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Master

Life cycle assessment of road construction:

A case study of the E39 Betna-Hestnes road project in Norway

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Preface and acknowledgments

This master's thesis marks the end of my five-year study at the university of Agder, Department of Engineering Sciences, Grimstad, Norway. This thesis carried in the period between January 2023 and May 2023 under the supervision of Associate Professor *Reyn Joseph O'Born* and has been submitted to the Faculty of Engineering and Science as fulfillment of the degree Master in Civil Engineering.

I express my gratitude to my supervisor, *Reyn Joseph O'Born*, for his support and invaluable guidance throughout the completion of this thesis. His expertise and advice have been instrumental in shaping the outcome of this work. Thank you, Reyn, for your dedication and assistance, it has been an honor to work with you.

Since I arrived to Norway in the autumn of 2016 and started my civil engineering study in 2018, I have faced challenges juggling my studies with work to support my family in Syria, which has been devastated by conflict since 2011. I dedicate this thesis in honor to the martyrs who have lost their lives in pursuit of freedom and those who remain detained in the dictator's prisons.
As Victor Hugo once said, "*When dictatorship is a fact, revolution becomes a right".*

Thank you, Mom, and Dad, for nurturing me and your unwavering support. I am deeply grateful to Etab, Alaa, and Udai for their unwavering support and guidance in my life. Their support has always been invaluable, and I express my deepest gratitude to you all.

Last but not least i am deeply grateful to my cherished wife, Rouhef, for her support, boundless kindness, and unconditional love. None of my achievements since i married you would have been possible without you being by my side. Thanks, from the bottom of my heart.

Muhammad Fadel Murad Kuj
Kristiansand, 22.05.2023

Summary

This master thesis assesses the environmental impacts caused by constructing E39 Betna-Hestnes Road Project in Trøndelag County, Norway, by using LCA methodology. additionally, this thesis seeks to identify potential measures that can be implemented to mitigate the project's environmental impacts.

Norway has made a commitment to reduce greenhouse gas emissions by 50% by the year 2030. This thesis is important for Bertelsen and Garpestad who are actively working towards achieving more environmentally friendly road construction. Furthermore, it also serves as a valuable resource for organizations, administrations, and stakeholders involved in the road construction sector, as it provides insights and strategies for effectively mitigating the impacts and emissions in their road projects.

The construction phase of the entire E39 Betna-Hestnes project results in a total of 19,900 tons of CO2 equivalent and had a total water consumption of approximately 118,500 m3. The total terrestrial acidification resulting from constructing the E39 Betna-Hestnes road project is calculated to be 85.2 tons of SO2 equivalent and terrestrial ecotoxicity is calculated to be 65654,3 ton1,4 dichlorobenzene. In general, the main contributors to these emissions are Concrete(B45), reinforcement rebar steel, asphalt, and prefabricated beams.

1.2 million liters of fuel consumed by just construction machinery and mass transport is remarkably high and huge. The material consumption activities have the biggest overall emissions related to (GWP, water use, and terrestrial acidification & ecotoxicity). The fossil-free construction site and machinery in E39 Betna-Hestnes will significantly mitigate carbon dioxide emissions during construction.

It becomes apparent that the use of timber instead of concrete in bridges could have more favorable environmental outcomes. This is primarily due to the quantities of cement and rebar steel required in concrete bridge structures, which leads to higher raw-materials demand and higher energy demand during the production phase from non-renewable sources.

Table of Contents

List of figures

List of tables

1. Introduction

The Norwegian Road transportation effectiveness and efficiency have been a matter of concern over the years [1]. With the rise in population and the urge to foresee better infrastructure to counter this population, the Norwegian government has put much effort and resources into road construction through mega projects, including the Ferry Free E39. In the quest to modernize road construction and infrastructure, the National Transport Plan aims to add a reduction of CO2 emission targets for all new road projects. Regarding Norwegian transport systems, road transportation remains an outstanding transport system for both goods and people. Poor planning and constructing decisions, avoiding sustainability assessment tools, and poor material choices will certainly cause an increase in emissions and resource consumption [2] (pages 3,4).

In terms of societal and economic perspectives, it is often the case that new road construction initiatives that serve to shorten travel time between regions, cities, and other locations tend to be more desirable and receive greater societal and political support.
Therefore, the government tends to prioritize projects that contribute to the reduction of travel time between regions [3] (page 3).

In recent times, the Norwegian government has decided to decrease the amount of funding allocated to the Norwegian Public Road Administration (NPRA), which will ultimately result to a reduction in the number of new road projects and road upgrade projects in the coming years. As a response to this reduction, the NPRA evaluated which projects that should be given priority for the year 2023 and is in total 44 road projects. Moreover, the NPRA is also working on a new National Transport Plan for the period 2025 to 2036. The government has scheduled the unveiling of this new plan for the spring of 2024 [4].

1.1 Norwegian journey towards sustainability

Developing in a way that ensures future generations can meet their needs is termed sustainable development (UN-United Nations). Sustainable development is an approach to economic growth and improvement that also considers environmental protection. It is generally agreed that economic, social, and ecological considerations must be factored into decisions and kept in check. To eradicate poverty and bring prosperity for all people while protecting the planet and its natural systems, the United Nations (UN) adopted a set of seventeen (17) goals in September 2015 known as the Sustainable Development Goals (SDGs) as part of its 2030 Agenda for Sustainable Development. It is worth noting that the SDGs recognize the differences in location, population, economy, legal systems, and political structures that exist between countries and regions. Regarding the overall corporate sustainability score, which considers a country's efforts across all 17 SDGs, Norway ranked second in the world in 2018 [5]. Norway has been a strong international supporter of the United Nations' Agenda 2030. The Norwegian government has declared that the SDGs should be the political framework, including poverty, climate change, and inequality, in the nationwide expectations for municipal and regional planning for 2019. In addition, the Norwegian government emphasized that regional and local authority's work is essential for Norway's commitment to achieving Agenda 2030 because of their proximity to citizens, local companies, and community groups. Most of the infrastructures and services affecting people's living situations and possibilities for development is the responsibility of local and regional authorities. Hence, the government hopes the SDGs will be implemented and become a cornerstone of local and regional planning and construction works [6] [7].

The Norwegian government has set a goal to mitigate emissions caused by infrastructure projects by 50 to 55 percent by 2030 [8].and the road construction sector must contribute.

Therefore, the Norwegian Public Road Administration's goals are to develop, build, and maintain roads and transport systems in Norway in a sustainable way. The NPRA focuses on [9]:

- Reducing the environmental impacts caused by constructing new road projects.
- Reducing the environmental impacts during operation and maintenance phases.
- The NPRA promotes sustainable procurement and supports environmentally friendly purchases.

The Norwegian Public Road Administration (NPRA) mandates that any project exceeding NOK 200 million must be certified with the BREEAM Infrastructure assessment scheme. This scheme assesses various aspects of infrastructure projects, including their environmental impact, resource efficiency, and social and economic sustainability [10].

According to page 221 of the Norwegian National Transportation Plan 2018-2029 (meld. St.33 2016-2017) showing that Norway's journey towards sustainability seems to be progressing in the right direction, as evidenced by the E39 Hordfast and Møreaksen road projects, which will show after building significant reductions in CO2 emissions with 92000- and 21400-tons CO2, respectively.

1.2 Environmental impacts of Road construction

There has been a worldwide increase in environmentalists' worries about things like climate change and fossil fuel consumption. Recent years have seen a rise in the scrutiny of environmental factors connected to building roads and highways [11].

The road construction project has several adverse impacts on the environment [12] [8], including:

- Using an excessive amount of water can put a strain on water sources, systems and even disrupt regular water flow.
- Roadside accidents caused by construction site traffic and activities can disproportionately negatively impact nearby residential areas.
- There may be noise, vibration, and dust pollution due to road construction.
- The construction sites and the associated work camps may produce wastewater. Surface water sources, including nullahs, sewers, water channels, etc., are at risk of contamination if sewage is not adequately treated or disposed of.
- Similarly, construction sites may produce waste every day.
- Disposal of construction trash created by Project activity could contaminate surface water, endangering the health of locals who rely on it for daily needs.
- Fugitive dust released from construction equipment and dust from either the unpaved landscape or working vehicles can hurt air quality.
- Due to construction activity, vegetation covers in construction locations may be destroyed, especially along the road construction.
- Existing wildlife in construction zones may be impacted by noise and disturbance caused by digging, truck traffic, human traffic, camping, and other construction-related activities.

Figure 1 shows direct and indirect emissions caused by construction and infrastructure projects and activities [8], where:

- Direct emissions mean emissions that are geographically related to the construction site's activities, such as mass transport (from and to the site), construction machinery (fuel and electricity), materials production, etc.
- Indirect emissions mean other emissions such as the transport of asphalt and concrete to the construction site that are not related geographically to the construction site, another example purchasing and producing concrete, reinforcement steel, and asphalt, these materials are often not related to the construction site and therefore not related geographically to the project activities and indirect emissions.

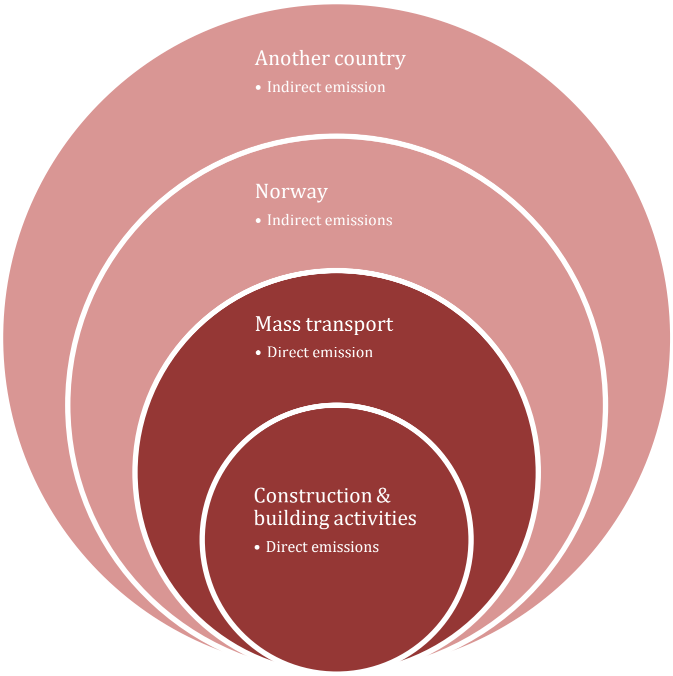


Figure 1 shows direct and indirect emissions caused by construction and infrastructure projects and activities [8] (original source in Norwegian)

Based on these definitions above the construction and infrastructure activities produce (directly and indirectly) 2193 KtCO2e yearly which is 15.3 % of total Norwegian emissions [13], where:
- 22% of 15.3 greenhouse gas emissions are related to the construction phase.
- 22% of 15.3 greenhouse gas emissions are related to the export of materials abroad.
- 11% of 15.3 greenhouse gas emissions are related to energy consumption.
- 45% of 15.3 greenhouse gas emissions are related to other sectors, such as material production, transport of materials, services, etc.

Figure 2 shows a breakdown of details of the emissions caused by construction activities in Norway [13].

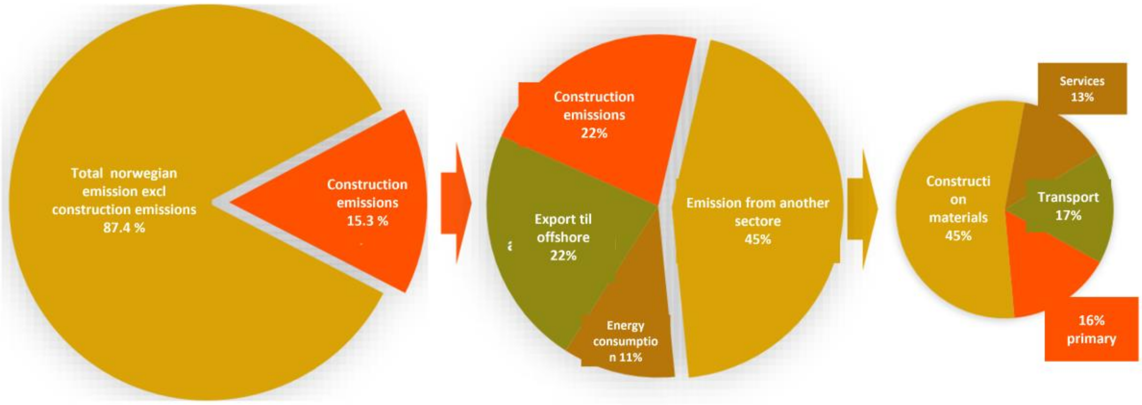


Figure 2 shows the greenhouse gas emissions from construction activities in Norway [13] (Original source in Norwegian).

1.3 Sustainable Roads

It is important to note that NTP 22/33 (Norwegian National Transport Plan 6.2 and P39) recommends minimizing environmental impacts and construction and operation expenses in all new and existing road projects.

Sustainable road practices include capturing and treating road water runoff, balancing earthworks to optimize cut and fill, using local sources to reduce the import of materials, and optimizing pavement thickness for required quality and loads. Throughout the production and construction phases of the Road life cycle, numerous building materials are employed to create the actual parts of the road. After being put through their paces, they'll be influenced by the lifespan of each pavement or the durability of each building material. Environmental impacts are the sum of ecological loads caused by each building material used in a road's construction. Consequently, it is essential to lessen the environmental impacts of each road component to lessen the road's overall ecological impact. Energy-saving or low-environmental-load structures can be used on construction sites and help lower overall environmental burdens if the construction material sector adopts eco-friendly systems and materials. Several research on life cycle assessment (LCA) methodologies have been undertaken to evaluate the ambient load reduction performance. Still, it is essential to compute the potential environmental impacts for each life cycle stage, from the manufacture of materials to the building and operation phases [14].

1.4 The aims

This master thesis aims to evaluate the environmental impacts of constructing the E39 Betna-Hestnes road project in Norway based on the LCA technique. E39 Betna-Hestnes Road Project is a 12.8 km new 2-lane road. The road will stretch approximately 9 km with a speed limit of 90 km/h. In addition, the road has 12 structures with various lengths between 11 to 136 m. The work will be carried out as a turnkey contract where the design is included in the delivery (Engineering, procurement, and construction EPC model). This thesis has been prepared based on the discussions above and the need to ensure the sustainability of new-road projects in Norway. The detailed case, methodology, results, and discussions are provided in the coming sections of this thesis [15].

2. Society perspective

Building roads is an important part of improving society and a stronger economy. But when planning and building these kinds of projects, the considerable impacts of building roads must be considered. In this chapter, we'll discuss how building Norway's E39 Betna-Hestnes route will affect the environment, the economy, and society.

The E39 road project (under) construction from Betna to Hestnes is extremely important to Norway's overall transportation network. It will be necessary to build a road that will have several bridges to achieve the required speed on the road. The ultimate purpose of the project is to lessen the amount of time spent while traveling, improve the safety of drivers, and broaden the range of possibilities for local transportation. Despite this, the project will have somehow consequences on the environment due to changes in land usage, use of power, and emissions of greenhouse gases.
The environmental impacts of building roads could substantially influence the health and well-being of the people living in the area. The noise, dust, and other air pollutants associated with construction can severely affect a person's health, including developing respiratory disorders and other conditions. Using construction trucks and other heavy equipment can worsen traffic problems and jeopardize the safety of motorists and pedestrians. As a result, it is essential to consider the environmental impacts that building roads will have on the environment and devise strategies to mitigate the negative impacts [16].

Transforming to a circular economy could help us reduce the negative impacts caused by road construction projects on the environment. A circular economy encourages the reuse of materials and products, as well as recycling and product repair, to reduce waste and increase resource utilization efficiency. Because it adheres to these eco-friendly living guidelines, this action deserves praise for being excellent. Roads can be constructed consistent with the concepts of the circular economy if eco-friendly building materials such as recycled asphalt and concrete are used and if maximum use is made of the currently available resources [17].

The E39 Betna-Hestnes project has implemented circular economy ideas to cut down on the usage of new materials. For instance, to reduce the negative effects of transportation on the environment, the project uses stone and gravel sourced from the construction areas. The amount of rubbish produced due to the project has been cut down, and additional attempts to recycle items have been made [15].

In general, the building of the E39 Betna-Hestnes route in Norway has substantial environmental impacts that should be taken into consideration. These repercussions should be taken into account, even if the project made the most efficient use of resources and incorporated ideas from circular economies to lessen its negative impacts on the environment, it is still essential to keep a close eye on the project's environmental impact and to take precautions to ensure that it will last and will be of benefit to society. Even with mitigation strategies, the project will, in any case, have some impact on the environment.

The "Go Green Tent." pilot project is a project that aims to promote sustainable and responsible production and consumption of materials, mitigate environmental impacts caused E39 Betna-Hestnes Road project, and improve economic growth. Bertelsen and Garpestad (construction company) have set up a waste station (tent) at the construction site to achieve an approx. 100% sorting rate and reuse of materials. Go Green (initiative) in corporation with NAV (Norwegian Labour and Welfare Administration) working together to improve the economic benefit by employing four unemployed workers, where the main task is sorting and recycling construction waste.

Figure 3 The "Go Green Tent." aims to promote sustainable and responsible production and consumption of materials bg.no

When a new road is created, there is a greater potential for harm to both the natural environment and the people living in the surrounding area. Some of the negative effects of construction on the environment include the destruction of habitat, the polluting of water and soil, and a rise in the concentration of greenhouse gases in the atmosphere.

Due to the use of heavy machinery and construction trucks, construction sites are substantial contributors to air pollution. These sites discharge particulate matter, nitrogen oxides, and volatile organic compounds into the atmosphere. These components can be considered contributors to ground-level ozone and fine particulate matter.

