of life. LCA methodology is open to new scientific findings and improvements in the state-of-the-art technique (ISO 14044, 2006). In this report, only the product's life cycle production phase is conducted. That is because the aim is not to measure how green the building is when finalised – Alma Tomingas project already achieved the LEED Gold certificate, which points that the building is sustainable and green as the final product. The study consists of measuring, researching, and analysing the construction processes.

That means all other four life cycle phases will be put aside. Because due to time constraints, creating a whole life cycle assessment for the project requires much more research, time, and access to data can become inaccessible and confidential for some of the phases of the given project.

The overall focus is on processes in the energy sector. The energy sectors' processes measured will be divided into two categories: 1) energy use as combustion engine-based machines and vehicles used for the whole construction process, 2) energy use as electricity-based vehicles and machines, and 3) overall maintenance energy usage.

Data collection, validation, and verification are done through the construction company NOBE and sub-contractor companies providing vehicle services and equipment. The output data is measured in terms of $CO_2$ emissions - how much fuel is consumed and how much emissions the fuel production generates. How much electricity is used and how much emissions generating such electricity produces, and how much diesel engines are producing emissions as they are burning fuel. The impact assessment includes analysing and comparing the Climate Change factor in kg of $CO_2$ equivalents.

The software used to create the LCA model is GaBi Sphera's life cycle assessment tool. There are many different suppliers of LCA software tools on the market, but this platform offers a largely trusted LCA database which is the largest on the market (GaBi Shpera, 2022). GaBi datasets are generated in compliance with the ISO 14044 (Life cycle assessment – Guidelines and requirements), which this report follows. Since the project is in Estonia, GaBi provides a variety of emission data measured in more than 30 countries, in which Estonia is one of them (GaBi Shpera, 2022).

The method to analyse the construction process's climate change impact is the ReCiPe 2016 tool. ReCiPe 2016 is a method for the life cycle impact assessment in life cycle assessments that translates emissions and resource extractions into a number of environmental impact scores (Huijbregt, 2016). The method derives characterisation factors at the midpoint level and endpoint level. Midpoint indicators focus on single ecological problems, i.e. climate change or ozone depletion, and endpoint indicators focus on effects on human health, biodiversity, and resource scarcity, where all midpoints are converted to endpoints to simplify the interpretation of the final results. (RIVM, 2018). The ReCiPe method is chosen for this study because it can measure a lot of different impact categories. For further research of this study, the other emissions and depletions related to the construction processes can be included but due to time constraints, only the climate change impact category is analysed and measured.

The results from the GaBi analysed and measured in this study are the climate change impact category. Climate change translates all the emissions from products and processes into kilograms of $CO_2$ equivalents, which can be used to detect which of the processes generates the largest amount of emissions throughout the project's construction phase, therefore having the highest environmental impact.

The used data includes analysing the whole project's construction diaries, gathering information about the work duration of specific vehicles on the construction site, gathering information from subcontractors about specific vehicles used on the construction site and their fuel consumption, and data for overall maintenance electricity usage for the construction phase. The emissions calculated during the construction phase include all vehicles, which's information has been stored by the contractor company and overall electricity maintenance of the construction site.

## 3.2 Assumptions and Simplifications

Due to time constraints, a simplified version of the LCA is performed. One constraint is access to data on how much different construction vehicles consume fuel. Fuel consumption differs per vehicle, per engine size, and by different work. If the work involves lifting heavy objects, the engine must work on a higher load, consuming more fuel. Most vehicle providers do not provide such data since there is no average fuel consumption for a vehicle. Although, the data for fuel consumption of the vehicles used was given by the company's board members, who have such data for their monthly expenses. Luckily, data for the fuel consumption of all vehicles was gathered by contacting the providers.

Next, because the average fuel consumption is subjective input, the vehicle renting providers provided a range of fuel consumption that specific vehicles had, which when implemented to the model, can provide a more realistic outcome.

For creating the models, ten-hour workdays were used, but it can be assumed that vehicles on the construction site do not work ten hours straight: machines idle from time to time, and the workers take breaks. Therefore, two different datasets were made for the models: minimum working hours (7h) and maximum working hours (10h). Validating this choice is done by the expertise of Lauri Joel Eerik, an object manager of Nordecon Betoon with work experience of 8+ years, who stated: "When considering how long machines daily operate, on the construction site, construction workers are allowed to take a ten-minute break in every hour worked and hour-long lunch break. This makes up to 2.5 hours on a 10-hour workday." (Eerik, 2022)

The following formula was used to calculate the number of emissions diesel engine machines and vehicles produce. Based on the U.S. Energy Information Administration, a working diesel engine produces 22.38 pounds of $CO_2$ by burning a gallon of diesel fuel (U.S. Energy Information Administration, 2014). That translated into kilograms of $CO_2$ per litre of diesel equals 2.68 kg/l of $CO_2$.

Not all vehicles were implemented into the model. Some machines were rented for one day (for a special occasion or a specific job), and all of the handheld tools used by the construction workers were not included. A rule of thumb used by LCA users/analysts, 5%-rule, is applied for the project. The 5%-rule means that in case of insufficient input data or inaccessible data for a process or materials can be omitted if the process contributes with less than 1% of mass or renewable or non-renewable primary energy of the total and all excluded materials and processes do not excel 5 per cent of the total energy use and mass (EeBGuide Project, 2012). That is mainly applied because due to time constraints and access to data. Construction contractors do not save data like tools used for construction, which lowly affects the analysis outcome. This also applies to electric vehicles, such as scissor lift, which consumes less than 1kW throughout a working day. Construction processes also include transporting materials to the construction site and idling vehicles and equipment activity. However, since the main contractor company saves no such data, the environmental effect of these processes are discarded.

# 4. Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is a methodological tool used to quantitatively analyse the life cycle of products/activities within the context of environmental impact (RIVM, 2018). When performing an LCA, the requirements of ISO 14044 apply (ISO 14044, 2006). The life cycle assessment for this project measures the environmental impact of the construction processes used for this research. Life-cycle assessment can be regarded as one of the most suitable methodologies for assessing environmental impacts and measuring the environmental performance of the building as a whole (Anton, 2014); therefore, the life-cycle assessment method fits the best. LCA is an iterative four-phase process including:

1) the goal and scope definition phase
2) Life cycle inventory analysis phase
3) life cycle impact assessment, and
4) interpretation phase.

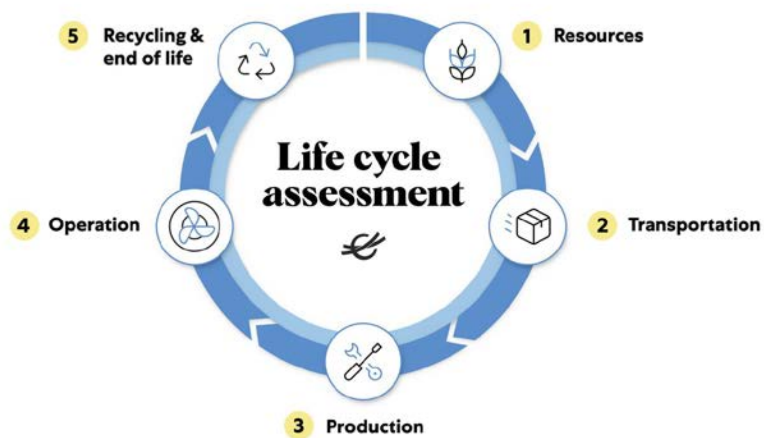


*Figure 2: Life cycle assessment phases (Climateworks, 2021)*

LCA is often used to measure the environmental performance for all phases of the project/building, but this study has a different approach to how the life cycle assessment is used. LCA considers the entire life cycle of a product, from raw material extraction and acquirement, through energy and material production and manufacturing to use and end-of-life treatment and final disposal. (ISO 14044, 2006) which is shown in Figure 2: Life cycle assessment phases (Climateworks, 2021). The production phase is the study's primary focus. The aim is to use LCA to measure the construction processes' environmental footprint, interpreted as the production phase. The product for LCA is the Alma Tomingas building itself, and the construction phase has lasted for over a year and a half. Various machines and vehicles have been used to construct this project, but emissions the processes have generated are not often measured for construction projects.

## 4.1 Phase 1: Goal

Setting the goal is essential for the whole life-cycle assessment project. The project's goal describes the intended application, reasons for carrying out the study, and the intended audience to whom the study's results are intended to be communicated (ISO 14044, 2006).

The goal is to analyse and measure the construction processes and understand what types of processes generate the most significant emissions and where the project can improve to reduce its environmental footprint. After the impact assessment, this study provides the company NOBE, to whom the recommendations will be addressed, with a better understanding of how big of an environmental impact the construction processes create and what alternatives could be considered for future projects.

Different machines used on the construction site are researched and analysed to measure their operation's environmental impact. Construction diaries are reviewed and analysed to create the most accurate and realistic model of the actual system in the LCA model. The regime for LCAs is to measure the whole life cycle of products, but the operation part is often set aside.

## 4.2 Phase 2: Scope Definition

The scope of the LCA depends on the subject and the intended use of the study. It should be sufficiently well defined to ensure the detail and depth of the study are compatible and sufficient to reach the stated goal (ISO 14044, 2006). The scope will include and define the following items:

1) Functional unit
2) System boundaries

### 4.2.1 Functional unit

The functional unit is a quantified description of the performance requirements related to the calculations and functions the LCA performs (Consequential-LCA, 2015). The functional unit defines what is being studied in the LCA (ISO 14044, 2006). The processes during the construction do not affect the environmental performance similarly and to compare the results, the measuring unit should be the same.

The functional unit of this study is "1kg of $CO_2$ emitted into the atmosphere from burning fuel in combustion engines, fuel production, and electricity production". This unit is selected to compare how much each construction process and sub-process affect the climate change indicators during the construction period.

### 4.2.2 System boundaries

LCA defines product systems as models describing the physical systems' key elements. The system boundaries set criteria to give confidence in the study's results and to reach the stated goals (ISO 14044, 2006). System boundaries should define which elements will be included in the model and which are excluded. Some of these elements were covered in the 2.2 Assumptions and simplifications chapter, mainly the elements to be discarded or simplified. The product system should be modelled as elementary and product flows, describing and identifying inputs and outputs that are measured or analysed in the study (ISO 14044, 2006).