The inhalation of these pollutants puts a strain on your lungs and has the potential to hasten your passing. The construction equipment, trucks, and blasts that contribute to noise pollution can hurt human health and welfare and even influence the behavior of animals. The clearing of land for the construction of roads and highways is one of the primary factors contributing to the deterioration of the natural environment. Losing vegetation and soil can make it more difficult for plants and animals to survive, leading to species extinction and an unstable environment. In addition to damaging habitats, the development of roadways can cause disruptions in the mating and feeding cycles of several animals. Environmental considerations should be paramount in infrastructure projects' planning and construction phases.

Recycling materials and mitigating the use of new resources and materials are two ways that can be used to construct roads in a way that is both sustainable and durable (circular economy). These strategies also contribute to the advancement of sustainable development. Increasing access to medical care, fostering innovation and, creating ecologically friendly infrastructure, promoting safe and healthy cities and communities are all potential Targets that could benefit from these techniques [18].

In conclusion, building roads that benefit society and the environment can get us closer to achieving a number of the Goals. When formulating, planning, and designing designs for infrastructure projects, it is essential to prioritize sustainability and the health and happiness of individuals whom the projects will directly impact in some way.

Figure 4 Sustainable development goals are directly associated with life cycle assessment and circular economy approaches [19].

3. Knowledge background

This chapter reproduces some known and relevant theoretical knowledge that relates to road construction and its activities that produce caused emissions during the construction of a new road.

3.1 Road building

In this chapter, I aim to provide a comprehensive overview of the road planning processes, design, and construction in Norway.

3.1.1 Road planning

Road planning is the first step in road building where engineers and construction experts are involved together to decide what type of road should be made, and what is the best solution that has the lowest possible costs with the lowest damage to the environment to connect two places.
In Norway, the NPRA has planning and developing responsibility for all national roads (with Nye Veier), whereas counties and municipalities have responsibility for planning their local roads [20].
The foundation for the planning of the (existing or new) road network is established by political and strategic principles, as well as legal statutes and regulations, often coming from the Norwegian Ministry of Transportation in National Transport Plan. The NTP is a ten-year investment plan for all types of transport in Norway and approves by the Parliament of Norway every four years and it is not binding [21].
The NPRA plays a crucial role in determining the priority of road projects within the Norwegian National Transport Plan (NTP). Then the NTP sends to approve by the National government and the funding is allocated to facilitate the development and building of a new road. Following this, regional and local authorities and municipalities take on the responsibility of further developing the road projects through local planning and zoning programs, as shown in Figure 5 Road Planning processes in Norway . [2].

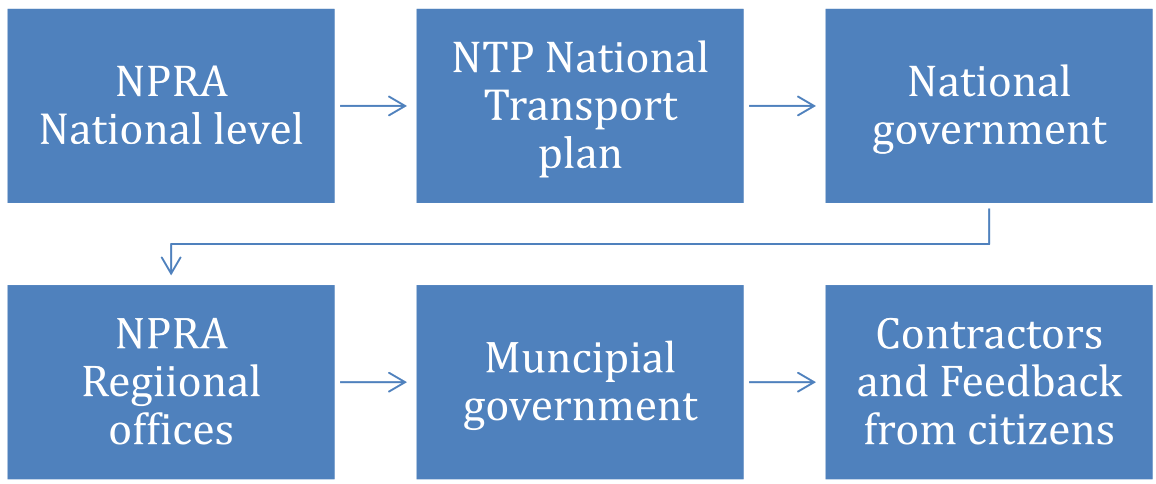


Figure 5 Road Planning processes in Norway [2].

3.1.2 Road designing

The Norwegian Public Road Administration NPRA is responsible for the minimum standards on any road project. As part of this responsibility, the NPRA periodically publishes road standards, guidelines, and guides that work as essential references for contractors, designers, and all stakeholders who are involved in any road project.

These publications outline the recommended practices, specifications, and requirements that should be followed to ensure the successful planning, design, and construction of a road project.

NPRA handbooks are published at two levels:

1- Standards (Normaler): contains precise technical specifications that are essential for design engineers, including the standards for road design such as curvature and slope, width, material requirements, speed limit based on the type of road, as well as the required thickness of structural layers based on the type of the soil and underground. Typically begin standards with the letters N or R.
2- Guidelines: contains different topics such as organizing accommodations for diverse road users and processes for determining when and how roads can be upgraded. Typically begin guidelines with the letter V.

During this phase, engineers propose multiple solutions and designs, which may vary in terms of cost, number of structures such as tunnels and bridges, potential environmental impact, and safety [22] [23].

3.1.3 Road construction

During this phase, the NPRA invites contractors to the meeting and delivers the bids for the road construction project, which enables the NPRA to keep the costs of building low. Subsequently, the bids are evaluated based on various factors, such as the lowest cost and lowest environmental impact. Once an agreement is reached on the start date, the construction work begins [15]. More details and information on construction processes, activities, and materials are in the chapter: Construction processes and activities, and Materials.

3.1.4 NPRA’s Process code system

Norwegian Public Road Administration NPRA’s process code uses to categorize all the processes, activities, and materials that are used in a road project and cover construction and maintenance work, in two publications (R761 & R762). The Process-codes handbook is used in road planning and construction for standardizing and describing various aspects of the works, activities, and processes. These Process-codes are reference frameworks and provide uniform rules and guidelines for executing, controlling, and measuring different types of work within the road construction industry. The process code system is composed of 10 categories and encompasses over 50 subcategories, resulting in more than 2800 individual codes. The 10 categories are as follows:

1- For internal use.
2- Preparatory measures and general costs.
3- Rock excavation and mass movement.
4- Tunnels.

5- Pipes and ditches.
6- Road foundation and structural layers.
7- Road surface.
8- Road equipment.
9- Bridges and quays.
10- For use in operation and maintenance phases.

These process codes should facilitate the work of preparing tenders and bidding documents. This will also make it much easier for contractors to price the work, and the codes will be the same in all road projects. R761 handbook lists process codes for all road types, except bridges and quays, where they are listed in R762 [2] [24] [25].
Therefore, by using process-codes handbooks R761&R762, road planning, and construction projects can achieve consistency and clarity in the description of construction activities, processes, and materials. Contractors and stakeholders can refer to these codes to understand the specific requirements, and specifications for each type of work involved in a project.

3.2 Construction processes and activities

3.2.1 Earthwork

As it is shown in Figure 2, there is approx. 3.5 % of Norwegian emissions are related to construction activities, such as rock excavation, vegetation clearance, and removal, topsoil removal, grubbing, etc. In traditional road projects, earthwork activities are carried out using fossil fuel-powered machinery, which contributes and increases emissions in the construction phase.
As previously mentioned, and to achieve the Sustainable Development Goals (SDGs), the Norwegian Public Roads Administration (NPRA) is committed to continuously improving and constructing road projects in an environmentally friendly way before the years 2030 and 2050. As such, the NPRA imposes strict environmental requirements in bidding documents on road construction projects, and NPRA works with various stakeholders on pilot projects for fossil-free construction sites and fossil-free earthwork activities [26] that contribute to achieving more environmentally friendly road projects.

3.2.2 Material use

Approximately 8% of Norway's emissions are attributed to the consumption and production of construction materials (for roads, bridges, tunnels, buildings, etc.), as it is shown in Figure 2.
NPRA requires EPD (environment product declaration)for the most important materials used in Road projects, such as Concrete, reinforcement, asphalt, etc. Contractors are incentivized by NPRA to submit EPDs during construction work to receive bonuses and achieve higher chances of winning tenders [27].
By imposing these requirements, NPRA ensures that the use of materials, material choices, and solutions are carried out in an environmentally friendly way. Even so, excess soil and materials generated from road excavation and cutting should be processed and repurposed locally for use in road structures, to prevent and mitigate the need for new materials (to be delivered) that result more emissions during the production and transportation phases [28].

3.2.3 Energy consumption

Norway is part of an international treaty on climate change, called the Paris Agreement, where Norway has committed to reducing emissions by at least 50%-55% by 2030 compared to emissions in 1990, and 90%-95% emission reduction by 2050 compared to 1990 emissions. This is a crucial step towards the Norwegian goal to be a low-emission society in 2050. The most emission-intensive activities on a construction site are emissions from construction machinery, mass transport, and material production. The material transportation varies and depends on the distance from the construction site to the material reception and production site [29].

3.3 Materials

This chapter provides a (brief) summary of the materials that are used in the E39 Betna-Hestnes Road project. The bulk of the information below was obtained from Handbook N200 and other sources.

3.3.1 Frost protection layer

The frost protection layer is crushed stone and designed to mitigate and prevent frost problems in road structural layers and the body (see Figure 6). This layer allows water to drain out and away quickly and prevents the formation of ice that can cause damage to the road (NTNU, Professor Inge Hoff, lecture in TBA4340).

3.3.2 Reinforcement layer

The reinforcement layer distributes the loads from traffic and protects the underlying layers from overloading and any damage, deformations, and rutting. The reinforcement layer also ensures the drainage ability as the frost protection layer (see Figure 6).

3.3.3 Base and subbase layers

The base and subbase layer (in Norwegian bærelag) are responsible for evenly distributing the weight of traffic to the reinforcement layer, without any damages, deformations, or crushing of materials.

3.3.4 Bearing layer

This bearing layer is made from bituminous masses (asphalted gravel Ag) and has the same function as the base and subbase layer, to distribute the weight of traffic to the reinforcement layer without any damage, deformations, or crushing of materials.

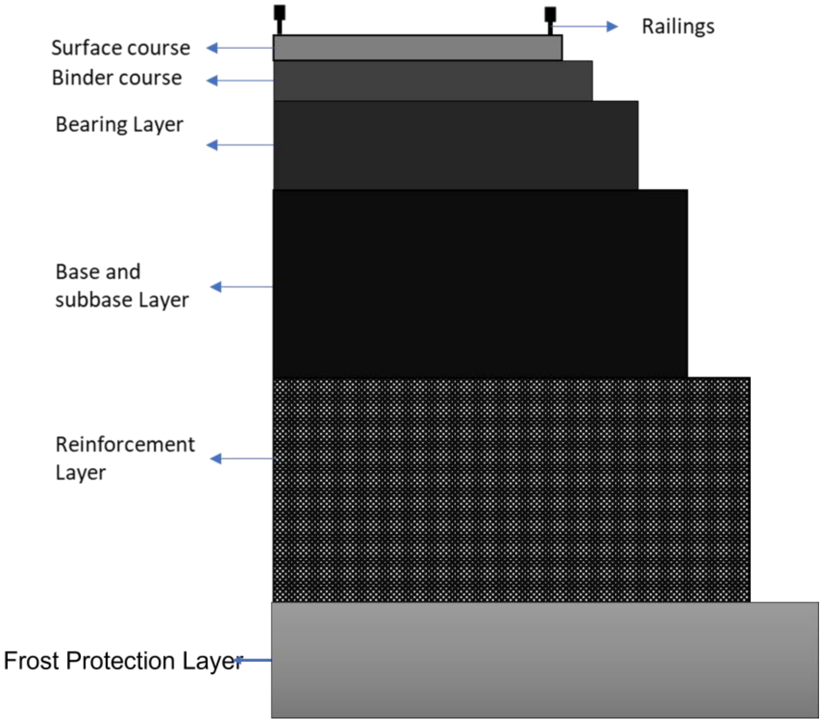


Figure 6 Typical road foundation cross-section of a road.

3.3.5 Binder layer

The top layer of the road called the binder layer or asphalt surface, provides a safe and smooth driving surface for road users and protects the road structure from damage caused by traffic and weather. The surface must have a slope to the road shoulders to ensure water runoff to the roadsides and ditches, and not least have good friction. The asphalt's stability, resistance to wear and climate-related stresses must also be sufficient to ensure that the road lasts for the expected service life.

3.3.6 Steel railing

Steel railing is used to provide a barrier between the roadway and other hazards such as steep slopes, deep ditches, or bodies of water (Handbook V161 & N101). In Norway, steel railings with reflexes are used also to provide a visual guide for drivers to help them to drive on the road line during long dark days.

3.3.7 Reinforcement steel B500NC

B500NC is steel reinforcement that is commonly used to reinforce concrete and add strength and durability in structures such as buildings, bridges, and roads. B500NC has 500 Mpa yield strength and NC ductility class [30].

3.3.8 Concrete B45, SV-40

B45, SV40 is factory-mixed concrete based on Norwegian standard NS-EN206 (situ cast concrete). B45, SV40 is commonly used as (situ cast) concrete walls, columns, and slabs. B45, SV40 has the following technical data:

1- Durability class 40
2- 45 MPa strength
3- 2300-2600 weight for each 1m3 B45, SV40 concrete.

EPD number NEPD-2510-1250-NO describe the materials that are used to produce 1 m3 B45, SV40 concrete and it is as follows:

1- 16.5% cement
2- 75.43% aggregate (gravel)
3- 7.16% water
4- 0.21% chemicals (such as plasticizers & superplasticizers)
5- 0.69% SCM (Supplementary Cementitious Materials) such as fly ash, silica fume, calcium carbonate, calcined clays, and metakaolin.

3.3.9 Waterproof membrane

A Topeka 4S waterproofing membrane is a layer of water-tight material that is laid under a binder layer (slitelag) to prevent water leaks from the road surface to road structural layers and avoid damage. Topeka 4S can be adhered to and installed under and around the foundations (see Figure 7) to prevent water penetration.

Based on information from the product data sheet from NCC (see Figure 8), Topeka 4S is made from:

- 41% gravel.
- 38% glacial flour.
- 21% filler (lime filler).

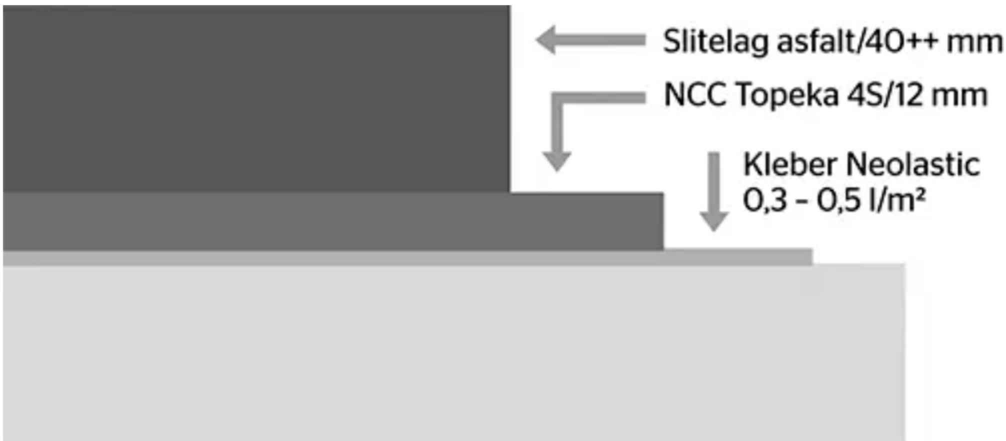


Figure 7 Waterproofing membrane Topeka 4S (from Binab)

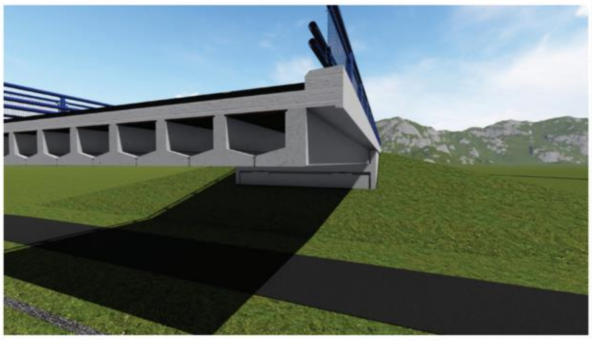
Tilslag	Forekomst	Dens.	FI	LA	Mølle	Sort	Andel
Grus	Lyngås	2.67		20	14.0	0/4	41.0
Steinmel	Lierskogen	2.85		15	7.0	0/4	38.0
Filler	Bitufill	2.74				Filler	21.0

Figure 8 Material inputs in Topeka 4S (from NCC - data sheet)

Each 1 m2 Topeka 4S has a 6.5 kg weight. See 12.10 Product data sheet and distance from Binab (Topeka 4S waterproof membrane).

3.3.10 Prefabricated beams

A prefabricated beam is a definition of beams that are fabricated off-site, tested beforehand to ensure strength, and then transported by special transportation equipment to the construction site for installation.