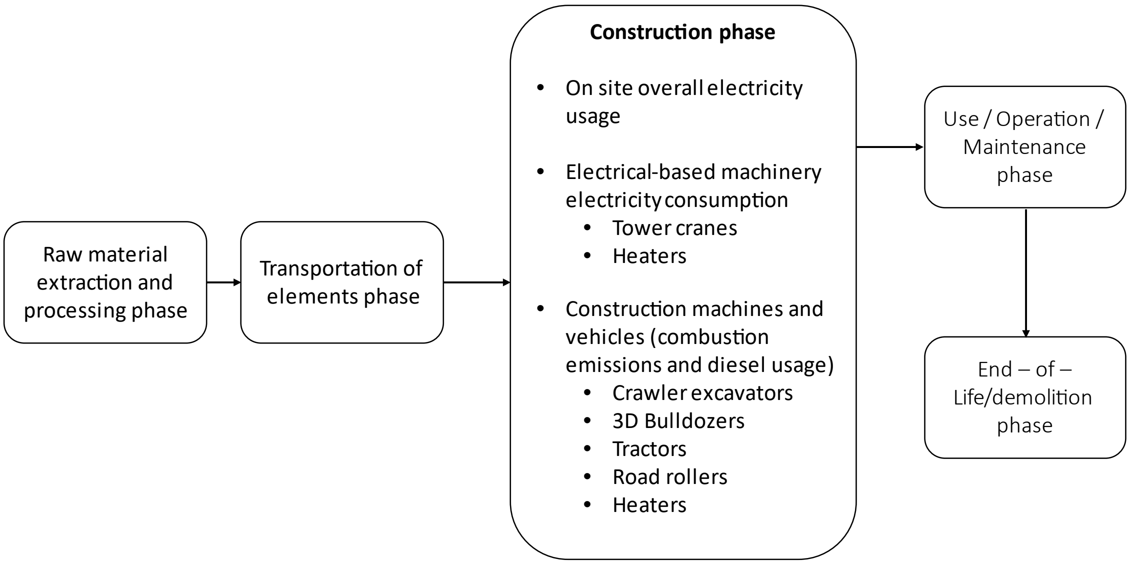


*Figure 3: LCA System Boundary*

Figure 3: LCA System Boundary describes the system using a process flow diagram which shows the unit processes and inter-relationships (ISO 14044, 2006).

The units included in the LCA process are construction processes in the energy sector – construction vehicles working and specific construction machinery. For combustion engine machines and vehicles, the first study unit is researching the fuel consumption of the machinery, which determines how much fuel is consumed throughout the construction phases' duration, which exact machines are used, the amount of fuel required for the whole construction project, and how much the production of the fuel is generating emissions (i.e. carbon dioxide). The second study unit is the number of emissions the machines and vehicles generate as they operate and work on the construction site. The third study unit is the amount of electricity required for the electrical machines and how much electricity production produces emissions in Estonia.

Only the production phase of life cycle stages will be included in this study. The building materials and their production, transportation of elements to the construction site, the use of the building afterward, and recycling of building materials will be not included in this study. These stages similarly produce emissions to the atmosphere, but since the study aims to measure and understand how much the production phase generates emissions, these stages will be discarded.

## 4.3 Phase 3: Life Cycle Inventory (LCI) Analysis

This section gives a detailed description of the processes analysed for the project. Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system (ISO 14044, 2006). The processes in the energy sector can be divided into four main categories: Combustion diesel-based machinery, diesel-based heaters, electricity-based machinery, and project maintenance electricity.

### 4.3.1 Combustion diesel-based machinery

Most of the machines working on the construction site were combustion engine vehicles—machines differed by size, weight, power, and, most importantly, fuel consumption. The vehicles operating on the construction site were crawler excavators, bulldozers, road rollers, tractors, and concrete helicopters. All vehicles/machines used on the construction site were provided by the machinery and vehicle renting company “Ehitus ja Masinad AS” besides the concrete helicopters. The required details for creating the LCA models were provided by the broad member of the company, Ago Rebane. Next, the descriptions of the machines are provided.


*Figure 4: Hyundai HX300L*

#### *4.3.1.1 Crawler excavators*

For the excavation and earthworks, the primary machines used were crawled excavators. Such machines are the most common foundation-creating vehicles in the construction regime since they have high mobility and enough strength to excavate the ground of mud or stones to prepare the foundation for the upcoming construction project. The models used for the Alma Tomingas construction project were Hyundai HX300L, Hyundai R210LC-9, Hyundai R110 7, and Bobcat S100.


*Figure 5:JCB 4CX PRO*

#### *4.3.1.2 3D Bulldozers*

For pavement works, 3D bulldozers were used. 3D bulldozers have GPS installed, making them more accurate and automating the height adjustments for the plough, making the work easier and evenly levelled. The bulldozer model used for road works on the Alma Tomingas project was Takeuchi TL 12-V2.

#### *4.3.1.3 Tractors*

The crawler excavators did most of the levelling and excavation works, but one tractor was also used on the construction site. Tractors were used for filling and levelling work for the foundation and transporting heavier objects on the construction site. The tractor model used on the Alma Tomingas project was JCB 4CX PRO.

*Figure 6:Takeuchi TL12V2*

#### *4.3.1.4 Road rollers*

Road rollers are often used for road construction or for creating compact foundations for large areas. The primary use of road rollers is to compact, crush, knead or vibrate loose materials by applying direct pressure on loosely bound foundation materials like soil, gravel, or asphalt in road and construction works (Constro Facilitator, 2021). The model used for road and construction works on the Alma Tomingas project was AMMANN 70AC-2.


*Figure 7: AMMANN 70 AC-2*

### 4.3.2 Heaters

During colder times of the year, for pouring concrete elements and creating monolithic reinforced concrete elements, to achieve a specific strength in the reinforced concrete, the temperature is essential when the concrete is hardening. At negative temperatures, freshly laid concrete water may not react with the cement, which entails the termination of chemical reactions with cement minerals, hydration stops, and concrete does not achieve the required strength (Shlyakhtina, 2020). During the project, because the initial construction started in January 2021, diesel and electric heaters were used to maintain the temperature for constructing the first and second floors.

The project used four heaters: 2 larger diesel-based generators, one smaller, and one electric heater. The two larger generators were MASTER BV680E with 220kW and MASTER BV470FS with 130kW. Those generators had the most significant fuel consumption because of their engine size and were used to warm up intermediate ceilings during the first four months of the construction. For each ceiling plate, the heater worked for three to four days to ensure that the ceiling floor achieved the strength to withstand the building's loads. The smaller diesel generator model was MASTER B150CED, which was used to heat the shafts and walls during colder times for the same purpose. The heaters were used for each wall constructed during winter or when the temperature fell below five degrees and usually worked for one day. Finally, the electric heater was used for the construction of the foundation. The organiser of the heaters mentioned that the electric heaters were used at the beginning of casting the reinforced concrete foundation to pre-heat the area/elements before and after casting. The heaters were not required after May when the outside temperatures did not drop below five degrees during the night and day.


*Figure 8: MASTER BV680E*

### 4.3.3 Electric machinery

For the construction project, the electric vehicles and machines were tower cranes, electric lifts/forklifts, and heaters, as mentioned in 3.3.2 Heaters. The vehicles consuming the most amount of electricity were the tower cranes.

#### 4.3.3.1 Tower cranes

At the start of the project, two tower cranes were assembled. The crane models were Liebherr 280EC-H16 and 200EC-H 12 Fr. Tronic, which took up to two weeks to be completely installed and ready for work. During this time, a truck crane was rented for the initial weeks, but since the trucks worked on the site for only two weeks, it made sense not to include them in the LCA calculations as they made up less than 5 per cent of the total emissions generated.

*Figure 9: Liebherr 280 ec-h 16 litronic*

Tower cranes were working for 186 days, excluding weekends and national holidays. They were used to mount more prominent reinforced concrete elements and lift materials to the higher floors. For such a large building, it is more efficient to construct tower cranes since it reduces the time consumed for transporting heavier items. Renting a truck crane for each time a lifting operation is required is much more time-consuming and monetarily inefficient.

The tower cranes were rented by "Viking Cranes OÜ", and the information and technical details were provided by the broad member Erich Reimets.

#### 4.3.3.2 Other

Many tools and smaller devices are used daily in unknown quantities on the construction site. These details are not written down or saved since it is not vital data for the main contractor. Most tools nowadays are battery-based, consuming 25-100 Watts which, compared to tower cranes, add up to a fractional amount.

### 4.3.4 Calculating data

Table 1: Combustion Engine Vehicles, Table 2: Diesel-based Generators, and Table 3: Electricity-based Machines, the data describes machines/vehicles, their fuel/electricity consumption, and working durations on the construction site, the quantities of the machines. The data for the vehicles and machines is provided by the construction company and by sub-contractors providing vehicle/machine renting services. For fuel-based machinery, the operation produces emissions and also the production of diesel. Electricity-based machinery during operation does not create emissions, but the production of electricity in Estonia is also included in the total emissions generated by electrical machinery.

*Table 1: Combustion Engine Vehicles*

| Vehicles | Model | Quantity | Duration (Days) | Fuel Consumption | Functional unit |
|---|---|---|---|---|---|
| **Excavators** | Hyundai HX300L | 1 | 20 | 12 - 18 l/h | l / h |
| | Hyundai R210LC-9 | 3 | 20 | 8 - 14 l/h | l / h |
| | | 2 | 36 | 8 - 14 l/h | l / h |
| | | 1 | 44 | 8 - 14 l/h | l / h |

| | | | | | |
|---|---|---|---|---|---|
| | Hyundai R-110 7 | 1 | 72 | 6-10 l/h | l / h |
| | Bobcat S100 | 1 | 71 | 6.8 l/h | l / h |
| | | | | | |
| **Bulldozer** | Takeuchi TL 12-V2 | 1 | 13 | 6-10 l/h | l / h |
| | | | | | |
| **Tractors** | JCB 4CX PRO | 1 | 47 | 7 - 10 l/h | l / h |
| | | | | | |
| **Road rollers** | AMMANN 70AC-2 | 1 | 13 | 5 - 8 l/h | l / h |
| | | | | | |
| **Concrete helicopters** | ATLAS COPCO BG370 | 2 | 4 | 1 l/h | l / h |

*Table 2: Diesel-based Generators*

| **Heaters** | **Model** | **Quantity** | **Duration (Days)** | **Fuel Consumption** | **Unit** |
|---|---|---|---|---|---|
| **Generators** | MASTER BV680E | 1 | 15 | 18.6 l/h | l/h |
| | MASTER BV470FS | 1 | 15 | 12.7 l/h | l/h |
| | MASTER B150CED | 1 | 89 | 3.72 l/h | l/h |

*Table 3: Electricity-based Machines*

| **Electrical Machines** | **Model** | **Quantity** | **Duration (Days)** | **Electricity Consumption** | **Unit** |
|---|---|---|---|---|---|
| **Tower cranes** | Liebherr 280EC-H16 Litronic | 2 | 186 | 2*3,5 kW/h | kW/h |
| | | 1 | 67 | 3,5 kW/h | kW/h |
| | | | | | |
| **Heater** | MASTER B3.3EPA | 1 | 60 | 3,3 kW/h | kW/h |

#### *4.3.4.1 Construction vehicles' operation emissions*

In Table 4: Total emissions generated through the operation of combustion engine vehicles, the calculation of how much emissions the vehicles and machines produce as they are operating. Quantification could be difficult since the construction data can be inaccurate – reliable data from the construction industry about emissions does not exist since emissions are not reported to the Environmental Protection Agency (Bilec, 2006). The operation data is categorised by four approaches: maximum and minimum working duration, average fuel consumption, minimum fuel consumption, and maximum fuel consumption. That is done to consider the uncertainty of the information and model's results due to imprecision of input and data variability (ISO 14044, 2006). As mentioned in 2.2

Assumptions and simplifications, the vehicles working on the construction site are not usually working 10 hours in a row. Some sub-contractors have deadlines for their tasks, and to ensure the salary of the permitted work, some workers work for longer. The function that determined the emissions is shown:

$$Emissions_{Total} = Days * Fuel\ consumption * 2.7\ kg \frac{CO_2}{liter\ of\ fuel}.$$

*Equation 1: Total emissions generated*

The fuel consumption and working durations were taken from Table 1: Combustion Engine Vehicles. Equation 1: Total emissions generated are the basis of how the machinery's operation emissions were calculated. The total emissions for concrete helicopters and Bobcat S100 do not differ by their fuel consumption since the data for these machines was obtainable from the manufacturer's technical specifications documents, and a range of fuel consumption was not provided.

The fuel consumption is also divided into three categories since the vehicles consume different amounts of fuel per task. "Ehitus ja Masinad AS" broad member Ago Rebane, who provided the vehicles' fuel consumption, stated that "fuel consumption of excavators is difficult to evaluate – it depends on the nature of the task. At the start of the project, two excavators were fracturing the limestone massif, one was digging the stones, and one loaded them onto the truck. Fracturing could take up to 1.5 times more fuel than digging, yet the fuel consumption for digging is affected by the soil type". Based on the statement, they provided a range of fuel consumption per vehicle, and from that, three categories were conducted: average, minimum, and maximum fuel consumption. Different working duration and fuel consumption data are determined in Table 4: Total emissions generated through the operation.

*Table 4: Total emissions generated by the operation of combustion engine vehicles*

| Vehicles | Model | Units | Total emissions generated through the operation | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | MAX Work Max Fuel | Min work Max fuel | Max work avg. Fuel | Min work Avg. Fuel | Max work Min fuel | Min work Min fuel |
| **Excavators** | Hyundai HX300L | kg/ $CO_2$ | 9,720 | 7,780 | 8,370 | 6,700 | 6,480 | 5,180 |
| | Hyundai R210LC-9 | kg/ $CO_2$ | 66,528 | 53,200 | 52,300 | 41,900 | 38,100 | 30,400 |
| | Hyundai R-110 7 | kg/ $CO_2$ | 19,440 | 15,600 | 15,600 | 12,400 | 11,700 | 9,330 |
| | Bobcat S100 | kg/ $CO_2$ | 13,035.6 | 10,400 | 13,200 | 10,400 | 13,000 | 10,400 |
| **Bulldozer** | Takeuchi TL 12-V2 | kg/ $CO_2$ | 7,020 | 5,620 | 5,620 | 4,490 | 4,210 | 3,370 |
| **Tractors** | JCB 4CX PRO | kg/ $CO_2$ | 12,690 | 10,200 | 8,880 | 7,110 | 7,610 | 6,090 |
| **Road rollers** | AMMANN 70AC-2 | kg/ $CO_2$ | 2,808 | 2,250 | 2,280 | 1,830 | 1,760 | 1,400 |
| **Concrete helicopters** | ATLAS COPCO BG370 | kg/ $CO_2$ | 216 | 173 | 216 | 173 | 216 | 173 |
| **Total** | | **kg/ $CO_2$** | **131,457.6** | **105,223** | **106,466** | **85,003** | **83,076** | **66,343** |

#### 4.3.4.2 Heater's operation emissions

In Table 5: Total emissions generated through the operation of combustion engine heaters, the calculation of emission generation from combustion engine heaters is determined. For heaters, there is no such uncertainty required as was for the combustion vehicles since the duration of the heaters were working was given precisely. The two larger engine heaters were used for ceiling and wall temperature maintenance and working around the clock when temperatures dropped below five degrees; 40kw heaters were used for shaft temperature maintenance and electrical ones for foundation temperature maintenance. To calculate the heaters' emissions generated through the operation, Equation 1: Total emissions generated was used. That resulted in:

*Table 5: Total emissions generated through the operation of combustion engine heaters*

| Heaters | Model | Units | Total emissions generated through the operation |
|---|---|---|---|
| **Generators** | MASTER BV680E | kg/ $CO_2$ | 18,079.2 |
| | MASTER BV470FS | kg/ $CO_2$ | 12,538.8 |
| | MASTER B150CED | kg/ $CO_2$ | 21,695.04 |

### *4.3.4.3 Emissions from fuel production*

Since Estonia is not producing diesel or any fuels, the fuel type used for the life cycle assessment model was EU-28: Diesel mix at the refinery from GaBi databases. The emissions that the production of diesel generates are programmed into the database. For each different category of emission generation, the required diesel amount differed as well, resulting in six different total emissions from diesel production. That resulted in:

*Table 6: Total emissions generated from the production of EU-28 Diesel mix at the refinery*

| | **Units** | **Total emissions generated from the production of EU-28 diesel at the refinery** | | | | | |
|---|---|---|---|---|---|---|---|
| **Combustion vehicles/machines** | | MAX Work Max Fuel | Min work Max fuel | Max work avg. Fuel | Min work Avg. Fuel | Max work Min fuel | Min work Min fuel |
| | kg/ $CO_2$ | 24,542.4 | 18,777 | 20,534 | 15,997 | 16,324 | 13,157 |
| | | **Total emissions generated from the production of EU-28 diesel at the refinery** | | | | | |
| **Generators** | kg/ $CO_2$ | 9,900 | | | | | |
| **TOTAL** | kg/ $CO_2$ | 34,442.4 | 18,777 | 30,434 | 25,897 | 26,224 | 23,057 |

### *4.3.4.4 Emissions from electricity production*

The electricity required is shown in Table 3: Electricity-based Machines. The GaBI software's database calculations determined the emissions from electricity production EE: Electricity grid mix (production mix) ts, where the main source of electricity comes from lignite (GaBi Shpera, 2022). The emissions are calculated by the input of how much electricity is consumed during the whole project and output is the emissions generated by the electricity production for the given amount. This resulted in:

*Table 7: Emissions generated from the production of electricity*

| Electrical Machines | Model | Quantity | Max working hours Total electricity consumption | Max working hours Emissions generated from the production of electricity | Min working hours Total electricity consumption | Min working hours Emissions generated from the production of electricity |
|---|---|---|---|---|---|---|
| **Units** | | | **kWh** | **kg/ $CO_2$** | **kWh** | **kg/ $CO_2$** |
| **Tower cranes** | Liebherr 280EC-H16 Litronic + 200EC-H 12 Fr.Tronic | 2 | 13,020 | 17,100 | 9,114 | 12,000 |
| | Liebherr 280EC-H16 Litronic | 1 | 2,345 | 3,080 | 1,876 | 2,470 |
| | | | | | | |
| **Heater** | MASTER B3.3EPA | 1 | 1,980 | 2,600 | 1,980 | 2,600 |

### 4.3.4.5 Project maintenance electricity consumption

The Alma Tomingas construction project has lasted more than 1.5 years. It is in its finalising phase and will be ready in a few months. The monthly electricity checks were gathered to understand how big the vehicles' CO2 generation is compared to the overall electricity consumption and emissions generated by the electricity production. The monthly kWh were summed together, and the electricity-based machines' electricity consumption was deducted from the total to make the other consumption as accurate as possible. The overall electricity consumption consists of office upkeep, lighting, and more. The overall total electricity consumption is equal to:

*Table 8: Project maintenance electricity consumption*

| **Project maintenance electricity consumption per month** | | |
|---|---|---|
| **Year-Month** | **Amount** | **Unit** |
| 21-Jan | 4,829 | kWh |
| 21-Feb | 30,120 | kWh |
| 21-Mar | 31,814 | kWh |
| 21-Apr | 23,550 | kWh |
| 21-May | 17,006 | kWh |
| 21-Jun | 9,356 | kWh |
| 21-Jul | 10,105 | kWh |
| 21-Aug | 13,779 | kWh |

| | | |
|---|---|---|
| 21-Sep | 18,191 | kWh |
| 21-Oct | 20,155.00 | kWh |
| 21-Nov | 32,059.00 | kWh |
| 21-Dec | 59,596.00 | kWh |
| 22-Jan | 60,316.00 | kWh |
| 22-Feb | 43,513.00 | kWh |
| 22-Mar | 39,307.00 | kWh |
| 22-Apr | 32,186.00 | kWh |
| 22-May | 26,694.00 | kWh |
| **SUM** | **472,576** | **kWh** |
| Total | Sum of electricity consumption (average from max and min) | |
| 472576 | 15,157 | **457,419** |

## 4.4 Phase 4: Life Cycle Impact Assessment (LCIA)

The life cycle impact assessment (LCIA) will be conducted with the GaBi software. Life cycle impact assessment is a phase of LCA aiming to access the contribution of each elementary flow to an impact on the environment (Hauschild and Huijbregts, 2015). To implement LCIA, mandatory elements needed to be covered according to (ISO 14044, 2006) are:

- Selecting impact categories: Impact categories are divided into three, namely damage to human health, damage to ecosystems, and damage to resource availability, which is shown in Figure 10: Overview of impact categories (RIVM, 2018). According to the goal and scope of the study, the global warming impact category is the chosen measurement category for measuring the environmental impact of the construction processes and the only one since the functional unit selected for this study applies only to that impact category.
- Assignment of Life cycle inventory results to selected impact categories:
- Calculation of impact category indicator results

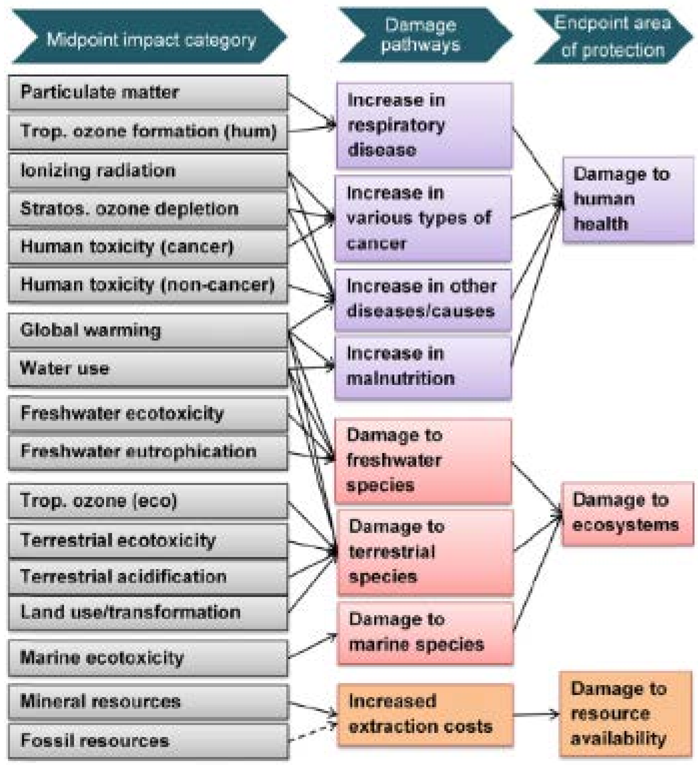


*Figure 10: Overview of impact categories (RIVM, 2018)*

Below in Table 9: Selection of impact categories, category indicators, and characterisation models, a detailed description of the choice of impact categories, assigned life cycle inventory results to impact categories, and the calculation of impact category results. The midpoint impact category of climate change is the impact assessment's main measurement category because the study aims to measure and analyse the environmental performance of construction processes in terms of climate change. The characterisation factor for climate change is widely used global warming potential, which quantifies the integrated infrared radiative forcing increase of greenhouse gas, expressed in kg CO2 equivalents (Huijbregt, 2016). The midpoint to endpoint factors for climate change includes damage to human health and terrestrial and freshwater ecosystems. It translates to years of life lost to disease and natural disaster increase due to increased global mean temperature, species loss related to changing biome distributions, and species loss due to decreased river charge (Huijbregt, 2016).