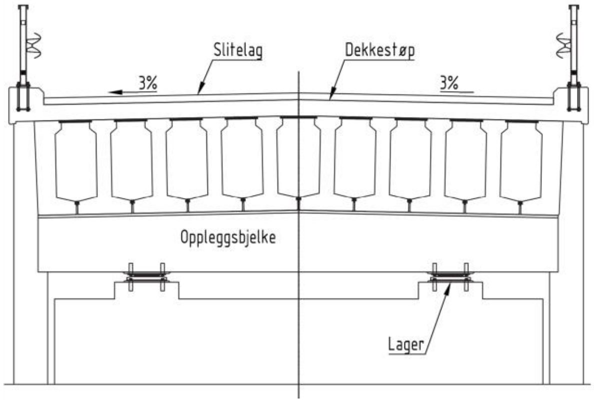


Figure 9 Illustration of prefabricated beams (Handbook V426)

The material inputs of one-unit NTB1200 are assumed to be:

1. B45, SV40 concrete.
2. Reinforcement B500NC

(see chapters 2.4 and 2.5 in Handbook V426)

3.3.11 Gravel cover

The gravel cover layer that is used in the E39 Betna-Hestnes road project is crushed rock (Fk) on roads with low AADT (Annual average daily traffic < 100). Crushed rock (Fk) produced from the construction site with electric crush machinery with 0/16 classification, which gives material size between 0.063 mm (for 5-9 % classification review) and 22.4 mm (for 100% classification review), (see 4.11.1-2 N200 handbook, page 282).

3.3.12 Bridge steel piles

Steel piles with a diameter of 150 mm are used as support for bridge structures. These steel pipes are drilled down through loose masses until they reach good rock underground, which helps to ensure the stability of the structures (see Figure 28).
The steel piles are assumed to be purchased from Geo Fundamentering & Bergboring AS in Trondheim and transported by lorry to the construction site.

3.3.13 Bridge bearing

Bridge bearing is commonly used in bridge construction to transfer the vertical and horizontal forces to the bridge fundament and substructure. The steel bearing is purchased from LAFU (Lager & Fuger AS) in Stavanger and transported by light commercial vehicle to the construction site. Figure 10 shows an illustration of a steel bridge bearing.

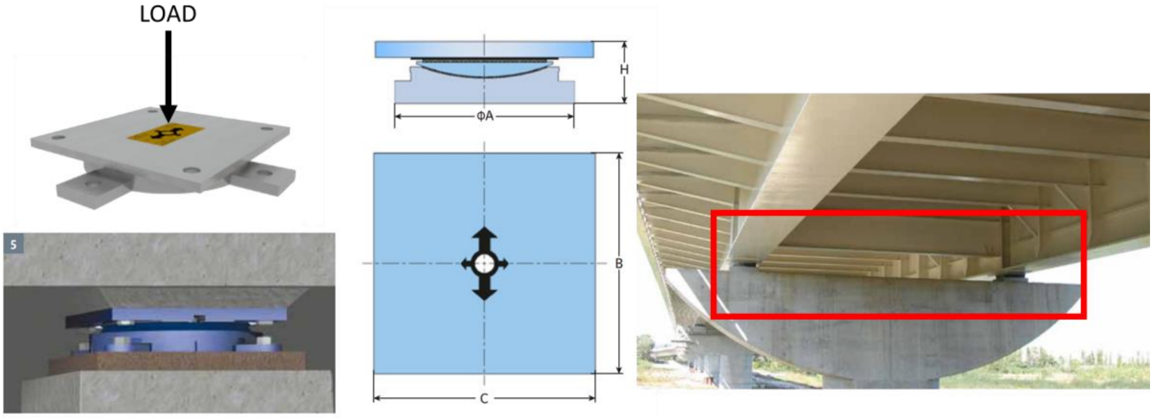


Figure 10 illustration of steel bridge bearing (lafu.no)

3.4 Circular Economy in Road construction projects:

The "Circular Economy" is a method of managing an economy in which efforts are made to minimize waste and increase returns on consumption [31]. This is accomplished by making the most of products and materials throughout their lifecycles. It is based on the idea that materials should be reduced, recycled, and reused whenever possible and emphasizes completing the material flow cycle. The circular economy can be established for constructing roads by using environmentally friendly materials, reducing waste, promoting recycling, and encouraging reuse. something that is implemented in the E39 Betna-Hestnes road project, where The Norwegian Public Road Administration imposes strict requirements on contractors to minimize material usage as much as possible [15], additionally, since 2002 NPRA started its investment in recycling and reusing materials with the Recycling Project until 2005, and the project extended in time beyond its designated timeline due to continued activity and involvement [32].

This can be accomplished in several ways, including by implementing good waste management practices, using recycled materials in construction, and developing materials so they can be separated and reused within the construction site.

Using recycled materials to make asphalt is one way to promote a circular economy for roads. This is merely one application of the technique. Since asphalt is typically used for road construction, producing it requires a lot of resources and energy. However, using recycled asphalt pavement, or RAP for short, can significantly lessen the harm that asphalt production causes to the environment. The existing asphalt pavement must first be ground and crushed to obtain RAP. Then, new asphalt can be created using recycled asphalt pavement (RAP). Utilizing cutting-edge road design techniques that focus on resource efficiency and waste minimization is another way to design roads per the principles of the circular economy. The strategy in question is "resource efficiency and waste reduction." Prefabricated components can hasten construction while minimizing waste [33].

For instance, modular design makes it easier to disassemble and reuse road parts after they have served their purpose. Construction sites can be more productive by using a modular design.

Additionally, waste management can lessen the detrimental effects of road construction on the neighborhood’s environment. This could entail employing techniques like sorting and recycling waste from the construction industry, composting organic waste, and minimizing waste from the construction industry through building practices that do not increase environmental exploitation.

In conclusion, promoting environmentally friendly road construction through the circular economy is a worthwhile and successful tactic. The use of recycled materials, separation, and recycling systems, reuse, and implementation of efficient waste management are some methods to lessen the detrimental effects of road construction on the environment surrounding the construction site.

3.5 Environmental Product Declaration

This chapter aims to give a brief overview about the Environmental Product Declaration (EPD) that is used in some materials in this thesis, such as Concrete B45-SV40.
EPD or Environmental Product Declaration is a document that provides information about the environmental impacts of a product or service during its life cycle. The EPD methodology is based on the LCA framework and ISO 14040 type III (ISO 14040 describes the fundaments and frameworks of life cycle assessment (LCA)). This environmental information can be used to compare the environmental performance of two products or services that have the same function.
In Norway, a group of stakeholders meets together to create and develop PCR. Then PCR documents are sent out for consulting to ensure transparency and accuracy. The last stage of the Norwegian EPD system is to get verification of the declaration, by using a third party that ensures all requirements are fulfilled [34].
EPD considers product category rules to ensure comparability and transparency between two different products or service EPDs. According to ISO 14025, The PCR should define the functional unit, allocation rules, system boundaries, inventory analysis, and data sources.

Figure 11 Logo of the Norwegian EPD Foundation (www.epd-norge.no)

3.6 Environmental impact categories

This chapter presents a brief and simple theoretical background related to damage pathways that are used in this thesis.

3.6.1 Terrestrial ecotoxicology

According to EPA (Environmental Protection Agency), terrestrial ecotoxicology is a study that focuses on the pollutant impact that affects terrestrial organisms and terrestrial plants on their environment, based on three elements [35]:

1- The source of environmental pollutants
2- The receptor of these pollutants (such as animals, plants, etc.)
3- And exposure pathway.
4- The term 1.4- dichlorobenzene is an organic compound that consists of two chlorine CL_2 atoms and benzene ring C_6H_6.

In short, Inorganic substances, such as sulfates, nitrates, and phosphates, that deposit in the atmosphere can alter soil acidity (after a rainy day for example). Consequently, variations in soil acidity levels can lead to changes and damages to all or some plant species [36] [37].

3.6.2 Global warming

According to EPA (Environmental Protection Agency) [38], global warming means the increase of the earth's overall temperature (°C), which is caused by releasing of GHGs greenhouse gases (kg), such as methane (CH4), Nitrogen dioxide (NO2), and Carbon dioxide (Co2) emissions.
It is important to consider GWP because rising temperature ultimately leads to damage to both human health and ecosystems.
The term CO2 eq or carbon dioxide equivalent is a metric measure used to compare greenhouse gas emissions in terms of their impacts on GWP (global warming potential) [39] [37].

3.6.3 Terrestrial acidification

Inorganic substances, such as sulfates, nitrates, and phosphates, that deposit in the atmosphere can alter soil acidity (after a rainy day for example). Consequently, variations in soil acidity levels can lead to changes and damage to all or some plant species [37].
Figure 12 shows that emissions, such as NOx, NH3, or SO2, lead to changes in soil hydrogen ions (H+) concentration. then ends to damage in the terrestrial ecosystem.
NOx = (Nitrogen Oxides)
NH3= (Ammonia)
SO2 = (Sulfur Dioxide)

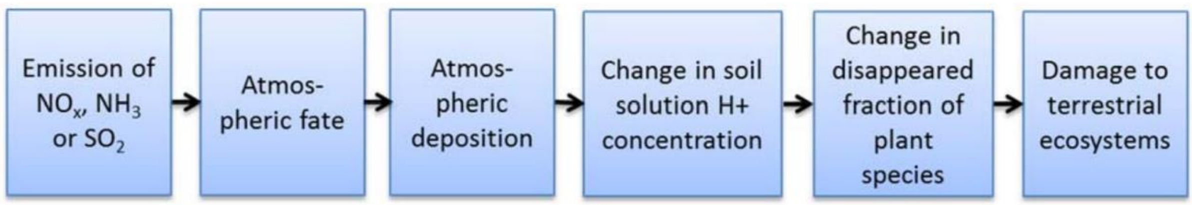


Figure 12 shows the chain of cause-and-effect that leads from acidifying emissions to the loss of certain species in terrestrial ecosystems [37].

Terrestrial acidification is a global challenge to the diversity of plant species, primarily originating from the deposition of acidifying compounds derived from atmospheric sources [40].
NOx emissions are primarily caused by the combustion of fossil fuels. In Norway, the main sources of NOx emissions are transportation and the combustion of fossil engines [41].
Fossil free construction sites will constribute to reduction of NOx (Veileder for tilrettelegging av fossilfrie og utslippsfrie løsninger på byggeplassen 2018).

3.6.4 Water use

Definition of Water Use in ReCiPe 2016 refers to the consumption of water in a production process (such as water consumption in concrete), or activity (such as water consumption during earthwork). Water use also refers to water that is transferred to other watersheds and disposed into the sea [37].

It is important to highlight that the definition of water use refers to all water that is consumed and no longer available in the watershed.
Figure 13 shows the relevant impact pathways that are covered in ReCiPe 2016.
After the first part of the chain (water consumption), it is clear that Water Use leads to a reduction in freshwater availability.

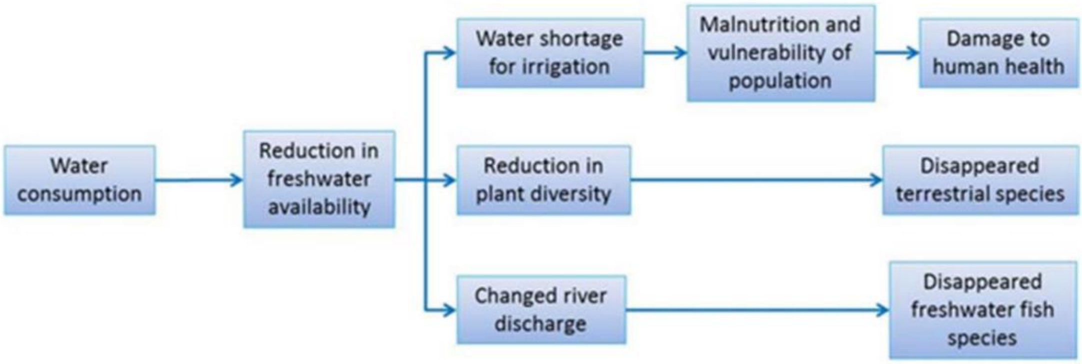


Figure 13 Chain of causation and effect related to water consumption [37].

3.7 Cumulative Energy Demand CED

CED Cumulative Energy Demand (also called primary energy consumption) is a method based on EcoInvent 2 data in SimaPro7, and it aims to calculate the amount of required energy to produce a product or service along the life cycle. CED takes into account all forms of energy inputs (non and renewable energy sources) [42]. There are three subcategories of CED:

1- CED for the production
2- CED for the use
3- CED for the disposal

CED is a sum of all these three subcategories [43].
In this thesis, CED is used to determine the energy demand of construction processes and activities in each road parcel, and where these are derived from.

3.8 Literature review

3.8.1 Mapping of construction materials reuse practices within large Norwegian municipalities by Rolf Andre Bohne and others (2023)

The practice of reusing materials in Norway is considered as it is the best practice internationally. Globally, material production contributes to approximately 40% of total greenhouse gas emissions, whereas in Norway, construction activities account for 15% of all waste generated between 2019 and 2021. Within this waste, 43% comes from demolition, 32% from new construction, and 25% from

rehabilitation projects. However, the reuse of construction materials (circular economy) in Norway is still in its early stages, primarily being explored through pilot projects.
The articles indicate that large-scale materials reuse is possible, but it comes with increased costs and requires improved planning before construction work starts. Many municipalities in Norway have adopted strategies to promote material reuse and circular economy principles. However, these strategies vary in terms of their goals and implementation stages.
The articles also highlight challenges associated with circular economy practices, including an underdeveloped market and certain legislative and technical barriers. To address these challenges, Norwegian municipalities have implemented various measures to enhance the reuse of materials in construction and building projects. These measures include establishing a value chain within the processes and incorporating intermediate storage facilities in municipalities to mitigate logistics challenges.

3.8.2 Assessment of carbon dioxide emissions during production, construction and use stages of asphalt pavements by Rolf Andre Bohne and others (2021)

This research aims to quantify the carbon dioxide (CO2) emissions associated to road pavement during its production, construction, and use phases. With the increasing of constructing new roads in recent years and the growing interest of road agencies to assess the environmental impacts of road building, asphalt becomes an interesting material to look deeper into its impact on the environment. The increasing volume of traffic requires more requests for asphalt and constructing new roads. globally expected 25 million kilometers of new road construction to be built by the year 2050.
Construction machinery is the main source of CO2 emissions during the construction phase. These emissions are primarily influenced by factors such as the type of material being moved, the terrain inclination, and the duration of work.
The study indicates that there are approximately 100 tons of CO2 during the production and construction phases of pavement, but the majority of CO2 emissions are related to the use stage of road pavement.

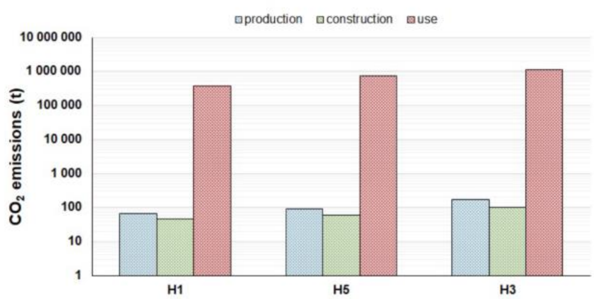


Figure 14 Amount of generated CO2 emissions related to all the phases (production, construction, and use) of road pavement.

3.8.3 Quantifying energy demand and greenhouse gas emissions of road infrastructure projects: An LCA case study of the Oslo Fjord crossing in Norway by Reyn O'Born and others (2016)

The study focuses on evaluating two alternative routes for crossing the Oslo Fjord. These routes differ in terms of their length and number of infrastructures. The first route spans 24,400 meters and

the second route is 18,010 meters (driving length). Various infrastructure elements, such as tunnels, bridges, and roads, are used to cross the fjord.
To assess the environmental impact of these two routes, the study used the Cumulative Energy Demand (CED) methodology. It considers all phases of road infrastructure, including material production, construction, operation, end-of-life considerations, and fuel consumption during traffic operations.
After analyzing and comparing the two alternatives, it is observed that alternative 2 has higher energy demands during the construction and production phases. Specifically, it consumes approximately 30,000 Gj annually. The study found that steel production, earthworks, and explosive usage contribute significantly to the overall energy demand in Alternative 2 during the production and construction phases.

Life cycle energy demand from infrastructure phase and traffic	(unit)	Alt 1	Alt 2
Production	GJ/year	4 086	26 923
Construction	GJ/year	2 272	2 685

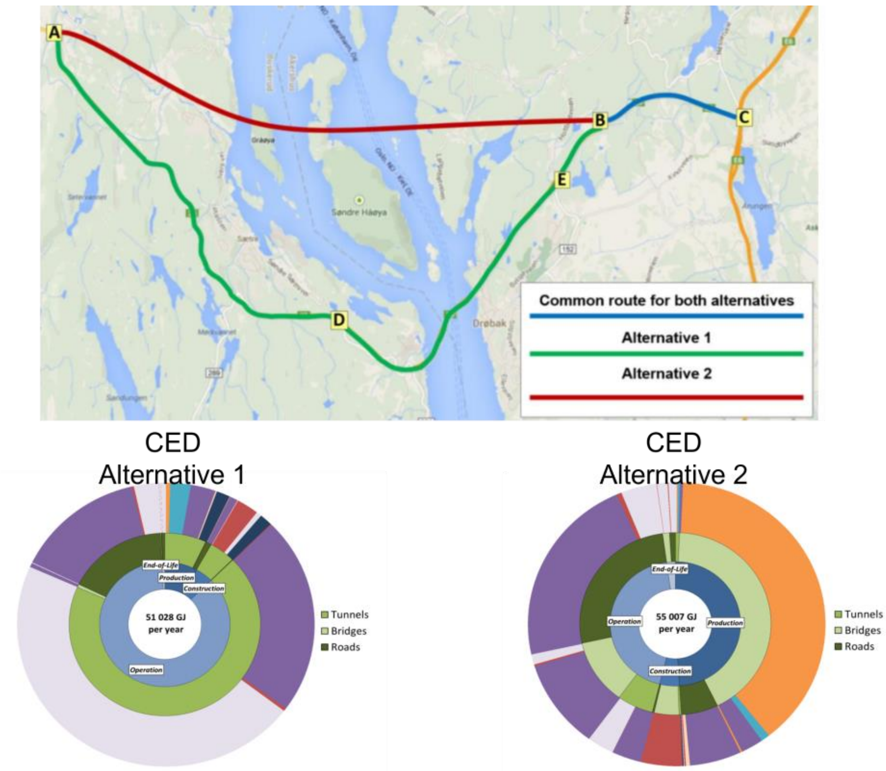


Figure 15 shows the total energy demand in the construction and production phases. The route map and contribution analysis for cumulative energy demand (CED) for Alternative 1 and 2.