*Table 9: Selection of impact categories, category indicators, and characterisation models*

| Impact Category | Climate change |
|---|---|
| LCI results | Amount of greenhouse gas per liter of fuel burned and required for the production of fuel and electricity |
| Characterisation model | ReCiPe 2016 v1.1 Midpoint |
| Category indicator | Infrared radiative forcing |
| Characterisation factor | Global warming potential (kg CO2-equivalent) |
| Category indicator result | Kilograms of CO2 equivalents per construction process |

| | |
|---|---|
| Environmental relevance | Carbon dioxide atmospheric concentration absorbs and radiates heat, which according to NOAA Global Monitoring Lab is responsible for about two-thirds of the total heating influence of all human-produced greenhouse gases. It is the most significant contributor to global warming (NOAA, 2022). |

## 4.5 Life Cycle Assessment Modelling

This chapter creates a model based on the construction processes described in the 3.3 Life Cycle Inventory (LCI) Analysis and the calculations from the 3.4 Life Cycle Impact Assessment (LCIA). The model is created using the software GaBi (GaBi Shpera, 2022), a powerful Life Cycle Assessment engine with an extensive database and many analysis tools to evaluate a product's entire life cycle impacts with user-friendly modelling. This study uses the educational license of GaBi software, meaning that access to different databases was limited.

The GaBi software works with the LCA models regarding plans, processes, and flows. In this study, the model was created using only processes and plans because only the construction phase and the processes involved were implemented. The machines and vehicle operations were designed as "consumption" processes since their primary function in the system is to consume fuel as they work for several hours. A plan creates a visual representation of the given phases' life cycle processes, which includes flows and processes. Plans can be distinguished by the plan icon ( ) at the top of a box. Processes in the plans can be indicated by the icon ( ) at the top of the box.

### 4.5.1 Construction/production phase

The main model describes the whole construction project's processes. The processes are categorised into three sections: 1) Diesel-engine machines, 2) Heaters and 3) Electricity-based machines. Each element described in 3.3 Life Cycle Inventory (LCI) Analysis is constructed into a process–plan function in GaBi. As mentioned in the 3.3.4 Calculating Data, six different versions of the same model are created with differences in fuel consumption and work durations. Figure 11: Construction processes of Alma Tomingas visualises the general plan for construction processes.

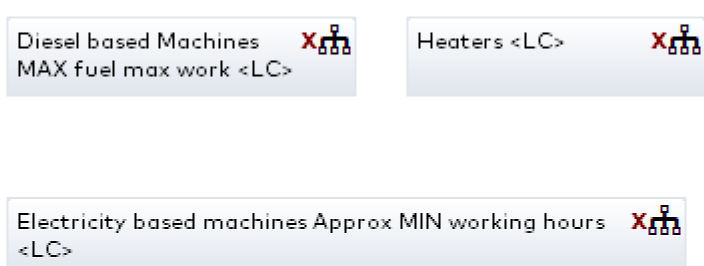


*Figure 11: Construction processes of Alma Tomingas*

### 4.5.2 Diesel-based machines and vehicles model

Diesel-based machines model includes all combustion-engine vehicles that were working on the construction site. Engine types group these vehicles to distinguish them from other processes in the LCA analysis. The first row describes the diesel EU-28: Diesel mix at the refinery with a tanker ( ) icon. That represents the type of fuel that was used to power the vehicles working on the construction site. The consistency of the fuel is determined by the GaBi database and the emissions produced by the fuel's production.

For each vehicle, a range of fuel consumption was provided by the sub-contractors working on Alma Tomingas. The processes with the gear ( ) icons were the diesel-powered vehicles. The machines types are arranged in the way of their individual fuel consumption, from largest to smallest. The vehicle on the left is the crawler excavator Hyundai HX300L (30 tons), which had the most significant fuel consumption (12-18l/h). The black arrows connecting the fuel and processes are the amount of fuel each of the processes consumed. The arrow already represents the quantity of the vehicles and the working duration of vehicles on the construction site. The two bottom processes are the same vehicles, crawler excavators R210LC-9 (20 tons), divided into 3 categories since the quantity of the same vehicle changed during the project's construction phase. The yellow boxes are the comments about how many days and hours the machines worked.

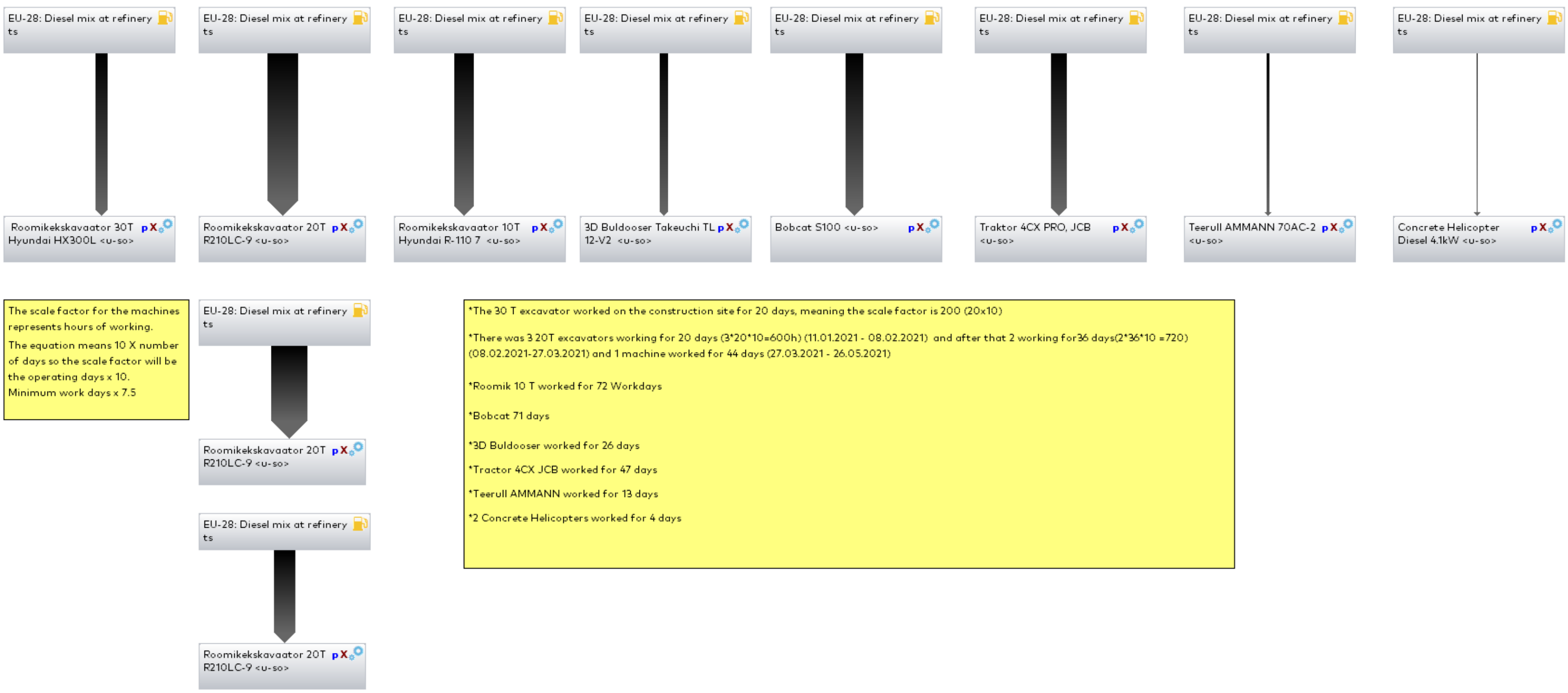


*Figure 12:Diesel-based machinery*

### 4.5.3 Heaters' model

The heaters model includes all combustion diesel-based heaters used on the construction site during concrete casting. The heaters are arranged in engine size order. The diesel type used was the same as for the combustion engine vehicles. The one electrical heater is not in this model since combining all electricity machines for final comparisons is better. The method for creating this model is the same as for the combustion diesel-based vehicle model -Figure 12:Diesel-based machinery.

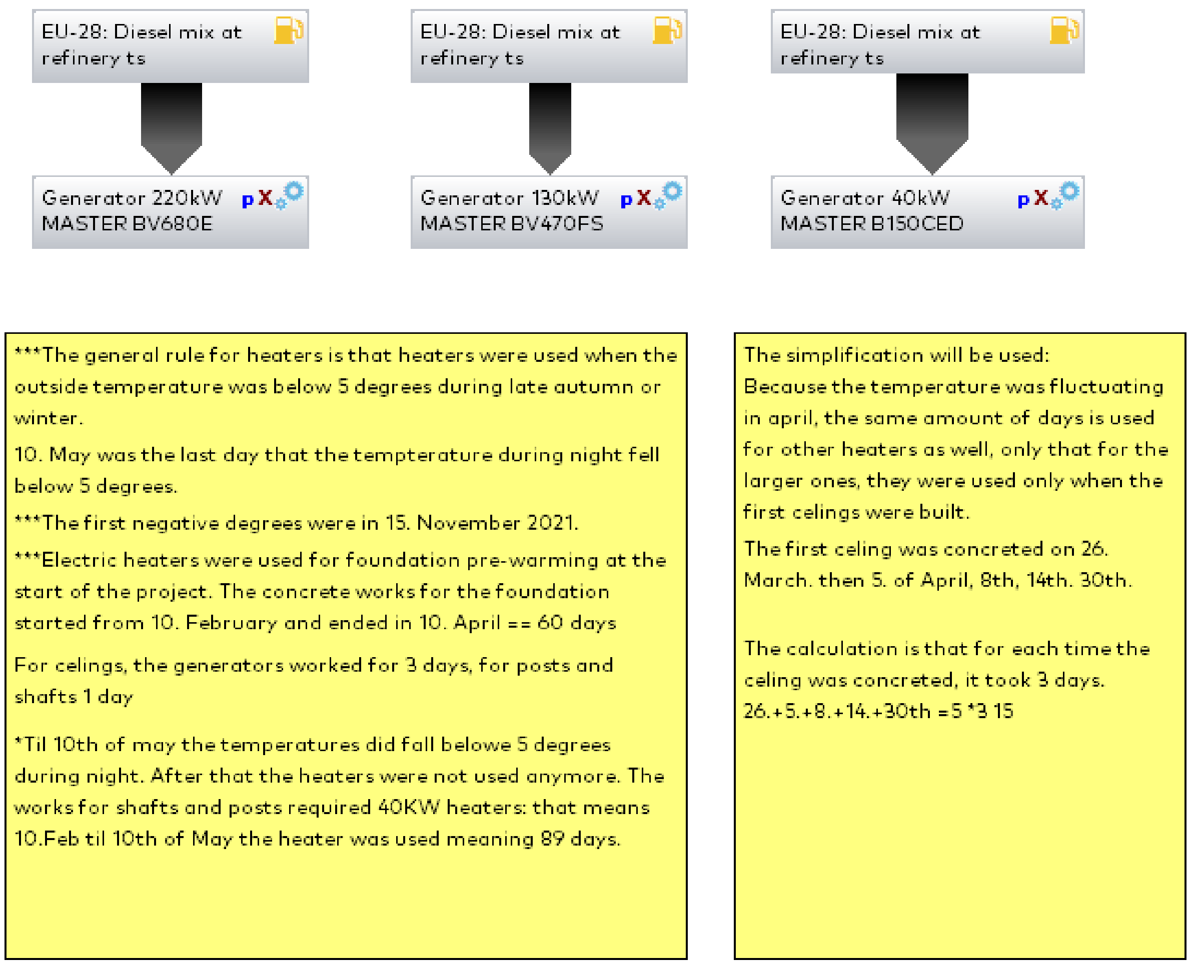


*Figure 13: Combustion engine heaters' model*

### 4.5.4 Electricity-based machines' model

The electricity-based machine's model includes all larger and more powerful electrical machines used for the Alma Tomingas project. On the model, the EE: Electricity grid mix, with the plan ( ) icon, the electricity production mix from the GaBi database is implemented into the model. The number of kilowatts per hour for each electrical machine was determined and then multiplied by the duration the machines worked on the site. The upper tower crane on the left in Figure 14: Electricity-based machines model represents the duration of two cranes working on the construction site. The lower plan represents the time when only one tower crane was operating. "Scissor Lift" was added to the model, but because of its low electricity usage, it was discarded with the 5% rule.

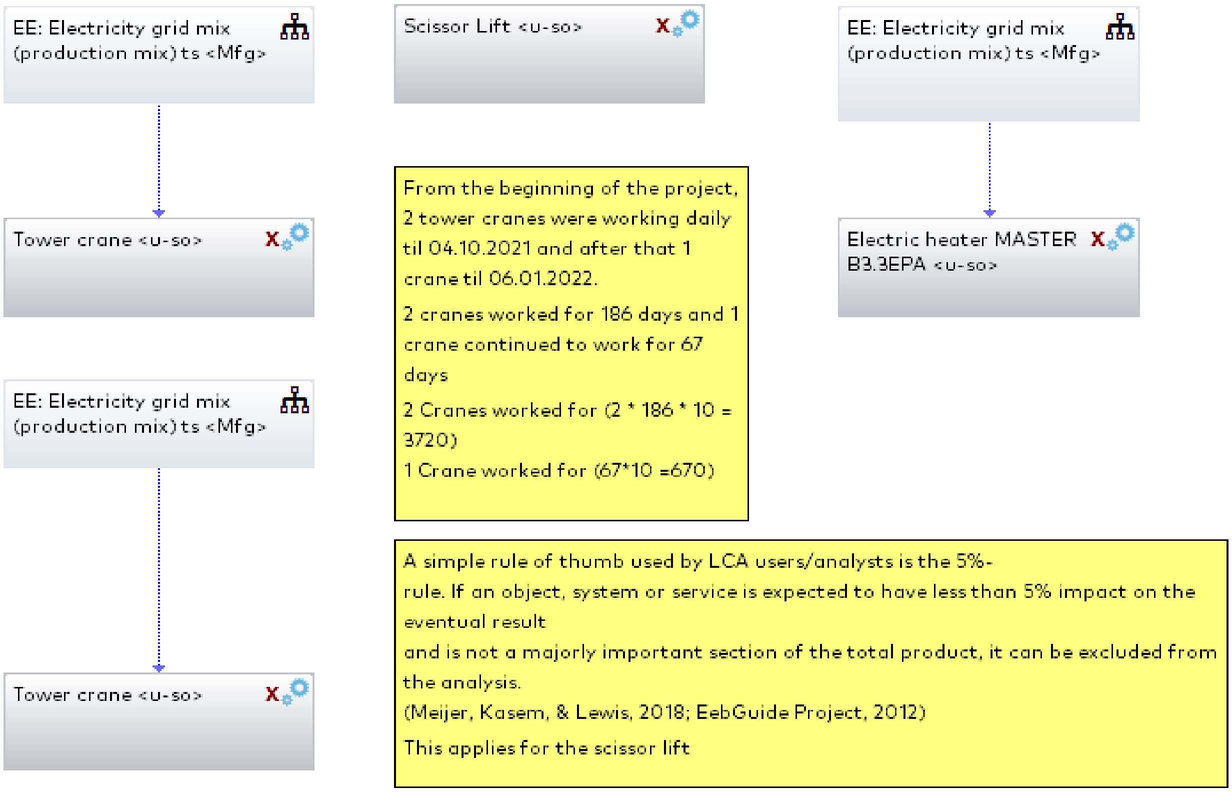


*Figure 14: Electricity-based machines model*

### 4.5.5 Project maintenance electricity consumption for 1.5 years

For the project duration till now, the monthly overall electricity consumption was provided by the contractor company NOBE. The model for the electricity consumption was simple since it consisted only of the EE: Electricity grid mix and the process of electricity consumption. The total consumption with deducting the consumption of the electrical machine equals 457419 kWh.

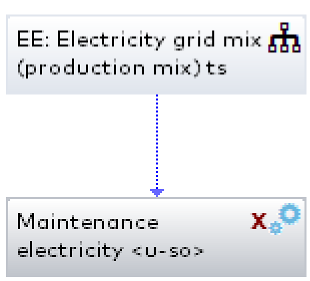


*Figure 15: Project maintenance of electricity model*

# 5. Life Cycle Analysis Results

This chapter presents the life cycle analysis of construction processes for Alma Tomingas are presented. The modelled processes and plans shown in the 3.5 Life Cycle Assessment Modelling are analysed and calculated by the GaBi software. The impact assessment category, discussed in 3.4 Life Cycle Impact Assessment (LCIA), chosen from the ReCiPe 2016 v1.1 Midpoint (H), is calculated and analysed. The "Climate Change" results are reviewed, and the outcome is discussed. Finally, the overall processes' emissions are compared to the emissions generated by the project's maintenance electricity consumption, and the results are discussed.

## 5.1 Impact Category

As discussed in 3.4 Life Cycle Impact Assessment (LCIA), the impact category measured and analysed in this study are environmental impacts, specifically climate change or global warming potential.

Carbon dioxide contributes the most to global warming. Carbon dioxide makes up to 65% of all global greenhouse gas emissions by gas, and fossil fuel use is the primary source of $CO_2$ generation (EPA, 2022). While carbon dioxide is an important greenhouse gas that keeps heat in our atmosphere, overconcentration is causing global temperatures to rise, disrupting other aspects of Earth's climate (UCAR, 2006). The issue with $CO_2$ overconcentration is that $CO_2$ remains in the climate system for a very long time – $CO_2$ emissions cause increases in the atmospheric concentrations of $CO_2$ that will last thousands of years (EPA, 2022). The function of how GaBI measured climate change is using $CO_2$ as its functional reference unit and translating substances into kg of $CO_2$ equivalents.

Transportation, the combination of gasoline and diesel fuel consumed for transportation of humans and goods, was the largest source of $CO_2$ emissions in 2020 and made up to 33% of the total U.S. $CO_2$ emissions (EPA, 2022). That includes highway and passenger vehicles, air travel, marine transportation, and rail (EPA, 2022). The construction vehicles working on the construction site affect climate change similarly to transportation.

## 5.2 Climate change impact results

The maximum working hours and maximum fuel consumption graph is displayed in Figure 16: Max work Max Fuel consumption graph. The minimum working hours and minimum fuel consumption graph is shown in Figure 17: Min work Min Fuel consumption graph.