3.8.4 Life cycle assessment (LCA) to evaluate the environmental impacts of urban roads: a literature review by Rolf Andre Bohne and others (2020)

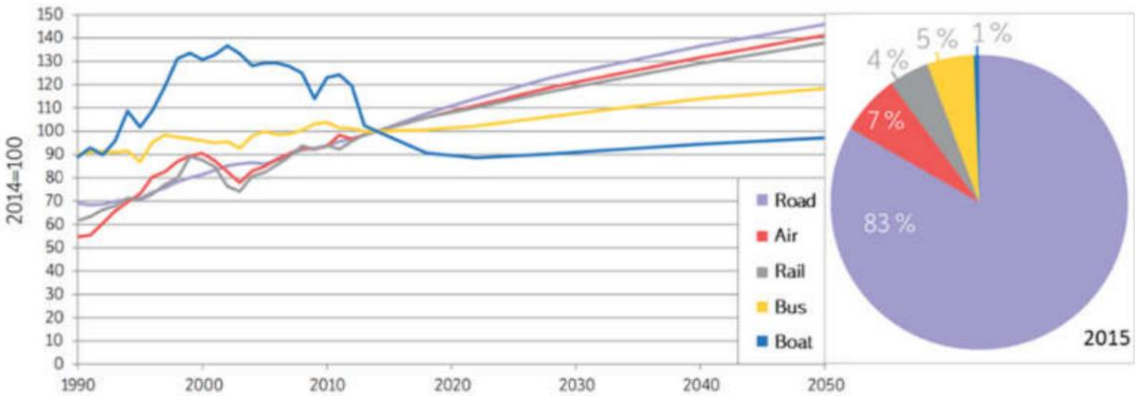
As per the findings of this study, roads play a significant role in the utilization of 105 million tons of bitumen and contribute to approximately 115 million tons of global greenhouse gas emissions (CO2-equivalent).
The study also highlighted the challenges associated with comparing life cycle assessments (LCA) in road construction and pavement. These challenges arise due to the use of different functional units

in the assessments, such as LCA per kilometer of road, per meter of road, per 1 kilometer of a four-lane or two-lane road with specific speed limits, and annual average daily traffic (AADT).
The figure below demonstrates that the study's findings indicate a significant disparity in the inclusion of different phases in road life cycle assessments (LCAs). Specifically, it reveals that 90% of the Road LCA studies considered the production, extraction of raw materials, and transportation phases. However, only 50% of the studies included the construction phase in their assessments. This disparity is because the construction phase is known to be a time-consuming phase of a road's life cycle, involving the use of heavy machinery and a high amount of energy demand.

PHASES INCLUDED IN THE BOUDANRY		**Results in %**	[4]
Production	Raw material supply	**89%**	x
	Transport	**89%**	x
	Manufacturing	**87%**	x
Construction	Transport	**51%**	x
	Construction	**49%**	x

3.8.5 Sustainability Review of Norwegian road construction and Infrastructure O'born, Bohne, and Others (2018)

Reducing emissions in the Road sector is important for Norway to achieve its climate goals. The figure below illustrates that all modes of transportation are expected to increase in the coming years. The National Transport Plan (NTP) has incorporated environmental strategies to meet emissions targets, with a specific aim of achieving a 40% reduction in CO2-equivalent emissions from construction by 2030.



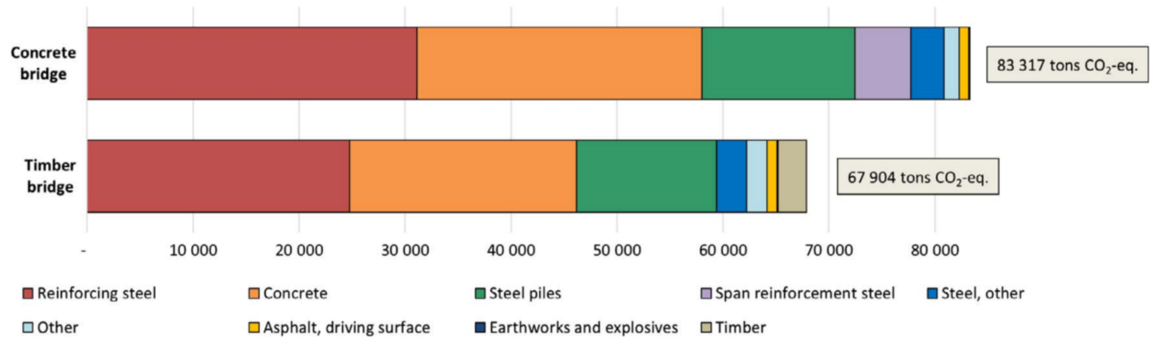
To achieve this goal, the Norwegian Public Roads Administration (NPRA) has allocated funds for several Ph.D. researchers and other experts to investigate the emissions and impacts related to road infrastructure. The NPRA has collaborated with universities to explore innovative and sustainable approaches to road construction. Notably, sustainability road projects and innovations will be implemented in the E39 Ferry-free road project, such as generating renewable energy from and along the road, as well as minimizing greenhouse gas emissions (GHGs), and reducing the energy demand.
Life Cycle Assessment (LCA) is a crucial tool for evaluating the environmental impact of new and planned road projects. Its application will continue to play a significant role in achieving Norway's climate goals.

3.8.6 Life cycle assessment of large-scale timber bridges: A case study from the world's longest timber bridge design in Norway by Reyn O'born (2018)

This research paper aims to use the Life Cycle Assessment (LCA) methodology in order to explore and analyze the environmental impacts of two proposed bridge designs (concrete and timber) intended for the new Mjøsa Bridge in Norway. The primary objective behind constructing the timber bridge is to effectively use local industry while mitigating the environmental impacts of road infrastructure projects.

The findings of the study show that the timber bridge design contributes significantly lower emissions in comparison to the concrete bridge in all impact categories considered in this research. additionally, more environmental benefits can be achieved through appropriate end-of-life treatment of timber materials.

The figure below shows that timber bridges have significantly lower CO2 emissions compared to concrete bridges.



4. Research question

The research question for the thesis is centered around the potential environmental impacts of the construction and production phases of the E39 Betna-Hestnes road project in Trøndelag county, Norway. The study also seeks to identify potential measures that can be implemented to mitigate the project's environmental impacts, using data from the contractor Bertelsen and Garpestad.

What are the environmental impacts of constructing the E39 Betna-Hestnes road project?

To answer this question, it will be used two LCA-methodologies, the ReCiPe Midpoint (H) methodology, and the CED (Cumulative Energy Demand) methodology.

4.1 Limitations:

- This thesis will not discuss and evaluate the environmental impacts in the operation and maintenance phases.
- This thesis will not study the end-of-life phase of a road project.
- This thesis will not discuss all causes that result in (ReCiPe midpoint) impact categories, **just** the following damage pathways will be discussed:
    - Terrestrial ecotoxicity
    - Global warming
    - Water use
    - Terrestrial acidification
- During writing this thesis, the E39 Betna-Hestnes road project is under construction, which makes it difficult to obtain precise and accurate data and quantities. Consequently, the data and quantities used in this thesis have been calculated and sourced from SWECO.

5. Case

In this chapter provide a detailed description of the case that has been used to answer the research question.

5.1 E39 Betna-Hesntes Road Project

An approx. 12.8-kilometer-long road will be constructed between Betna and Hestnes, located in Heim municipality in Trøndelag county. The project entails developing and building a two-lane road, which will have 8.4 km with a speed limit of 90 km/h, mainly from Betna to Otneselva, while other parts of the road will have a speed limit of 80 km/h. Additionally, the project will mainly be built on untouched terrain and will require the construction of 12 structures (8 bridges and 4 culverts) that vary in length from 11 to 136 meters. The 12.8-kilometer-long road will be divided into three parcels [15]:

- P1 Betna-Klettelva.
- P2 Klettelva-Otneselva.
- P3 Otneselva-Hestnes.

Bertelsen & Garpestad serves as the primary contractor for the E39 Betna-Hestnes project. Figure 16 below shows an overview of the three parcels comprising the E39 Betna-Hestnes Road Project [15].

Figure 16 Map provides an overview of the three sections/parcels E39 Betna-Hestnes Road Project [15].

Currently, the distance from Betna to Hestnes, as measured along the current E39 route, is approximately 17.5 km see the gray line in Figure 17. The Betna-Hestnes Road Project is a part of the E39 Betna-Stormyra Road Project, which forms part of a larger endeavor to enhance and expand the western Coastal Highway in Norway. This project is widely known as the "ferry-free E39," which starts from Kristiansand in southern Norway to Trondheim [15] [44]. E39 Betna-Hestnes Road Project has approx. 1500 AADT “annual average daily traffic” with 17% heavy traffic [15].

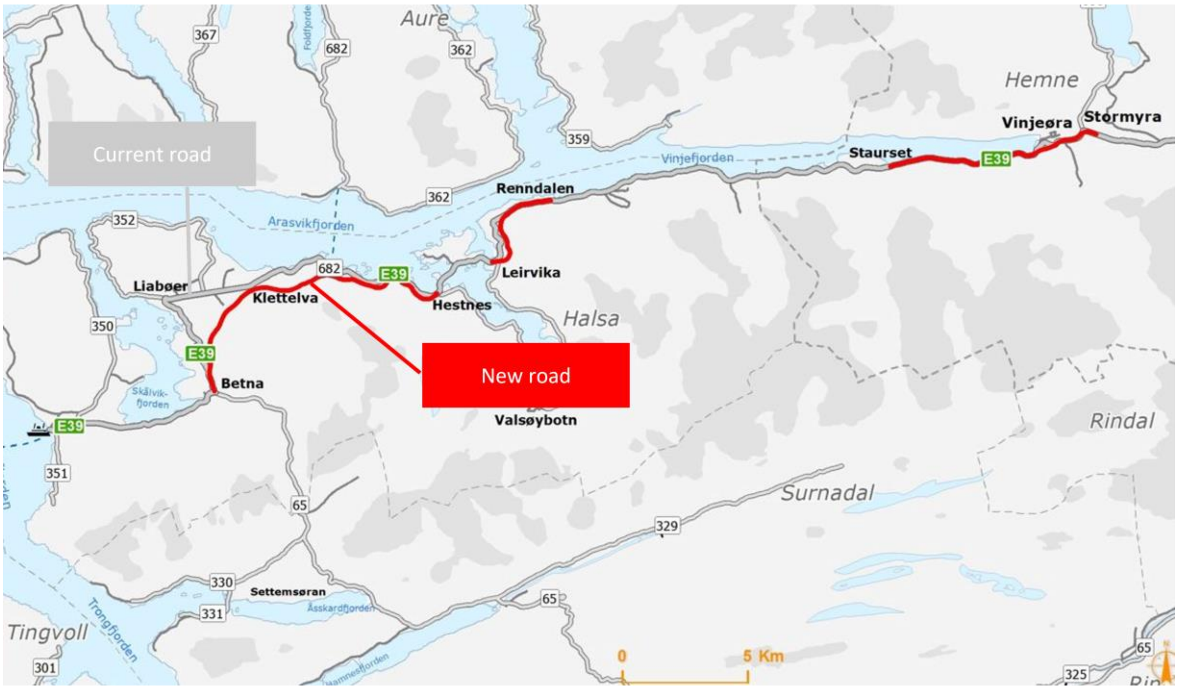


Figure 17 Map showing the alignment of the E39 Betna-Stormyra Road project [15].

The new road will adhere to the Norwegian Road Standard H1, featuring a 9-meter width with reinforced center markings to separate lanes see Figure 18 below.

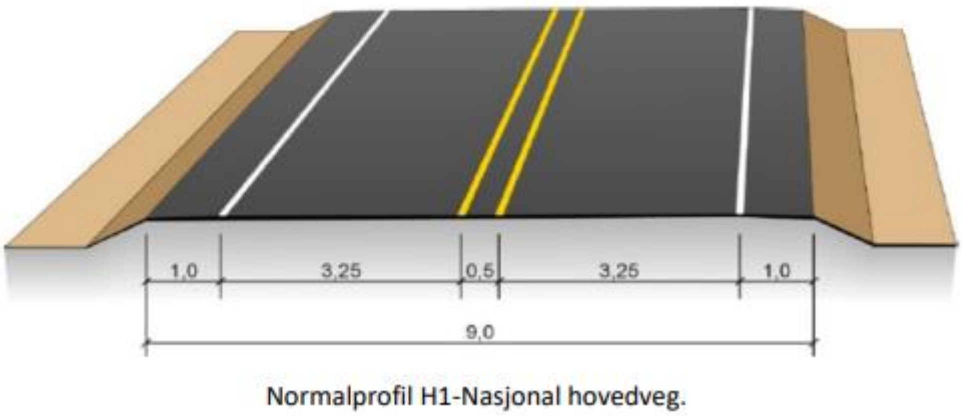


Figure 18 Typical H1 cross-section of the national highway [15].

As per the contract requirements, the contractor is obligated to ensure that the work aligns with The Civil Engineering Environmental Quality Assessment and Awards Scheme BREEAM Infrastructure (previously known as CEEQUAL) or an equivalent and comparable system. The contractor must appoint a dedicated CEEQUAL assessor for this work and achieve the "Excellent" certification levels [15].

5.1.1 Social objectives of E39 Betna-Hestnes Road Project:

The social objectives of the E39 Betna-Hestnes Road Project are as follows [15]:

- Establish a transportation system that is more secure, efficient, and dependable for traffic.
- Reduce the potential for head-on collisions and decrease the impact of downhill runs.
- Less travel time between Møre and Romsdal and Trøndelag counties. This would save approx. 7 minutes in travel time and reduce traveling distance by 4.8 km.

- Enhance and stimulate economic growth by improving the efficiency of transportation between the coastal counties and Trøndelag.

5.1.2 project outcome objectives:

The key objective of the project is to build the road sustainably, with a focus on minimizing greenhouse gas emissions. The project outcome objectives of the E39 Betna-Hestnes Road Project are as follows [15]:

- Enhance traffic safety while ensuring improved accessibility and flexibility for all categories of road users.
- Mitigate noise and dust impact.
- Maximize preservation of riparian vegetation and minimize impacts on vulnerable species and biological diversity in the project area by implementing appropriate measures during the construction of the road, particularly concerning the crossing of rivers and streams.
- The contractor is required to ensure the project is constructed with minimal greenhouse gas emissions.

5.1.3 Bridge structures

The E39 Betna-Hestnes Road project has mainly 8 bridges which are as follows:

1. K10 Skarahaugvegbrua approx. 56 m.
2. K30 Inner Våglandselvbrua approx. 75 m.
3. K40 Glåmsvegbrua approx. 40 m.
4. K50 Klettelvbrua approx. 75 m.
5. K720 Hennaelvbrua approx. 80 m.
6. K001 Otnesbrua approx. 136 m could be longer because of the slope.
7. K002 Skogsvegbrua approx. 44 m will be longer because of the slope.
8. K004 Hestnesbrua approx. 61 m will be longer because of the slope.

5.2 Betna-Klettelva parcel 5400 m.

The existing E39 Betna-Klettelva parcel is unsuitable to be European highway because it is a narrow road and has bad curvature. The main objective of the zoning plan will be to make the E39 safer for road users and make better accessibility, additionally to reduce land use for the road. This parcel will adhere to the Norwegian Road Standard H4 with a length of approx. 5400 m, featuring a 10-meter width and has 4 bridges (2 bridges for new E39 and 2 bridges for local roads) [15]:

Bridge	Type of material	Length m	Width m	Number of Spans
K10 Gurålivegbrua	Concrete bridge	36	8	17+22+17
K30 Inner Våglandselvbrua	Concrete bridge	52	10.7	23+29+23
K40 Glåmsvegbrua	Concrete bridge	36	5	40
K50 Klettelvbrua	Concrete	65	9	23+29+23

	bridge			

Figure 19 below shows parcel E39 between Betna and Klettelva, with the various bridges in the parcel.