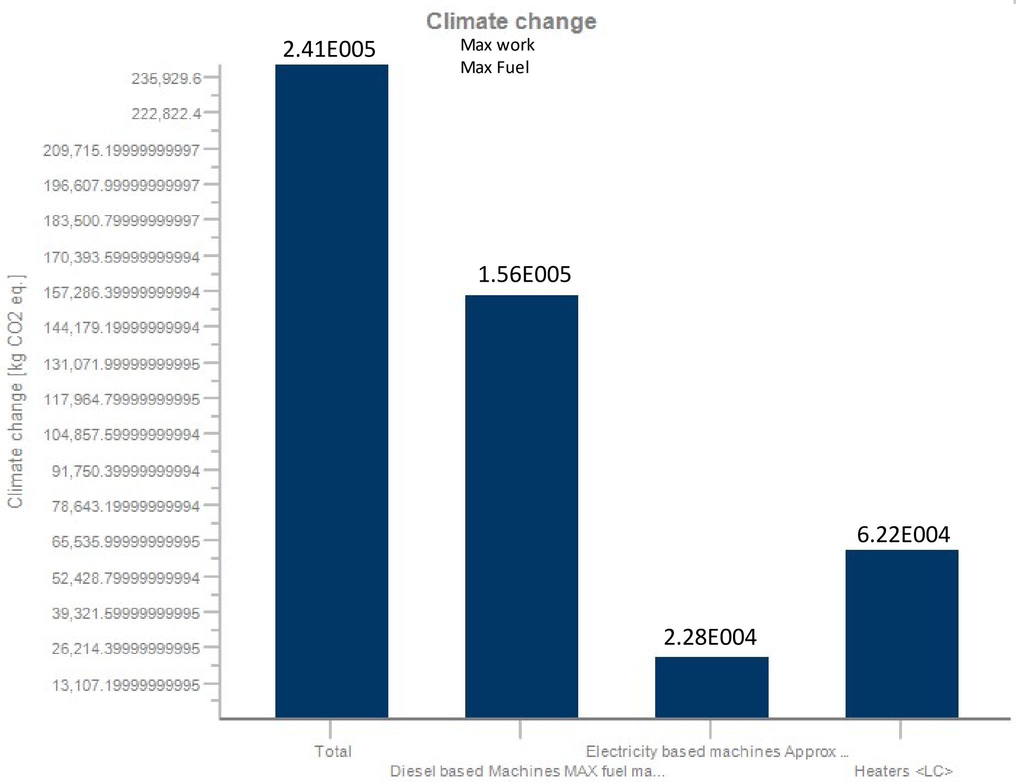


*Figure 16: Max work Max Fuel consumption graph*

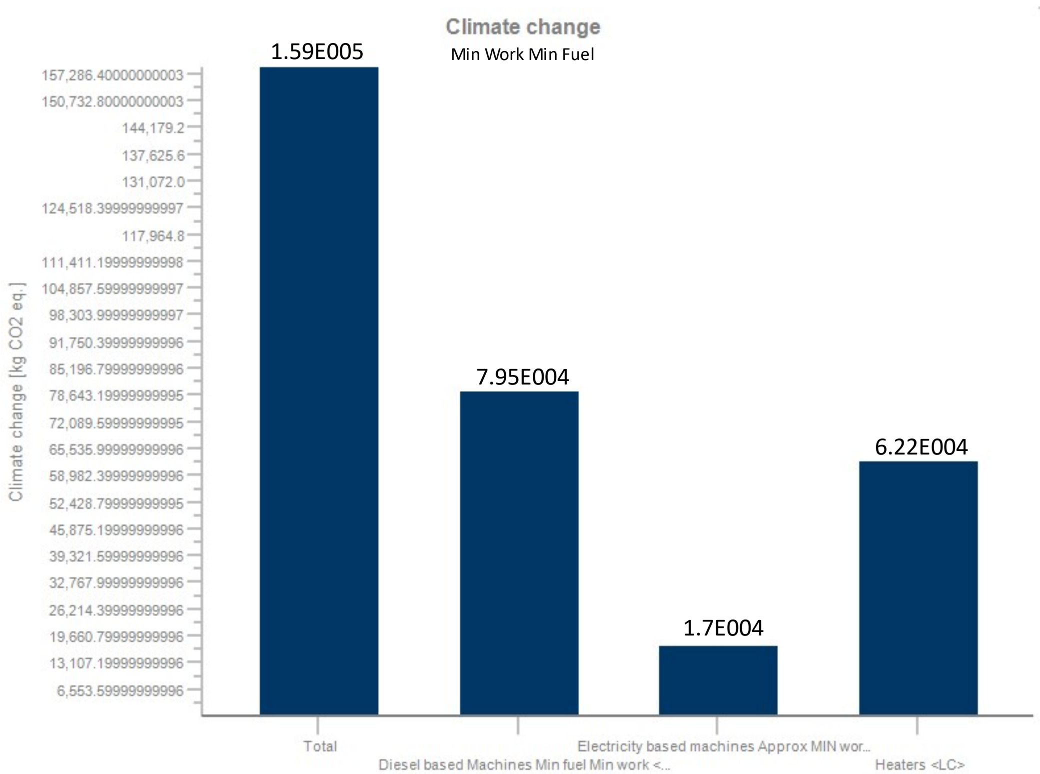


*Figure 17: Min work Min Fuel consumption graph*

These graphs show the total impact of the construction processes. From the chart, for both alternatives, the diesel-based machines have the highest impact out of the three categories, which makes logical sense. For the minimum working hours, the heaters are almost making the same amount of emissions, differing by 18.000 kg $CO_2$ compared to maximum working hours, where the difference is 93.000 kg $CO_2$. The electrical machines have the lowest impact of the three categories, which also makes logical sense since the machines do not produce any emissions as they are operating – only from the production of electricity required for the machines to work.

The closest number to the average emissions generated by the processes is the version of maximum work duration and average fuel consumption. For the proceeding comparison, the average data graph is used.

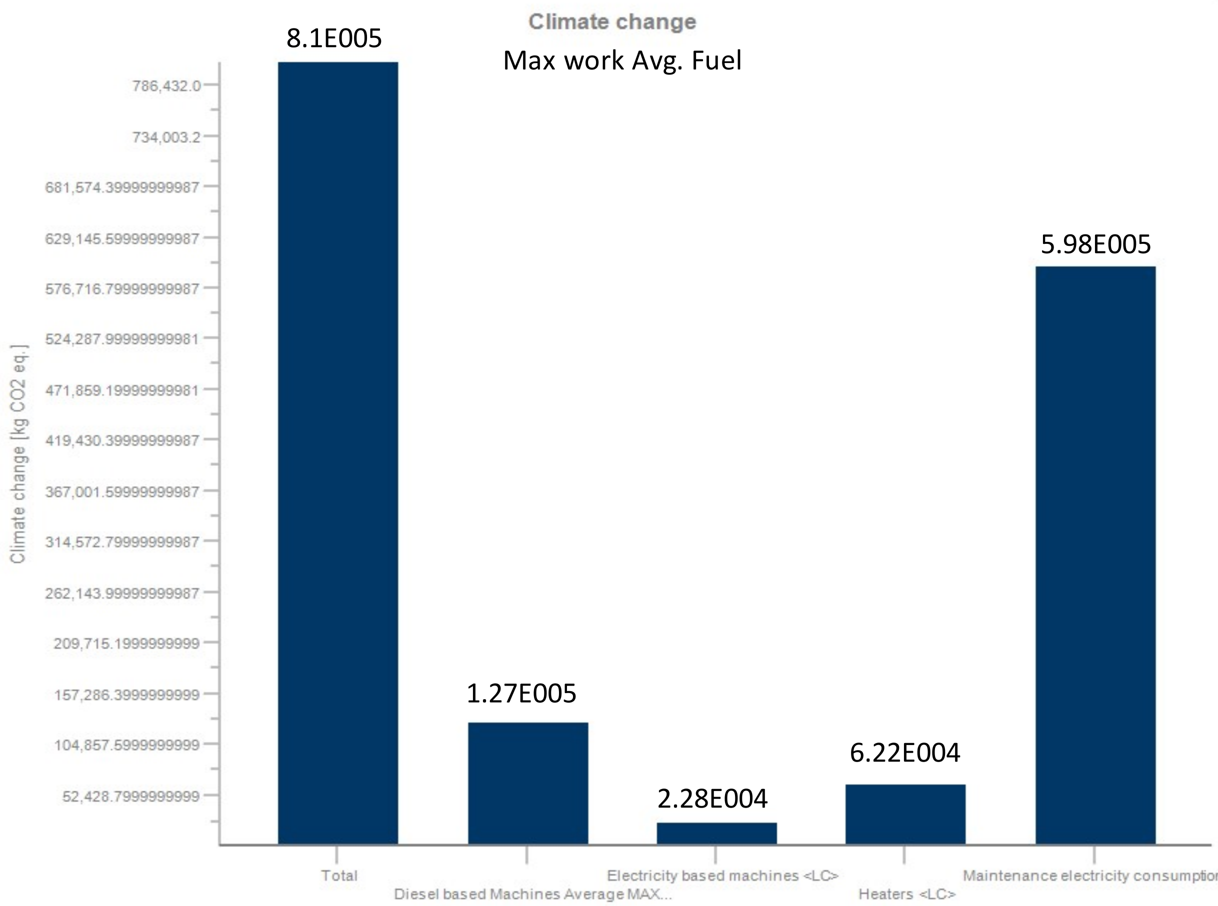


*Figure 18: Overall project emissions*

From Figure 18: Overall project emissions, a better understanding of the whole project's emissions generation is perceived. Although out of all the vehicles and machines, the diesel-based vehicles made up the most significant amount of emissions out of the three, it makes only a fraction of the total emissions generated. The project's electricity consumption makes up almost 70% (68.74%) of the emissions the project generates, whereas diesel-based machines make up 15%.

# 6. Discussion

After creating the life cycle inventory, calculating the amount of work the machines did and how much fuel they consumed, determining the emissions produced from the construction processes, and comparing the results, the recommendations can be conducted.

The method used for determining the emissions for the construction processes was using GaBi's ReCiPe 2016 impact assessment tool. Due to time constraints, only the climate change impact in terms of $CO_2$ was used for emissions comparison and measurements. ReCiPe converts all the different emissions into $CO_2$ equivalents but this is applied only for electricity production. The emissions from electricity production can be considered valid since GaBi has the electricity production from different sources determined for Estonia, meaning that the emissions generated should be validated and verified.

For vehicles and other fuel-based machines, only the amount of $CO_2$ produced by the engines working was included, but for further research, the other emissions should be added as well to make the results more valid and accurate. Although the emissions from vehicles had the largest environmental impact, other emissions from diesel-burning will result in an even bigger emission amount. This arguably makes the results less valid since it is a simplified version of the emissions generated. Including all the emissions a burning engine generates, like $SO_2$, $NO_2$, and other emissions that the ReCiPe tool converts, will make the results more validated.

The environmental performance has been calculated – the total amount of $CO_2$ emissions the project generated was 810.000 kg $CO_2$. Evaluating whether this result is good or bad is difficult since there have not been any similar projects where the emissions of construction processes are measured. In work (Bilec, 2006), a similar study on a parking garage was conducted, and the results were:

**Table 5.** Emissions

| Construction process | $SO_2$ (kg) | CO (kg) | $NO_2$ (kg) | VOC (kg) | Lead (kg) | PM10 (kg) | Total $CO_2E$ (kg) |
|---|---|---|---|---|---|---|---|
| Construction services | 25 | 1,880 | 1,115 | 410 | 0 | 40 | 125,680 |
| Upstream and maint. construction equipment | 5 | 95 | 5 | 40 | 0 | 0 | 11,860 |
| Transportation | 975 | 1,015 | 3,135 | 1,420 | 0 | 210 | 397,495 |
| Equipment (diesel) | 285 | 540 | 2,385 | 445 | 0 | 165 | 128,115 |
| On-site electricity | 140 | 10 | 65 | 15 | 0 | 5 | 18,570 |

*Figure 19: Bilec 2006 emissions table*

For a parking garage building, which should be a relatively smaller project than a 10-floor office building, the total emissions, without considering the emissions from transport, were 284.225 kg $CO_2$. Since this study did not include the transportation of materials and elements, it is difficult to compare. Although comparing the emissions from on-site electricity consumption, the amount differs a lot – Alma Tomingas had emissions from on-site electricity of about 598.000 kg $CO_2$ and the parking garage only 30.430 kg $CO_2$.

What is interesting to point out is that the emissions generated by diesel-based equipment did not differ exceptionally. The parking garage project had emissions from diesel-based equipment of 128.115 kg $CO_2$; the Alma Tomingas project had emissions from diesel-based machines from the average fuel consumption and a work duration of 127.000 kg $CO_2$. It is not easy to compare with the averages because the maximum working duration and maximum fuel consumption differ by 60.000 kg $CO_2$, shown in Table 4: Total emissions generated from the operation of combustion engine vehicles.