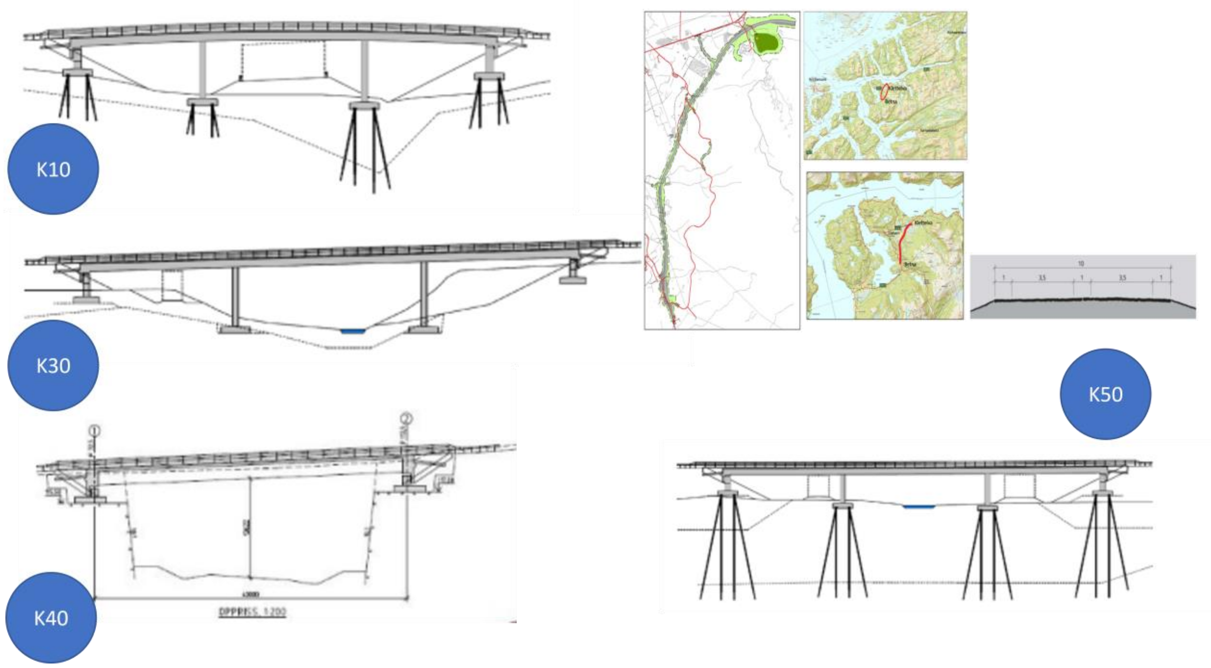


Figure 19 shows all bridges in the parcel Betna-Klettelva with zoning plan and road section H4

5.3 Klettelva-Otneselva parcel 4100 m.

The existing E39 Klettelva-Otneselva parcel is unsuitable to be a European highway because it is a narrow road and has bad curvature. The main objective of the zoning plan will be to make the E39 safer for road users and make better accessibility, additionally to reduce land use for the road. This parcel will adhere to the Norwegian Road Standard H4, then from profile number 6538 to 6683, the road standard will change from being an H4 to becoming an H2 road standard with a road width of 8.5 m. The transition section is taken over 145 m. The parcel's length is approximately 4,100 meters and will have 1 bridge which is as follows [15]:

Bridge	Type of material	Length m	Width m	Number of Spans
K720 Hennaelvbrua	Concrete bridge	86	9	23+34+23

Figure 20 below shows parcel E39 between Klettelva and Otneselva, with the various bridges in the parcel.

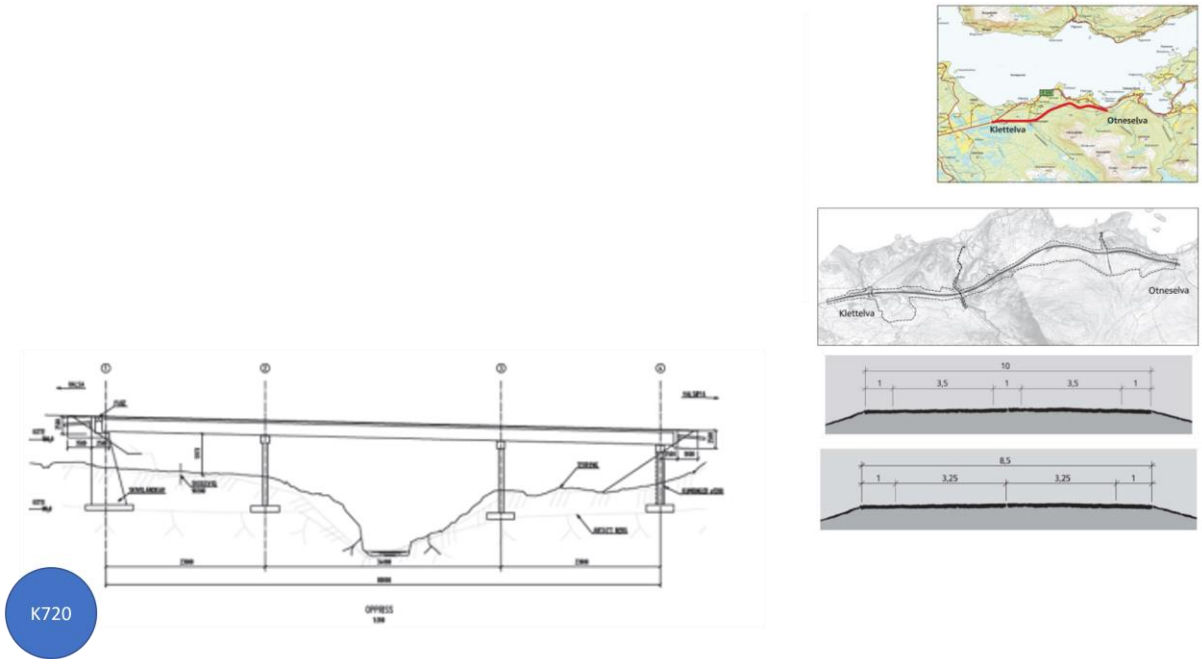


Figure 20 shows all bridges in the parcel Klettelva-Otneselva with zoning plan and 2 road sections H4 and H2

5.4 Otneselva- Hestnes parcel 3400 m.

The existing E39 Otneselva-Hestnes parcel is unsuitable to be European highway because it is a narrow road and has bad curvature. The main objective of the zoning plan will be to make the E39 safer for road users and make better accessibility, additionally to reduce land use for the road. This parcel will adhere to the Norwegian Road Standard H4, then from profile number 6538 to 6683, the road standard will change from being an H4 to becoming an H2 road standard with a road width of 8.5 m. The transition section is taken over 145 m. The parcel's length is approximately 3400 meters and will have 3 bridges (2 bridges for the new E39 and 1 bridge for local roads)which are as follows [15]:

Bridge	Type of material	Length m	Width m	Number of Spans
K001 Otnesbrua	Concrete bridge	117	9	16+22+16
K002 Skogsvegbrua	Concrete bridge	35	5	23+34+23
K004 Hestnesbrua	Concrete bridge	72	11.10	2.5+17+22+17+2.5

Figure 21 below shows parcel E39 between Klettelva and Otneselva, with the various bridges in the parcel.

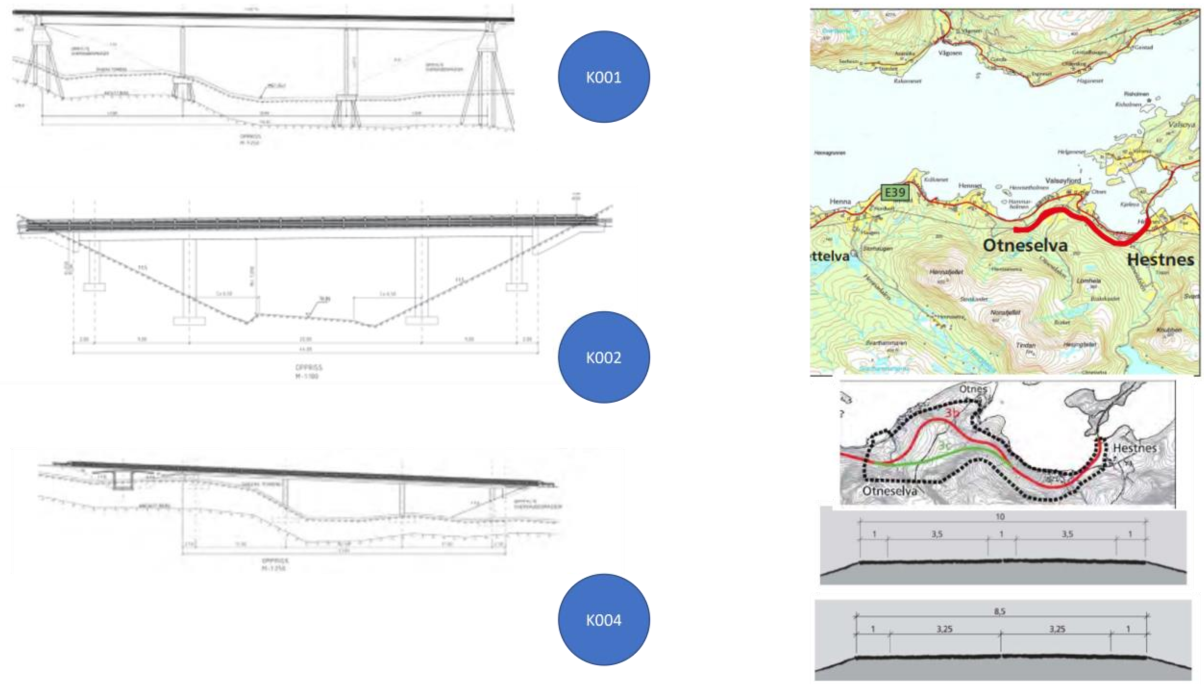


Figure 21 shows all bridges in the parcel Otneselva-Hestnes with zoning plan and 2 road sections H4 and H2

5.5 Overview of the materials used in E39 Betna-Hestnes

The aim of this chapter is to provide a brief overview (summary) of the material types used in the E39 Betna-Hestnes Road Project. The information will be presented in a point-by-point format for clarity and ease of understanding. More information about the materials is given in the Knowledge chapter materials:

1. Frost protection layer: The frost protection layer that is used in the E39 Betna-Hestnes road project is crushed stones larger than 80 mm and 180 mm from the construction site.
2. Reinforcement layer: In E39 Betna-Hestnes Road Project the crushed stone from the construction site is used.
3. Base and subbase layers: In E39 Betna-Hestnes Road Project the crushed stone from the construction site (Fk) is used.
4. Bearing layer: In E39 Betna-Hestnes Road Project the Asphalted gravel (Ag) is used.
5. Binder layer: In E39 Betna-Hestnes Road Project the Asphalt gravel concrete (Agb) is used.
6. Reinforcement steel B500NC: In E39 Betna-Hestnes Road Project the B500NC rebar is used in the bridge structures along the road.
7. Concrete B45, SV-40: In E39 Betna-Hestnes Road Project the B45, SV40 concrete is used in the bridge structures along the road.
8. Waterproof membrane: In E39 Betna-Hestnes Road Project the Topeka 4S is used in bridge structures and along the road.
9. Prefabricated beams: In E39 Betna-Hestnes road project prefabricated beams type NTB1200 but with different lengths are used.
10. Gravel cover: gravel cover (Fk) layer with 0/16 classification is used in the E39 Betna-Hestnes road project.
11. Bridge steel piles: In the E39 Betna-Hestnes Road project, steel piles with a diameter of 150 mm are used.
12. Bridge bearing: both fixed and free Sliding steel bridge bearing is used in bridge structures.

6. Methodology

6.1 LCA Life cycle assessment

The Life Cycle Assessment (LCA) methodology is a universally recognized and established technique for evaluating the environmental impact of a commodity or framework over its entire life cycle. i.e., from the extraction of raw materials, via production and material and energy consumption, to waste disposal. Utilizing it is prevalent among various entities such as corporations, governmental bodies, and scholars for pinpointing areas of ecological concern, enhancing the development of products, and facilitating the generation of reports on sustainable practices. Life Cycle Assessment (LCA) methodology is founded on four International Organization for Standardization (ISO) standards: ISO 14040, ISO 14041, ISO 14042, and ISO 14043. The criteria above serve as a set of directives for the execution of Life Cycle Assessment (LCA) investigations, aiming to guarantee the outcomes' dependability, lucidity, and comparability. The ISO 14040 standard outlines the fundamental structure and underlying principles for conducting a Life Cycle Assessment (LCA) investigation. On the other hand, ISO 14041 offers direction on determining the objective and scope of an LCA study. The International Organization for Standardization's (ISO) 14042 and 14043 standards guide the inventory analysis and impact assessment stages of a Life Cycle Assessment (LCA) investigation [45].
A complete Life Cycle Assessment consists of four sections and is shown in Figure 22 below [46] :

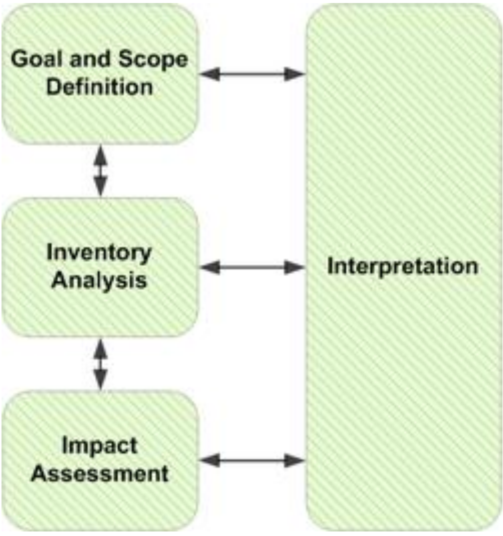


Figure 22 shows the four phases of a life cycle assessment, as described by ISO 14040

6.1.1 Goal And Scope

The goal definition is the first step in conducting an LCA and plays an essential role in framing the 'precise' aims and purpose of the study in detail, while the scope aims to define the boundaries and the systems that need to be assessed in the LCA study [34].
The main goal of this thesis is to investigate the environmental impacts of constructing the E39 Betna-Hestnes Road project.
E39 Betna-Hestnes Road Project is divided into three parcels as shown in the chapters:

- 5.2 Betna-Klettelva parcel
- 5.3 Klettelva-Otneselva parcel
- 5.4 Otneselva- Hestnes parcel

Each part or parcel of the E39 Betna-Hestnes road project has different lengths, quantities to be filled and removed, and the number and type of bridges.

This master thesis is important to achieve SDGs and mitigate the environmental impacts caused by infrastructure (road) projects. The results from this study will show the contractor, owner, and designer the environmental impacts caused by constructing E39 Betna-Hestnes Road Project.
The Functional unit (FU) in this thesis is the environmental impacts from the production and construction stages (Cradle to the site) of **each road parcel**.
Maintenance and operation activities (Use stage) and End-of-life will not be studied in this thesis.

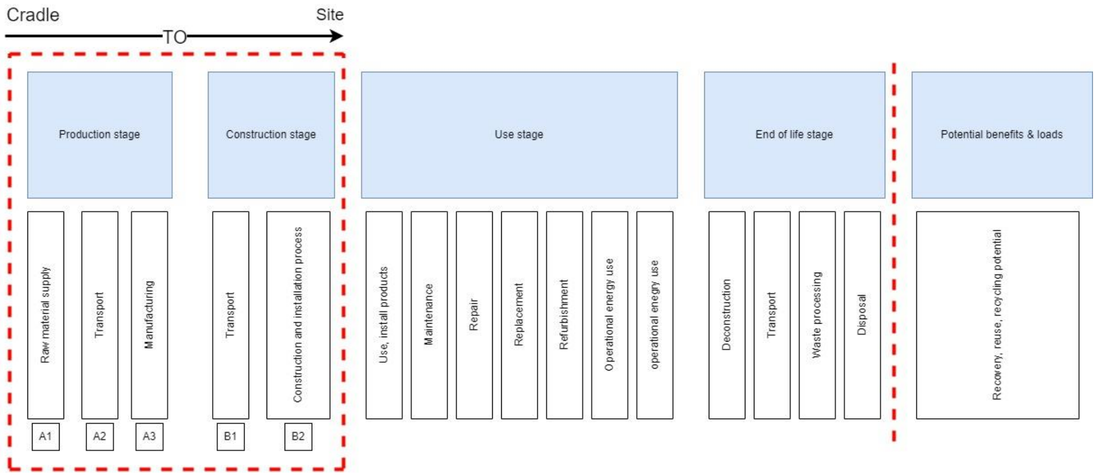


Figure 23 LCA system and chosen boundaries according to the EN-17472 (2020) and EN-15804 (2019) standards [47].

6.1.2 LC-Inventory analysis

The second phase of conducting an LCA study is the inventory analysis, which entails collecting information on the inputs and outputs of every process and activity involved in the life cycle of the road project. An inventory analysis aims to generate a thorough inventory encompassing all the environmental impacts linked to road construction. The constituents employed in the production of the road, including but not limited to aggregates, asphalt, and concrete, are referred to as raw materials. The process of inventory analysis generally entails the collection of data about the energy consumption associated with the road construction process and encompasses the utilization of electricity and fuel for machinery and transportation purposes. Inputs are determined with respect to the road design during the bidding process or in the contract. Therefore, the inputs of the LCI are identical to the tender given to a road builder [34].
Therefore, the results chapter displays the in-depth Life Cycle Inventory (LCI).
Chapter 6.3 Data collection provides a brief description of how the data is collected, sorted, and organized.

6.1.3 Impact Assessment:

The third phase is called the "impact assessment," During this stage, the roadway's environmental impact is measured and compared with methods already established for this purpose. This phase is called the "impact analysis" phase. These methods convert the inventory data into environmental impacts in terms of the environmental impact categories selected in the first step [34].
The ReCiPe and CED (Cumulative energy demand) impact methodologies are used in this thesis. The following impact categories with ReCiPe methodology are chosen:

1. GWP
2. Water use
3. Terrestrial ecotoxicology
4. and terrestrial acidification.

Additionally, CED is used to determine the energy demand of construction processes and activities in each road parcel, and where these are derived from.

6.1.4 Interpretation

The final step of an LCA is interpretation. In this step, the findings of the impact assessment should be considered and evaluated, and then provide a clear and comprehensible summary of the findings to the users (reader). The interpretation step also aims to find what are the main anthropogenic sources that cause the impacts [34].

6.2 SimaPro

In this thesis, the SimaPro software program has been used. SimaPro is software that is widely used to evaluate the environmental impacts of any product, service, and process throughout its life cycle systematically and transparently [48]. Reyn O'Born his Handbook *SimaPro for LCA Practitioners-UiA* is used as a guide to carry out this thesis. This handbook uses as a guide for using the SimaPro program and is a part of the BYG404 Life Cycle Assessment course at the University of Agder.
Ecoinvent 3 databases are used in SimaPro which includes various categories such as energy production, building material, transport, etc. The impact assessment methods that are used in this report are:

- ReCiPe 2016 Midpoint (H).
- CMD Cumulative energy demand 1.11.

6.3 Data collection

The Contractor Bertelsen & Garpestad shared the quantities report on the 27th of March based on process codes from The Norwegian Public Roads Administration handbook R761 and R762.
Environmental Product Declarations (EPD) have been used in this thesis to gather comprehensive information about a product's or material's build-up (inputs) (if it is possible to reach them as quickly as possible).
The quantities are summarized and organized based on 3 main categories:

1- Earthwork activities
2- Materials consumption
3- And energy consumption for small cars

In the external environment report (Ytremiljø rapport see 12.1), energy consumption is categorized based on various purposes, (such as diesel consumption for machinery use and diesel consumption for mass transport), these diesel consumption (for machinery use and mass transport) data are specifically related to earthwork activities and Materials Consumption, therefor diesel and electricity consumptions (excluded energy for small cars) are integrated in earthwork and material consumption activities.

It is worth noting that obtaining the data from the contractor was a time-consuming process, it was received just four days before the Easter holiday. This delay led to low-quality results and getting more challenges. The quantities Excel sheet is attached.

6.4 Characterization method ReCiPe

When performing an LCA study, it is essential to choose a suitable characterization method for impact assessment calculations. In general, the results of LC-impact assessment may differ based on the chosen method. Therefore, it is important to select the right method that is appropriate for the geographic location and available data.

ReCiPe method is commonly used with EcoInvent data and is widely accepted. In this thesis ReCiPe 2016 midpoint (H) is used. ReCiPe 2016 midpoint characterizes the environmental impacts (damage pathways) of human activities or processes at a midpoint level, the letter (H) in ReCiPe 2016 midpoint (H) stands for hierarchist. In short, ReCiPe 2016 midpoint (H) measures the potential effects of an activity on specific environmental indicators, such as global warming, acidification, ecotoxicity, etc (see Figure 24) [49] [37].

According to the SimaPro Handbook [49], characterization shows the emission for each impact category according to the activities/processes, then divides them in terms of percentages. This characterization method is beneficial to identify which process/activity contributes to each impact category.

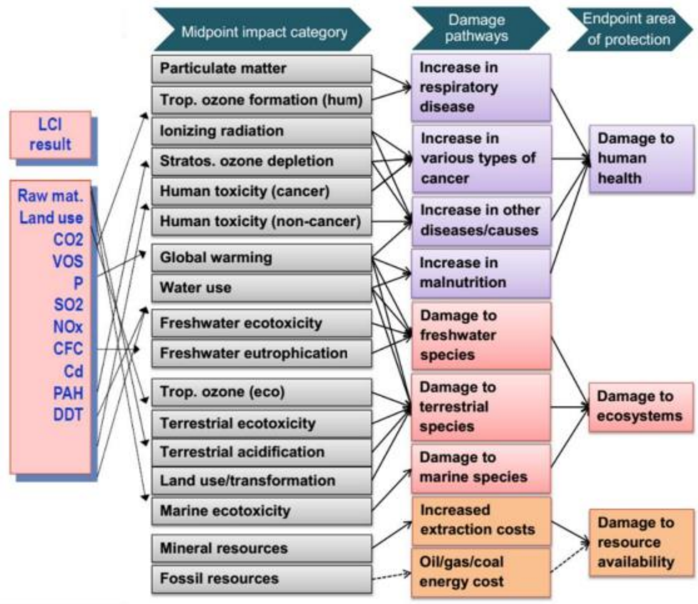


Figure 24 Overview of the impact categories that are covered in the ReCiPe2016 Midpoint methodology and their relation to the areas of protection [49].

6.5 Literature review

The main aim of incorporating a literature review in this master's thesis is to show an understanding and knowledge of the research topic, which is LCA in road construction, through an extensive review of relevant literature on various scientific platforms such as Researchgate, Scopus, and others.

The information on road construction and its life cycle environmental impact in Norway was searched using specific keywords such as "road construction," "environmental impact," and "Norway" on several search engines and databases. The articles that were taken into consideration for the study were the ones that were published between 2015 and 2023.

A solid foundation for gaining an understanding of the environmental impacts of road construction in Norway was laid by using knowledge and information from research papers written by Reyn O'born & Rolf André Bohne and their co-researchers.

This literature review evaluation covered a total of five papers. Based on their applicability to the topic and attention to the environmental impacts of road construction in Norway, these studies were chosen:

1- Mapping of construction materials reuse practices within large Norwegian municipalities by Rolf Andre Bohne and others (2023).
2- Assessment of carbon dioxide emissions during production, construction and use stages of asphalt pavements by Rolf Andre Bohne and others (2021).
3- Quantifying energy demand and greenhouse gas emissions of road infrastructure projects: An LCA case study of the Oslo Fjord crossing in Norway by Reyn O'Born and others (2016).
4- Life cycle assessment (LCA) to evaluate the environmental impacts of urban roads: a literature review by Rolf Andre Bohne and others (2020).
5- Sustainability Review of Norwegian road construction and Infrastructure O'born, Bohne, and Others (2018).

7. Results

This master thesis seeks to find the environmental impacts of three parcels of the E39 Betna-Hestnes Road Project in Trøndelag County, inc. structures, from Cradle to site. The whole road project is divided into three parcels as shown in the Case chapter and it is as follows:

1- P1 means parcel 1 = Betna – Klettelva 5400 m.
2- P2 means parcel 2= Klettelva – Otneselva 4100 m.
3- P3 means parcel 3= Otneselva – Hestnes 3400 m.

The flowchart Figure 25 illustrates the E39 Betna-Hestnes project construction process, the left-side showing activities related to earthwork, and the right-side representing materials consumption.
The figure shows the transportation method (by road or sea) and the needed inputs in each material.
More detailed information on each is in Life Cycle Inventory chapter.

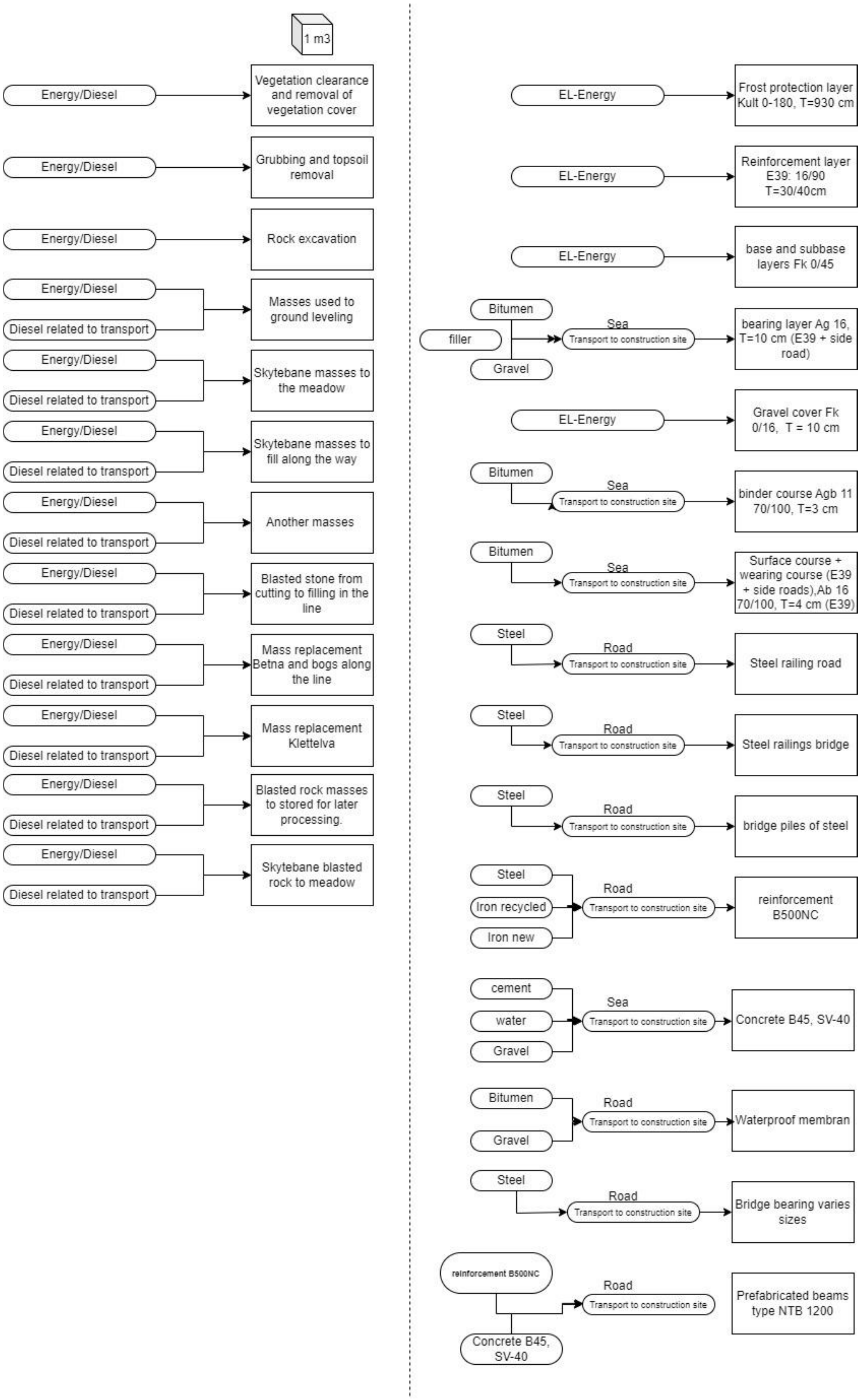


Figure 25 Flowchart of constructing E39 Betna-Hestnes.

7.1 Life Cycle Inventory

The external environment (Ytremiljø) report does not specifically allocate some amounts that are consumed in each parcel of the road. As a result, and in some activities, it is presented as a percentage of the total length for each road parcel, where:

1. P1 = (5400m/12800m) *100%= 42%
2. P2 = (4100m/12800m) *100%= 32%
3. P3 = (3400m/12800m) *100%= 26%

7.1.1 Earthwork

Earthwork contains 12 different processes and activities where are some of them calculated by Sweco in the External environment report (YM-rapport), more details are in Table 1.
In general, earthwork activities in road construction are tasks involved in shaping, excavating, and manipulating the natural terrain to create the foundation and alignment for the road.
These activities mainly consist of vegetation removal, grubbing, and movement of top-soil, rock, and other materials and masses to create good and necessary slopes.

Table 1 Activities related to earthwork.

	Description	Process code	sum quantity	P1	P2	P3	unit	sum percentage	P1 - percentage share of its total quanitiy	P2 - percentage share of its total quanitiy	P3 - percentage share of its total quanitiy	comment
Earthwork	Vegetation clearance and removal of vegetation cover	21.2 and 21.31	175463,00	69814,0	59823,0	45826,0	m3	1,00	40 %	34 %	26 %	Allocated by Sweco
	Grubbing and topsoil removal	21.32	4523,00	1600	0,0	2923,0	m3	1,00	35 %	0 %	65 %	Allocated by Sweco
	Rock excavation	22.1	1009025,00	379605,0	445554,0	183866,0	m3	1,00	38 %	44 %	18 %	Allocated by Sweco
	Masses used to ground leveling	25.2	46845,00	19675,0	14990,0	12180,0	m3	1,00	42 %	32 %	26 %	Allocated to all pacels as percentage of total road length
	Skytebane masses to the meadow	25.4	89000,00	0,0	89000,0	0,0	m3	1,00	0 %	100 %	0 %	Allocated to meadow in P2
	Skytebane masses to fill along the way	25.4	181000,00	76020,0	57920,0	47060,0	m3	1,00	42 %	32 %	26 %	Allocated to all pacels as percentage of total road length
	Another masses	25.7	160000,00	67200,0	51200,0	41600,0	m3	1,00	42 %	32 %	26 %	Allocated to all pacels as percentage of total road length
	Blasted stone from cutting to filling in the line	26.1	531481,00	223222,0	170074,0	138185,0	m3	1,00	42 %	32 %	26 %	Allocated to all pacels as percentage of total road length
	Mass replacement Betna and bogs along the line	26.1	114285,00	114285,0	0,0	0,0	m3	1,00	100 %	0 %	0 %	Allocated to bogs and allong P1
	Mass replacement Klettelva	26.1	64058,00	0,0	64058,0	0,0	m3	1,00	0 %	100 %	0 %	Allocated to meadow in P2
	Blasted rock masses to stored for later processing.	26.3	122000,00	51240,0	39040,0	31720,0	m3	1,00	42 %	32 %	26 %	Allocated to all pacels as percentage of total road length
	Skytebane blasted rock to meadow	26.4	79000,00	50580,0	15680,0	12740,0	m3	1,00	64 %	20 %	16 %	Allocated to all pacels as percentage of total road length

Following is some information on each process:

1. Vegetation clearance and removal of vegetation cover
   a. This process is calculated by Sweco for each parcel.
   b. The work has been done with diesel machinery.
2. Grubbing and topsoil removal
   a. This process is calculated by Sweco for each parcel.
   b. The work has been done with diesel machinery.
3. Rock excavation
   a. This process is calculated by Sweco for each parcel.
   b. The work has been done with diesel machinery.
4. Masses used to ground leveling
   a. This process is calculated for all parcels as a percentage of total road length.
   b. The work has been done with diesel machinery.

5. Skytebane masses to the meadow
    a. This process is just for parcel 2(P2).
    b. The work has been done with diesel machinery.
6. Skytebane masses to fill along the way.
    a. This process is calculated for all parcels as a percentage of total road length.
    b. The work has been done with diesel machinery.
7. Another masses
    a. This process is calculated for all parcels as a percentage of total road length.
    b. The work has been done with diesel machinery.
8. Blasted stone from cutting to filling in the line.
    a. This process is calculated for all parcels as a percentage of total road length.
    b. The work has been done with diesel machinery.
9. Mass replacement Betna and bogs along the line
    a. This process is just for parcel 1(P1).
    b. The work has been done with diesel machinery.
10. Mass replacement Klettelva
    a. This process is just for parcel 2(P2).
    b. The work has been done with diesel machinery.
11. Blasted rock masses to store for later processing.
    a. This process is calculated for all parcels as a percentage of total road length.
    b. The work has been done with diesel machinery.
12. Skytebane blasted rock to the meadow.
    a. This process is calculated for all parcels as a percentage of total road length.
    b. The work has been done with diesel machinery.

7.1.2 Materials inventory

Materials consumption contains 16 different types of materials where all of these materials are calculated by Sweco (Excl. Road and bridge railings), more details in Table 2:

Table 2 Materials inventory

	Description	Process code	sum quantity	P1	P2	P3	unit	sum percentage	P1 - percentage share of its total quanitiy	P2 - percentage share of its total quanitiy	P3 - percentage share of its total quanitiy	comment
Materials consumption	Frost protection layer Kult 0-180, T=930 cm	52.3	71666,00	23413,0	24773,0	23480,0	m3	100 %	33 %	35 %	33 %	Allocated by Sweco
	Reinforcement layer E39: 16/90 T=30/40cm	53.2	75018,00	35029,0	20469,0	19520,0	m3	100 %	47 %	27 %	26 %	Allocated by Sweco
	base and subbase layers Fk 0/45	54.2	5676,00	3923,0	935,0	818,0	m3	100 %	69 %	16 %	14 %	Allocated by Sweco
	bearing layer Ag 16, T=10 cm (E39 + side road)	55.1	12878,00	5456,0	3850,0	3572,0	m3	100 %	42 %	30 %	28 %	Allocated by Sweco
	Gravel cover Fk 0/16, T = 10 cm	61.1	1840,00	1072,0	554,0	214,0	m3	100 %	58 %	30 %	12 %	Allocated by Sweco
	binder course Agb 11 70/100, T=3 cm	65.11	4052,00	1865,0	1142,0	1045,0	m3	100 %	46 %	28 %	26 %	Allocated by Sweco
	Surface course + wearing course (E39 + side roads),Ab 16 70/100, T=4 cm (E39)	65.21	4835,00	2060,0	1523,0	1252,0	m3	100 %	43 %	31 %	26 %	Allocated by Sweco
	Steel railing road	75.232	6500,00	2730,0	2080,0	1690,0	m	100 %	42 %	32 %	26 %	Steel railings that uses for road, allocated to all pacels as percentage of total road length / Assumed to be type Nordic W N2 - delevered by SVB gruppen
	Steel railings bridge	87.2	1089,00	407,0	176,0	506,0	m	100 %	37 %	16 %	46 %	Allocated by Sweco / Assumed to be type Flexsafe - delevered by SVB gruppen
	bridge piles of steel	83.5	2080,00	920,0	0,0	1160,0	m	100 %	44 %	0 %	56 %	Allocated by Sweco
	reinforcement B500NC	84.3	1705,00	573,0	352,0	780,0	t	100 %	34 %	21 %	46 %	Allocated by Sweco
	Concrete B45, SV-40	84.4	8302,00	2930,0	1822,0	3550,0	m3	100 %	35 %	22 %	43 %	Allocated by Sweco
	Waterproof membran	87.1	4598,00	1609,0	774,0	2215,0	m2	100 %	35 %	17 %	48 %	Allocated by Sweco
	Bridge bearing varies sizes	87.3	32,00	16,0	4,0	12,0	item	100 %	50 %	13 %	38 %	Allocated by Sweco
	Prefabricated beams type NTB 1200		750,00	540,0	0,0	210,0	item	100 %	72 %	0 %	28 %	Allocated by Sweco

Figure 6 shows a typical road foundation cross-section and its different layers.

Before starting to list the information, it is important to clarify that **tkm** (ton-kilometer) represents the amount of 1 ton of a material or product transported in a 1-kilometer distance.