The most effective way to reduce $CO_2$ emissions is to reduce the usage of fossil fuels (EPA, 2022). That is visible from the work of (Bilec, 2006) and this study's outcome. The more electricity-based machines and vehicles come to market; the more environmentally friendly the construction processes can become. Some existing research assumed that the impacts of the construction phase are negligible (Bilec, 2006), but from this study, construction processes make up many emissions. To change all the vehicles to electric ones for optimal energy savings is difficult to say or calculate at the moment since there are no such vehicles on the market. In order to make some estimations, data about how much the electricity-based machines consume electricity and how much electricity is required for the machinery's operations need to be gathered. Gathering extra data would be another project in itself and beyond the scope of this current study. This yields another question that will then the energy consumption in total be lower if all machines are electricity-based? From the calculations of how much fuel-based heaters generated emissions compared to two tower cranes working for 120 days, which results in fewer emissions, it can be assumed that changing to electrical ones will result in fewer emissions. Since there is no data about electrical vehicles in construction, the energy consumption should be lower, but this was not measured.

Regulations in terms of construction vehicles and their emissions are another aspect of future construction. Currently, in Estonia for example, there are no regulations in terms of operating construction vehicles on the construction site, and there are no officials coming to detect or check how environmentally harmful the machines are. Therefore, this does not affect the contractor companies, but rather the providers of construction vehicles.

In order to create recommendations for the main contractor company NOBE, it needs to be concluded that in the construction processes, the two main contributors are diesel-based vehicles and the project's maintenance electricity consumption. It is difficult to change the way of construction for the main contractor because to replace some of the vehicles with electrical ones; there needs to be providers for such services. The company Volvo has designed a three-ton small electric excavator with a battery of 20kWh. It is the first electric compact excavator, which is the first step toward a brighter and more sustainable future for the construction industry (Volvo, 2022). This excavator can be used for smaller digging works, but it should be considered that the excavator that demolished the stone beneath the foundation weighed thirty tonnes. There is currently a shortage of electric vehicle batteries because of the raw material shortage, which means that there will not be many providers of such construction equipment and vehicles in the near future.

To reduce the emissions generated through electricity production for the whole project, the contractor company should use only renewable energy for their projects. The electricity consumption for the entire project had the largest impact on the emissions generated. Many options exist to reduce the environmental impact, renewable energy being the most impactful option. If the contractor company adapts to only using renewable energy for their electricity source, the environmental impact of the construction processes will be three times less based on the data from this study, shown in equation 2: renewable energy vs conventional.

*Table 10: Results of climate change impacts*

Construction processes

| Maximum Work, Average Fuel consumption | kg CO2 equivalent |
|---|---|
| **Diesel-based construction Vehicles** | **106,466** |
| **Diesel-based Heaters** | **52,323** |
| **Diesel production** | **30,434** |
| **Electricity production for machines** | **22,780** |
| **On-site electricity** | **598,494** |

# 7. Conclusion

The goal of this LCA study was to create a model of the project Alma Tomingas office building’s construction phase and measure its environmental impacts on the construction processes. Results of the study show that in order to make the construction processes more environmentally friendly, it needs to reduce the amount of fossil fuel-based machines and vehicles. Most of the emissions from the construction processes came from fuel-based machines and vehicles working on the construction site. Fuel-based machines and vehicles produced nearly 88% of the total emissions from the construction processes, whereas electricity-based vehicles and machines only 12%. When analysing the construction project's total emissions, the maintenance electricity consumption generated the most amount of emissions. The more electricity-based machines and vehicles are used, the “greener” the construction process. From the main contractor’s perspective, the company should invest in buying electricity from renewable energy as their main electricity source to make the process greener from the current possibilities that can be adapted since there are not many electricity-based vehicles available on the market for construction.

The life cycle inventory results were calculated based on the climate change impact category. The climate change category used global warming potential, which quantifies the integrated infrared radiative forcing increase of greenhouse gas and is expressed in kg CO2 equivalents. The diesel-based machines made up to 15% of the total emissions generated, and the emissions generated for the production of on-site electricity made up 70% of the total emissions for the construction processes.

There is still room for improvement to make this study more detailed and accurate. For future research, other emissions should also be considered to understand better how many other emissions the construction process generates. Suppose the contractor companies store more information about the construction processes, like what tools were used, which lighting laps were rented, and more. In that case, the analysis could be more precise and realistic. Here the 5%-rule was used to neglect any processes that contributed to the total result with less than 5% impact. The lack of data is the main obstacle to making these LCA analyses. Information like what type of vehicle was on the construction site for a specific job and how long it operated is not currently stored in the construction industry. Therefore it is difficult to make a life cycle analysis covering all processes from the construction site.

The results of this study can be used for other future projects to understand what construction processes most likely generate the most amount of emissions. The current construction regime consists of fast and reliable construction and emissions that machines generate are commonly not in focus for construction companies. There is a limited amount of research done on the construction processes.

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# 8. Appendix

## 8.1 The equation for calculating renewable energy vs conventional

The data for this calculation was taken from Table 10: Results of climate change impacts