Following is some information on each material (see 12.5 An email with a reply from contractor B&G.):

1. Frost protection layer Kult 0-180, T=930 cm:
    a. This process is calculated by Sweco for each parcel.
    b. The work has been done with Electric machinery.
2. Reinforcement layer E39: 16/90 T=30/40cm:
    a. This process is calculated by Sweco for each parcel.
    b. The work has been done with Electric machinery.
3. Base and subbase layers Fk 0/45:
    a. This process is calculated by Sweco for each parcel.
    b. The work has been done with Electric machinery.
4. Bearing layer Ag 16, T=10 cm (E39 + side road):
    a. This process is calculated by Sweco for each parcel.
    b. This material is purchased from Velde AS in Sandnes and transported by sea at an approximate distance of 650 km (see 12.6 Sea transport distance from Velde AS in Sandnes to the construction site (asphalt and B45SV40 concrete)).
    c. 1 m3 of bearing layer Ag 16 is approximately 1500 kg [50]
    d. EPD Environmental Product Declaration number NEPD-1389-456-NO is used to define the material inputs for each 1 m3 Ag 16:
        i. 0.88% gravel crushed*1500 kg=1320 kg.
        ii. 0.8% filler*1500 kg=120 kg.
        iii. 0,04% bitumen*1500 kg= 60 kg.
    e. 1.5 ton*650 km= 975 tkm
5. Gravel cover Fk 0/16, T = 10 cm:
    a. This process is calculated by Sweco for each parcel.
    b. The work has been done with Electric machinery.
6. Binder course Agb 11 70/100, T=3 cm:
    a. This process is calculated by Sweco for each parcel.
    b. This material is purchased from Velde AS in Sandnes and transported by sea at an approximate distance of 650 km (see 12.6 Sea transport distance from Velde AS in Sandnes to the construction site (asphalt and B45SV40 concrete)).
    c. 1 m3 of binder course Agb 11 is approximately 1600 kg [50]
    d. 1.6 ton*650 km= 1040 tkm
7. Surface course + wearing course (E39 + side roads),Ab 16 70/100, T=4 cm (E39)
    a. This process is calculated by Sweco for each parcel.
    b. This material is purchased from Velde AS in Sandnes and transported by sea at an approximate distance of 650 km (see 12.
    c. 1 m3 of Ab 16 is approximately 1500 kg [50]
    d. 1.5 ton*650 km= 975 tkm
8. Steel railing road (Nordic W N2)
    a. This process is calculated for all parcels as a percentage of the total road length.
    b. This material is purchased from Sirdal Veibetong AS (SVB Gruppen) in Sirdal and transported by lorry>32 tons at an approximate distance of 1000 km (see 12.7 The distance between Sirdal and the construction site (steel railings).
    c. It is assumed railing type Nordic W N2 FMK-EU4, see Figure 26.

d. 1 m of Nordic W N2 has approximately 84 kg of steel
   i. CE marking number: 0402-CPR-SC0563-11
   ii. Volume = 1m length*0.35m width*0,03m thickness = 0.0105 m3 of steel used to produce 1m Nordic W N2 railing.
   iii. It is assumed that 1 m3 steel = approx. 8000 kg/m3 [51], consequently 1 m Nordic W N2 railing = 0.0105 m3*8000 kg/m3= 0.084 ton
e. 0.084 ton*1000 km= 84 tkm

Nordic W N2

Figure 26 Road guard type Nordic W N2.

9. Steel railing bridge (Flexsafe)
   a. This process is calculated by Sweco for each bridge in each road parcel.
   b. This material is purchased from Sirdal Veibetong AS (SVB Gruppen) in Sirdal and transported by lorry>32 tons at an approximate distance of 1000 km (see 12.7 The distance between Sirdal and the construction site (steel railings)).
   c. It is assumed railing type Flexsafe, see Figure 27.
      i. It is assumed that 1 m of Flexsafe has 250 kg of steel.
      ii. CE marking number: 0402-CPR-SC0226-15
   d. 0.250 ton*1000 km= 250 tkm

Flexsafe

Figure 27 Road guard type Flexsafe

10. Bridge piles of steel
   a. This process is calculated by Sweco for each bridge in each parcel.
   b. This material is assumed to be purchased from GEO fundamentering & bergboring AS in Trondheim and transported by lorry>32 tons at an approximate distance of 120 km. (See 12.8 The transport distance from Geo fundamentering & bergboring AS in Trondheim to the construction site (steel bridge piles).
   c. It is assumed to be Ø150 on all bridges and 1 m of steel piles = 139 kg.
      i. The dimension of piles varies based on the type of underground, the bearing capacity of the soil, and many other factors, and therefore it is assumed to be Ø150 that is used on all bridges.

d. 0.139 ton*120 km= 16,68 tkm

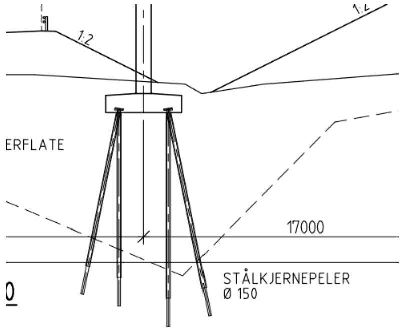


Figure 28 An example of designed steel piles, this drawing has been taken from a technical drawing for Otnesbrua K001.

11. Reinforcement B500NC
    a. This process is calculated by Sweco.
    b. This material is assumed to be purchased from Norsk Stål AS and transported by lorry>32 tons from Trondheim at an approximate distance of 140 km.
    c. EPD Environmental Product Declaration number NEPD-2676-1376-NO is used to define the material inputs for each 1 kg B500NC reinforcement:
        i. 0.60 kg reinforcement.
        ii. 0.40 kg steel (from recycled steel)
    d. 0.001 ton*140 km= 0,14 tkm
12. Concrete B45, SV-40
    a. This process is calculated by Sweco for each bridge in each parcel.
    b. This material is purchased from Velde AS in Sandnes and transported by sea at an approximate distance of 650 km (see 12.6 Sea transport distance from Velde AS in Sandnes to the construction site (asphalt and B45SV40 concrete).
    c. EPD Environmental Product Declaration number NEPD-2510-1250-NO is used to define the material inputs for each 1 m3 B45, SV40 concrete, with approx weight 2500 kg.
        i. 413 kg cement.
        ii. 179 kg water.
        iii. Aggregate 1885,75.
    d. 2.5 ton*650 km= 1625 tkm
13. Waterproof membrane (Topeka 4S)
    a. This process is calculated by Sweco for each bridge in each parcel. This material is purchased from Binab in Lierskogen and assumed to be transported by lorry>32 tons at an approximate distance of 600 km (see 12.10 Product data sheet and distance from Binab (Topeka 4S waterproof membrane).
    b. The technical data sheet shows that 1 m2 of Topeka 4S waterproofing membrane has a 6.5 kg weight and has the following inputs:
        i. 79% aggregate (41% glacial flour and 38% crushed fines)
        ii. 21% bitumen (bitufill)
        iii. 0.0065 ton*600 km= 3,9 tkm
14. Bridge bearing
    a. This process is calculated by Sweco for each bridge in each parcel.

b. This material is purchased from LAFU (Lager & Fuger) AS in Stavanger and assumed to be transported by a light commercial vehicle at an approximate distance of 950 km from Stavanger to the construction site (see12.11 An e-mail and distance from LAFU (Bridge bearing).
c. It is assumed that the average weight of each bearing has 200 kg of steel.
d. 0.2 ton*950 km= 190 tkm

15. Prefabricated beams type NTB 1200
    a. This process is calculated by Sweco for each bridge in each parcel.
    b. This concrete is assumed to be B45-SV40 and transported by a lorry>32 tons at an approximate distance of 140 km from Trondheim to the construction site.
    c. Volume is approximately 4.7 m3 (see the volume calculation in 12.12 Prefabricated beams)
    d. The volume of B45-SV40 concrete is 4,7 m3.
    e. The reinforcement steel is assumed to be 0,3 ton in each beam.
    f. The total weight of 1-unit prefabricated beam = (4,7 m3*2.5 t) +0,3=12 t
    g. 12 ton*140 km= 1680 tkm

7.1.3 Energy and fuel Inventory

The external environment (Ytremiljø) report does not specifically mention the exact amount of energy consumed in each parcel. As a result, it is presented as follows:

1- **Diesel consumption of construction machinery**: Allocated for each activity in each parcel, see Table 3.
2- **Diesel consumption of transport**: Transport activities are under process codes 25 and 26 based on NPRA handbooks for process-codes R761 &R762, and therefore diesel consumption related to transport is allocated to activities under process-codes 25 and 26, see Table 4.
3- **Electricity consumption**: Electricity consumption is allocated to activities/processes that require electricity, such as the production of the frost protection layer, reinforcement layer, base and subbase layers, and gravel cover, which are carried out and done by fully electric curch-machines, therefore the amount of electricity is allocated based on material consumption as a percentage of total material consumption that produced in construction site, See Table 5 and 12.14 SimaPro's processes.
4- **Diesel, gasoline, and electricity consumption of small cars**: In this thesis, the amount of diesel, gasoline, and electricity consumption of small cars for each parcel of the E39 Betna-Hestnes road project, are allocated as a percentage of the total length of each parcel. It helps to estimate approximately the energy and fuel consumption of small cars in each parcel and activity See Table 6. There are approx. 38 megajoules of energy in 1-liter diesel and 35 MJ energy in 1-liter bensin (gasoline) [52] [53]. It is important to mention that an incorrect Input was used in Simabro; however, due to the small quantity (178 L) of gasoline consumed and the limited timeframe, a different Input was used instead (see 12.14 SimaPro's processes).

Table 3 Diesel inventory of construction machinery

	Description	Process code	sum quantity	P1	P2	P3	unit	share of total sum	L diesel total	L diesel total/m3	Description	P1	P2	P3	Unit
Machine - diesel (Diesel consumption of construction machinery) total = 950424.5 L	Vegetation clearance and removal of vegetation cover	21.2 and 21.31	175463,00	69814,0	59823,0	45826,0	m3	6,810 %	64720,62	0,37		25751,33	22066,09	16903,21	L diesel
	Grubbing and topsoil removal	21.32	4523,00	1600	0,0	2923,0	m3	0,176 %	1668,34	0,37		590,17	0,00	1078,17	L diesel
	Rock excavation	22.1	1009025,00	379605,0	445554,0	183866,0	m3	39,160 %	372185,17	0,37		140019,67	164345,37	67820,12	L diesel
	Masses used to ground leveling	25.2	46845,00	19675,0	14990,0	12180,0	m3	1,818 %	17279,07	0,37		7257,25	5529,16	4492,67	L diesel
	Skytebane masses to the meadow	25.4	89000,00	0,0	89000,0	0,0	m3	3,454 %	32828,21	0,37		0,00	32828,21	0,00	L diesel
	Skytebane masses to fill along the way	25.4	181000,00	76020,0	57920,0	47060,0	m3	7,025 %	66762,98	0,37		28040,45	21364,15	17358,37	L diesel
	Another masses	25.7	160000,00	67200,0	51200,0	41600,0	m3	6,210 %	59017,00	0,37		24787,14	18885,44	15344,42	L diesel
	Blasted stone from cutting to filling in the line	26.1	531481,00	223222,0	170074,0	138185,0	m3	20,627 %	196040,08	0,37		82336,83	62732,86	50970,40	L diesel
	Mass replacement Betna and bogs along the line	26.1	114285,00	114285,0	0,0	0,0	m3	4,435 %	42154,74	0,37		42154,74	0,00	0,00	L diesel
	Mass replacement Klettelva	26.1	64058,00	0,0	64058,0	0,0	m3	2,486 %	23628,19	0,37		0,00	23628,19	0,00	L diesel
	Blasted rock masses to stored for later processing.	26.3	122000,00	51240,0	39040,0	31720,0	m3	4,735 %	45000,46	0,37		18900,19	14400,15	11700,12	L diesel
	Skytebane blasted rock to meadow	26.4	79000,00	50580,0	15680,0	12740,0	m3	3,066 %	29139,64	0,37		18656,75	5783,67	4699,23	L diesel
	Σ		2576680				m3	100 %	950424,50		Σ	950424,50			

Table 4 Diesel inventory of transport

Note thats all quantites under process code 25 and 26 it goes to transport and mass movement

	Description	Process code	sum quantity	P1	P2	P3	unit	share of total sum	L diesel total	L diesel total/m3	Description	P1	P2	P3	Unit
Transport - diesel (Diesel consumption of transport) total = 254882.5 L	Masses used to ground leveling	25.2	46845,00	19675,0	14990,0	12180,0	m3	3,376 %	8604,34	0,18		3613,84	2753,31	2237,18	L diesel
	Skytebane masses to the meadow	25.4	89000,00	0,0	89000,0	0,0	m3	6,414 %	16347,23	0,18		0,00	16347,23	0,00	L diesel
	Skytebane masses to fill along the way	25.4	181000,00	76020,0	57920,0	47060,0	m3	13,043 %	33245,49	0,18		13963,10	10638,56	8643,83	L diesel
	Another masses	25.7	160000,00	67200,0	51200,0	41600,0	m3	11,530 %	29388,28	0,18		12343,08	9404,25	7640,95	L diesel
	Blasted stone from cutting to filling in the line	26.1	531481,00	223222,0	170074,0	138185,0	m3	38,300 %	97620,69	0,18		41000,69	31238,64	25381,37	L diesel
	Mass replacement Betna and bogs along the line	26.1	114285,00	114285,0	0,0	0,0	m3	8,236 %	20991,49	0,18		20991,49	0,00	0,00	L diesel
	Mass replacement Klettelva	26.1	64058,00	0,0	64058,0	0,0	m3	4,616 %	11765,96	0,18		0,00	11765,96	0,00	L diesel
	Blasted rock masses to stored for later processing.	26.3	122000,00	51240,0	39040,0	31720,0	m3	8,792 %	22408,56	0,18		9411,60	7170,74	5826,23	L diesel
	Skytebane blasted rock to meadow	26.4	79000,00	50580,0	15680,0	12740,0	m3	5,693 %	14510,46	0,18		9290,37	2880,05	2340,04	L diesel
	Σ		1387669				m3	100 %	254882,50		Σ	254882,50			

Table 5 Electricity inventory

	Description	Process code	sum quantity	P1	P2	P3	unit	share of total sum	kWh electricity total	electricity kWh total/m3	Description	P1	P2	P3	Unit
Electricity consumption total = 556421.7 kWh	Frost protection layer Kult 0-180, T=930 cm	52.3	71666,00	23413,0	24773,0	23480,0	m3	46 %	258602,58	361 %		84484,44	89391,92	84726,21	kWh
	Reinforcement layer E39: 16/90 T=30/40cm	53.2	75018,00	35029,0	20469,0	19520,0	m3	49 %	270698,07	361 %		126400,10	73861,19	70436,78	kWh
	base and subbase layers Fk 0/45	54.2	5676,00	3923,0	935,0	818,0	m3	4 %	20481,51	361 %		14155,92	3373,89	2951,71	kWh
	Gravel cover Fk 0/16, T = 10 cm	61.1	1840,00	1072,0	554,0	214,0	m3	1 %	6639,53	361 %		3868,25	1999,08	772,21	kWh
	Σ		154200,00				m3	100 %	556421,70		Σ	556421,70			

Table 6 Energy and fuel inventory of small cars

	Description	sum quantity	P1 42%	P2 32%	P3 26%	unit	Σ
Energy and fuel consumptions of small cars	Desiel consumpiton	48653	20434,26	15568,96	12649,78	L	48653
	Bensin consumption	178	74,76	56,96	46,28	L	178
	Electricity consumption	1065	447,3	340,8	276,9	kWh	1065

7.2 Life Cycle Impact Assessment by using ReCiPe methodology.

In this chapter, the environmental impacts of the constructing E39 Betna-Hestnes road project will be presented for each road parcel by using ReCiPe 2016 midpoint (H) - characterization method.
The analysis will be presented in two different levels for each road parcel:

1- Firstly, presenting the environmental impact from all three main categories/processes together (earthwork, materials consumption, and energy consumption for small cars) in each road parcel.
2- Secondly, presenting the environmental impacts of each main category/process, in other words, the environmental impacts of all sub-categories/sub-processes in each main category for each road parcel.

Figure 29 illustrates the presentation level of data for each road parcel (L1=Level 1, L2=Level 2).

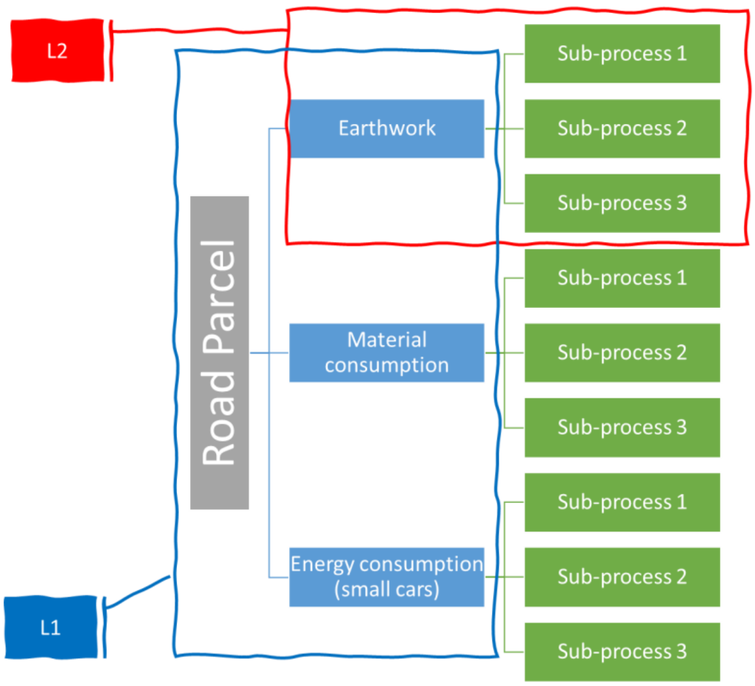


Figure 29 illustrates the presentation level of data for each road parcel

7.2.1 P1 Betna – Klettelva

This section presents the environmental impacts of road construction processes related to P1 Betna-Klettelva and is categorized into three main categories:

1- Earthwork
2- Material consumption
3- Energy and fuel for small cars

(*see Life Cycle Inventory for more detailed processes and activities in each category*).
Figure 30 illustrates the contributions of each category to the categorized environmental impacts.
The green color presents the earthwork activities. (see 7.1.1 Earthwork for more details).
The orange color presents materials consumption. (see 7.1.2 Materials inventory for more details).
The yellow color presents the energy and fuel consumption of small vehicles. (see 7.1.3 Energy and fuel for more details).