*Equation 2: renewable energy vs conventional*

$$\frac{598{,}494}{106{,}466 + 52{,}323 + 30{,}434} = 3{,}184$$

## 8.2 Graphs of all six GaBi Climate Change results

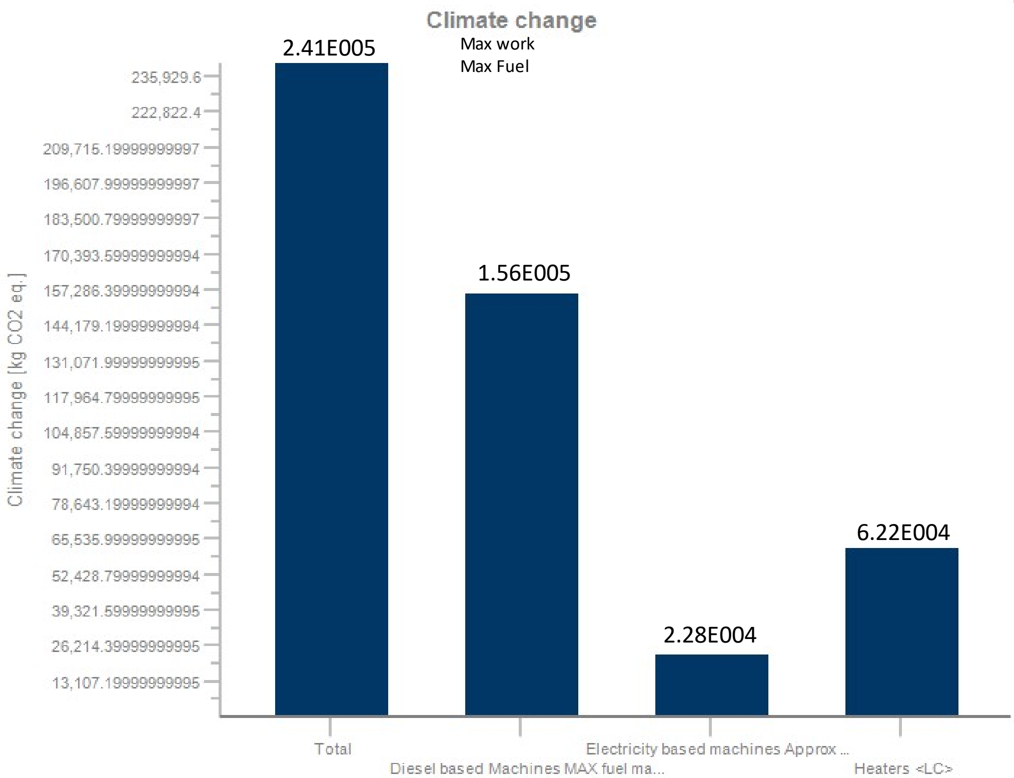


*Figure 20:Max work Max fuel*

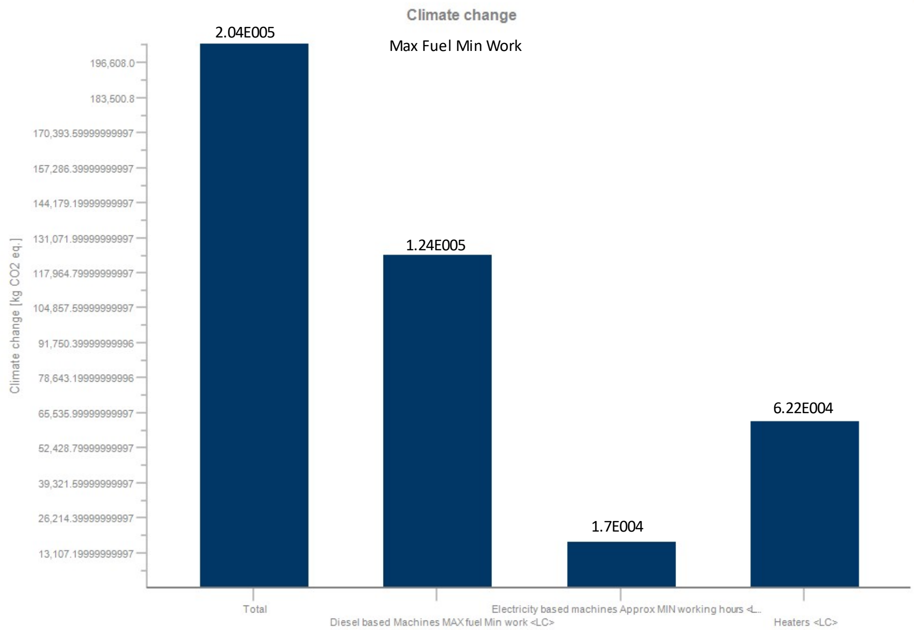


*Figure 21:Max Fuel Min work*

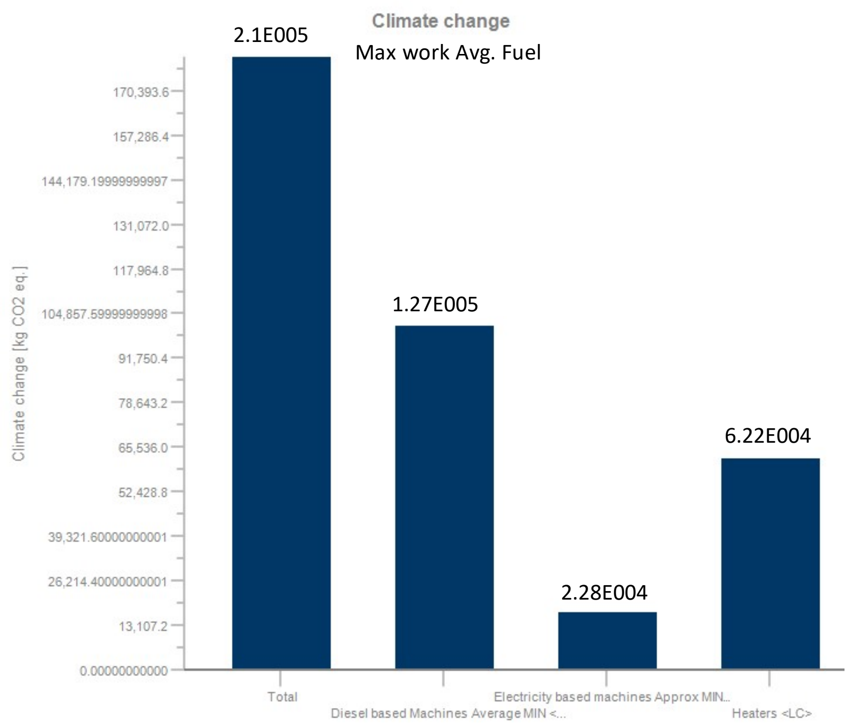


*Figure 22: Max work Average Fuel*

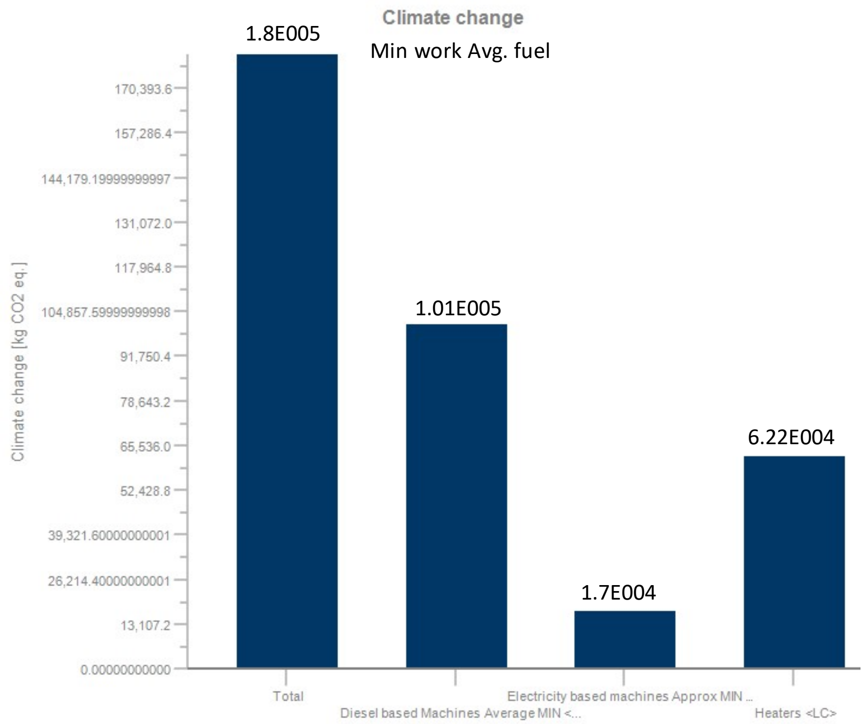


*Figure 23: Min work Average fuel*

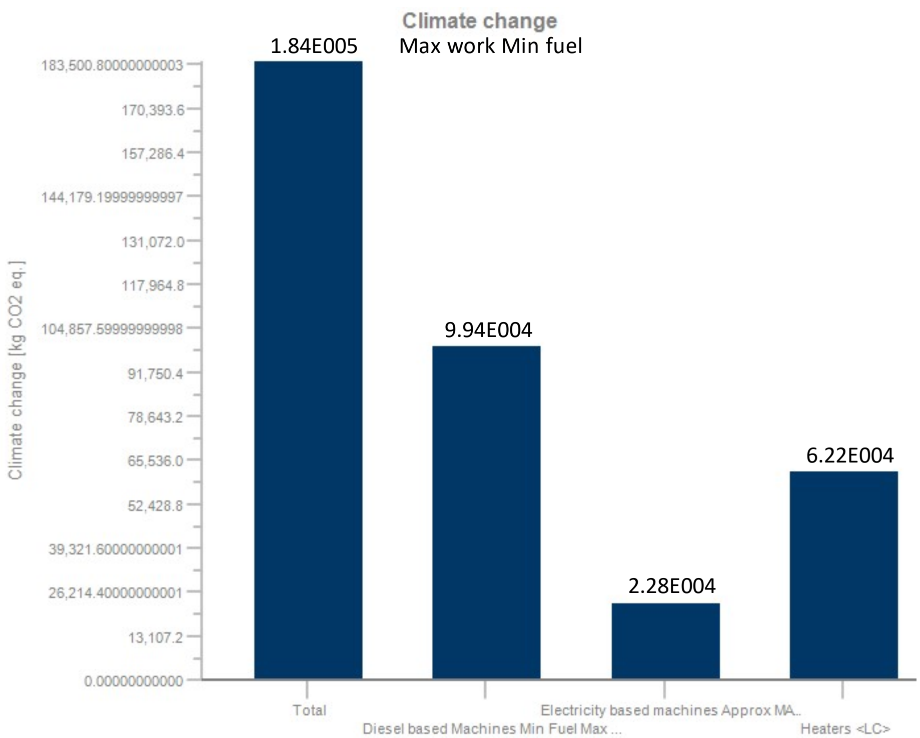


*Figure 24: Max work Min fuel*

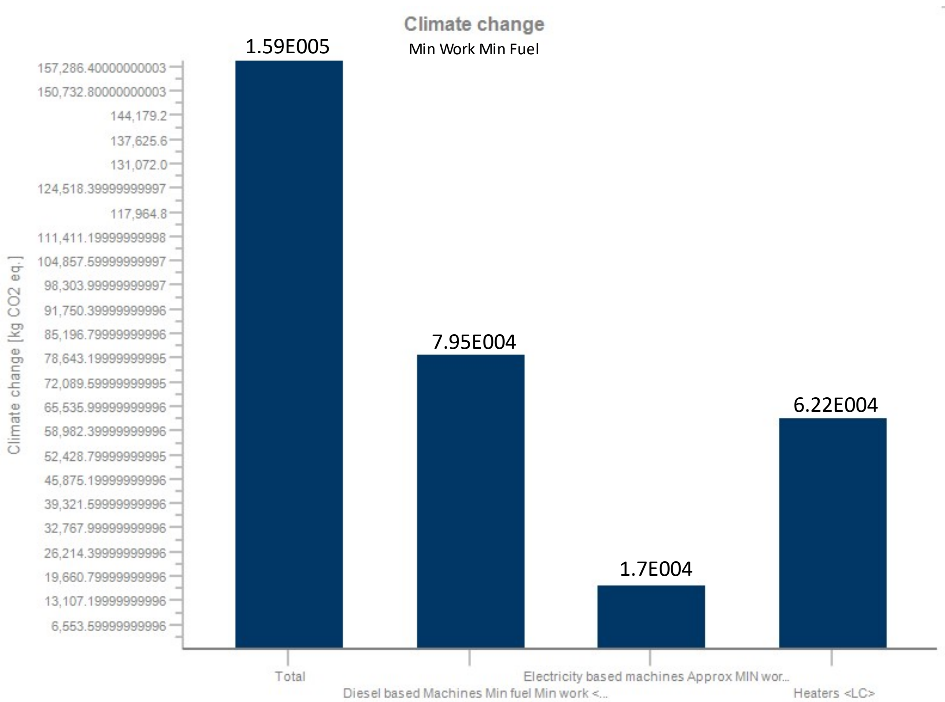


*Figure 25: Min work Min Fuel*

## 8.3 Detailed results of diesel-based machines average fuel and maximum work

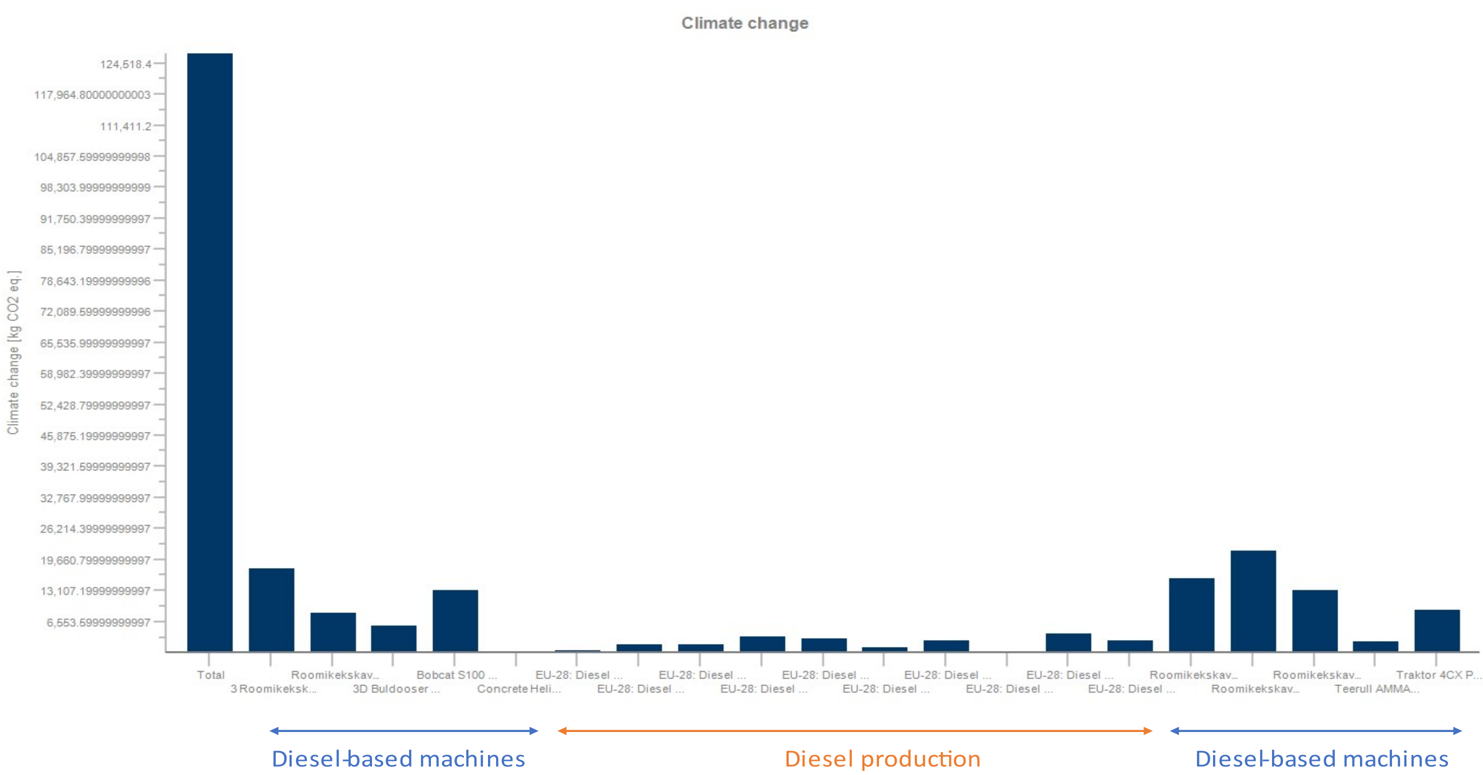


*Figure 26: Diesel-based machines*