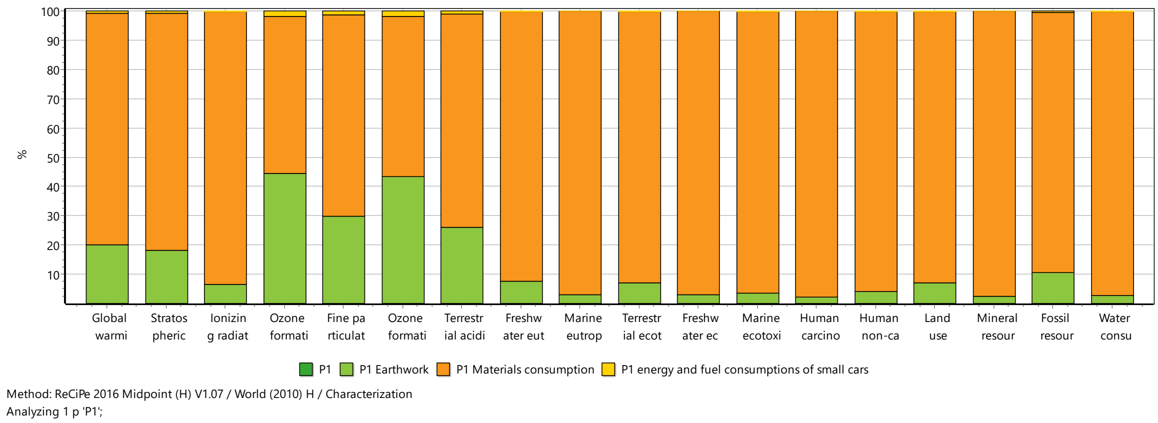


Figure 30 The (P1) environmental impacts of road construction processes in different environmental categories.

According to Table 7 P1-environmental impacts, terrestrial ecotoxicity has the highest environmental impact category with 28,347,341 kg 1,4- dichlorobenzene (see 3.6.1 Terrestrial ecotoxicology). Terrestrial ecotoxicity impacts are generated during the conversion processes of materials that change their shape or form, such as the production of reinforcement steel, concrete (made of cement, water, aggregate, fly ash, etc.), and asphalt.

The next highest impact is GWP, which is 8,579,937 kg CO2eq. (see 3.6.2 Global warming).
The main reasons that contribute to the high amount of CO2eq are material production, fuel consumption (burning during earthwork activities), cement production, asphalt, and (steel) reinforcement production, deforestation, and land-use alteration.

Water consumption ranks eleventh with a total of 49,911 m3, primarily attributed to material production, which accounts for the largest share of consumed water with a volume of 48,461 m3.

Terrestrial acidification ranks fourteenth with a total impact of 36,863 kg SO2 eq, primarily attributed to material production, which accounts for the largest share with 26,913 kg SO2 eq.

Table 7 P1-environmental impacts.

Impact category	Unit	Total	P1	P1 Earthwork	P1 Materials consumption	P1 energy and fuel consumptions of small cars
Global warming	kg CO2 eq	8579937	0	1727018	6782139	70780,184
Stratospheric ozone depletion	kg CFC11 eq	5,571677	0	1,012814	4,517327	0,041535758
Ionizing radiation	kBq Co-60 eq	298807,1	0	19549,76	278450,5	806,83567
Ozone formation, Human health	kg NOx eq	47441,91	0	21039,07	25540,65	862,18717
Fine particulate matter formation	kg PM2.5 eq	16148,28	0	4826,39	11124,1	197,79168
Ozone formation, Terrestrial ecosystems	kg NOx eq	49169,33	0	21379,4	26913,81	876,13398
Terrestrial acidification	kg SO2 eq	36862,96	0	9558,321	26912,93	391,71368
Freshwater eutrophication	kg P eq	3344,789	0	255,554	3078,759	10,476259
Marine eutrophication	kg N eq	151,9482	0	4,673405	147,0829	0,19187949
Terrestrial ecotoxicity	kg 1,4-DCB	28347341	0	2033201	26230794	83346,34
Freshwater ecotoxicity	kg 1,4-DCB	254072,3	0	7865,164	245884,5	322,7206
Marine ecotoxicity	kg 1,4-DCB	362165,9	0	12279,21	349382,9	503,7397
Human carcinogenic toxicity	kg 1,4-DCB	2933004	0	65065,68	2865271	2667,781
Human non-carcinogenic toxicity	kg 1,4-DCB	4107508	0	162921	3937901	6685,2435
Land use	m2a crop eq	339812,3	0	23622,58	315220,9	968,74769
Mineral resource scarcity	kg Cu eq	112532,2	0	2676,815	109745,6	109,76977
Fossil resource scarcity	kg oil eq	5210397	0	547026	4640952	22418,371
Water consumption	m3	49911,44	0	1380,663	48461,59	69,185296

7.2.1.1 Level two of impact assessment – P1 Earthwork

Figure 31 shows the **characterization** of the emissions for each impact category related to earthwork activities in terms of percentages, and it is as follows:

- ‘Rock excavation’ activities are responsible for 28.2 % of the environmental impacts, as indicated by the yellow color in the chart.
- ‘Blasted stone from cutting to filling in the line’ activities are responsible for 24.6 % of the environmental impacts, as indicated by the dark red color in the chart.
- ‘Mass replacement Betna and bigs along the line’ activities are responsible for 12.6 % of the environmental impacts, as indicated by the red color in the chart.
- ‘Skytenane masses to fill along the way’ activities are responsible for 8.39 % of the environmental impacts, as indicated by the dark blue color in the chart.
- ‘Another masses’ activities are responsible for 7.42 % of the environmental impacts, as indicated by the light blue color in the chart.
- ‘Skytebane blasted rock to meadow’ activities are responsible for 5.59 % of the environmental impacts, as indicated by the dark gray color in the chart.
- ‘Blasted rock masses to stored for later processing’ activities are responsible for 5.66 % of the environmental impacts, as indicated by the dark purple color in the chart.
- ‘Vegetation clearance and removal of vegetation cover’ activities are responsible for 5.19 % of the environmental impacts, as indicated by the green color in the chart.
- ‘Masses used to ground leveling’ activities are responsible for 2.17 % of the environmental impacts, as indicated by the light violet color in the chart.

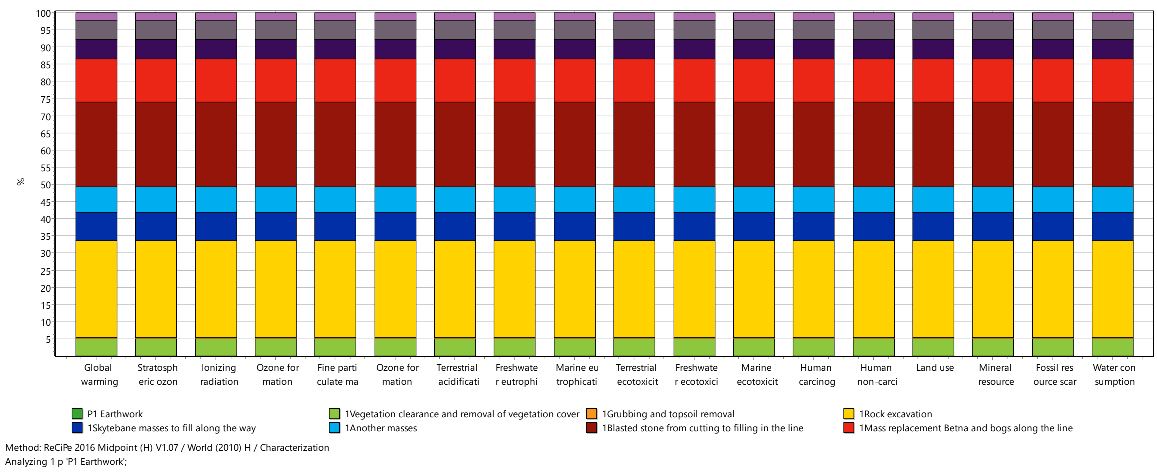


Figure 31 Characterized environmental impacts related to earthwork activities in the P1 road parcel

Table 8 provides numerically the categorized environmental impacts of each earthwork activity in the P1 road parcel.

Table 8 Categorized environmental impacts of earthwork activities in the P1 road parcel

Impact category	Unit	Total	1Vegetation clearance and removal of vegetation cover	1Grubbing and topsoil removal	1Rock excavation	1Skytebane masses to fill along the way	1Another masses	1Blasted stone from cutting to filling in the line	1Mass replacement Betna and bogs along the line	1Blasted rock masses to stored for later processing	1Skytebane blasted rock to meadow	1Masses used to ground leveling
Global warming	kg CO2 eq	1727018	89562,327	2052,5929	486984,09	144967,84	128148,37	425677,61	217938,04	97713,132	96454,532	37519,63
Stratospheric ozone depletion	kg CFC11 eq	1,012814	0,05252406	0,001203749	0,28559308	0,085016769	0,075152945	0,24963974	0,12781033	0,05730412	0,056566011	0,022003485
Ionizing radiation	kBq Co-60 eq	19549,76	1013,8413	23,235255	5512,6369	1641,0291	1450,6335	4818,6505	2467,0484	1106,108	1091,8607	424,72045
Ozone formation, Human health	kg NOx eq	21039,07	1091,0759	25,00532	5932,5904	1766,043	1561,143	5185,7359	2654,9884	1190,3715	1175,0389	457,07571
Fine particulate matter formation	kg PM2.5 eq	4826,39	250,29423	5,7362531	1360,944	405,13257	358,12824	1189,6146	609,05782	273,07278	269,55545	104,85377
Ozone formation, Terrestrial ecosystems	kg NOx eq	21379,4	1108,7251	25,409806	6028,5559	1794,6105	1586,396	5269,6203	2697,9355	1209,6269	1194,0463	464,46936
Terrestrial acidification	kg SO2 eq	9558,321	495,68988	11,36024	2695,2525	802,33615	709,24743	2355,9469	1206,1956	540,80116	533,83534	207,6554
Freshwater eutrophication	kg P eq	255,554	13,252908	0,30373066	72,061049	21,451491	18,962644	62,989276	32,249193	14,459016	14,272776	5,5519349
Marine eutrophication	kg N eq	4,673405	0,24236053	0,005554428	1,3178054	0,39229087	0,34677646	1,1519068	0,58975219	0,26441705	0,26101121	0,10153016
Terrestrial ecotoxicity	kg 1,4-DCB	2033201	105440,8	2416,4965	573321,35	170669,15	150867,75	501145,86	256576,21	115036,66	113554,93	44171,474
Freshwater ecotoxicity	kg 1,4-DCB	7865,164	407,88358	9,3478919	2217,8166	660,21065	583,61163	1938,6154	992,53058	445,00387	439,27197	170,87141
Marine ecotoxicity	kg 1,4-DCB	12279,21	636,79394	14,594069	3462,4884	1030,7307	911,1432	3026,5954	1549,5536	694,74669	685,79796	266,767
Human carcinogenic toxicity	kg 1,4-DCB	65065,68	3374,2745	77,331755	18347,201	5461,6858	4828,0096	16037,47	8210,8493	3681,3573	3633,9394	1413,5579
Human non-carcinogenic toxicity	kg 1,4-DCB	162921	8449,0015	193,63455	45940,402	13675,767	12089,076	40156,96	20559,524	9217,9204	9099,1884	3539,4727
Land use	m2a crop eq	23622,58	1225,0557	28,075875	6661,0892	1982,9061	1752,8452	5822,524	2981,0106	1336,5445	1319,329	513,20282
Mineral resource scarcity	kg Cu eq	2676,815	138,81833	3,1814438	754,80749	224,69485	198,62528	659,7847	337,79598	151,45177	149,50099	58,154053
Fossil resource scarcity	kg oil eq	547026	28368,504	650,1505	154250,24	45917,977	40590,477	134831,66	69030,992	30950,239	30551,582	11884,191
Water consumption	m3	1380,663	71,600503	1,6409431	389,31889	115,89438	102,44807	340,30749	174,23033	78,116655	77,110468	29,995027

7.2.1.2 Level two of impact assessment – P1 Materials Consumption

Figure 32 shows the characterization of the emissions related to material consumption activities in terms of percentages for each impact category.

Figure 32 and Table 9 provide the following:

- The materials with the highest GWP impact can be identified by looking at the top three materials in Table 9, which are as follows:
    - Binder course Agb 11 with approximately 24 % of total GWP.
    - Prefabricated beams with approximately 21 % of total GWP.
    - Concrete B45, SV-40 with approximately 19 % of total GWP.
- The top three materials with the highest water use are:
    - Reinforcement B500NC with approx. 15% of total water use.
    - Prefabricated beams with approx. 15% of total water use.
    - Concrete B45, SV-40 with approx. 12 % of total water use.
- The top three materials with the highest terrestrial acidification are:
    - Binder course Agb 11 with approximately 42 % of total terrestrial acidification
    - Prefabricated beams with approximately 13 % of total terrestrial acidification.
    - Bearing layer Ag16 with approximately 12 % of total terrestrial acidification.
- The top three materials with the highest terrestrial ecotoxicity are:
    - Prefabricated beams with approx. 20% of total terrestrial ecotoxicity.
    - Reinforcement B500NC with approx. 19% of total terrestrial ecotoxicity.
    - Binder course Agb 11 with approximately 17 % of total terrestrial ecotoxicity.

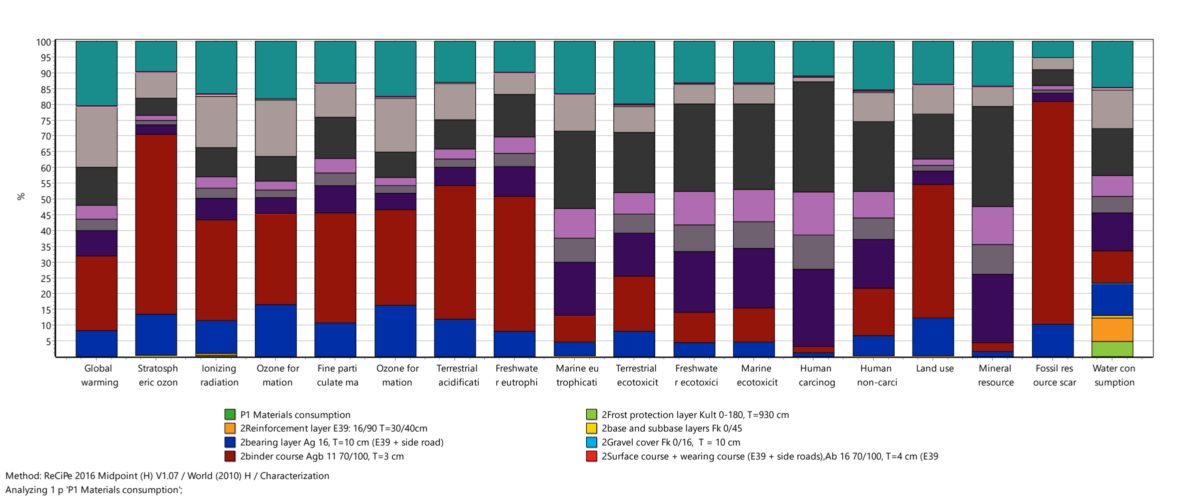


Figure 32 Characterized environmental impacts related to material consumption activities in the P1 road parcel

Table 9 Categorized environmental impacts of materials consumption activities in the P1 road parcel.

Impact category	Unit	Total	2Frost protection layer Kult 0-180, T=930 cm	2Reinforcement layer E39: 16/90 T=30/40cm	2base and subbase layers Fk 0/45	2bearing layer Ag 16, T=10 cm (E39 + side road)	2Gravel cover Fk 0/16, T = 10 cm
Global warming	kg CO2 eq	6782139	1479,0183	2212,8105	247,8191	557055,67	67,719113
Stratospheric ozone depletion	kg CFC11 eq	4,517327	0,005881334	0,008799268	0,000985456	0,58884494	0,000269286
Ionizing radiation	kBq Co-60 eq	278450,5	1076,2902	1610,275	180,3394	28733,286	49,279591
Ozone formation, Human health	kg NOx eq	25540,65	3,1167519	4,6630804	0,52223199	4216,3534	0,14270525
Fine particulate matter formation	kg PM2.5 eq	11124,1	1,625009	2,4312323	0,2722808	1188,3064	0,074403523
Ozone formation, Terrestrial ecosystems	kg NOx eq	26913,81	3,1819409	4,7606119	0,53315483	4347,3394	0,14569003
Terrestrial acidification	kg SO2 eq	26912,93	3,476335	5,2010652	0,58248248	3164,8844	0,15916931
Freshwater eutrophication	kg P eq	3078,759	0,71437837	1,0688062	0,11969873	246,07765	0,032708906
Marine eutrophication	kg N eq	147,0829	0,069092235	0,10337129	0,011576852	6,7430611	0,003163494
Terrestrial ecotoxicity	kg 1,4-DCB	26230794	5059,0873	7569,0756	847,68288	2095607,3	231,63805
Freshwater ecotoxicity	kg 1,4-DCB	245884,5	77,484611	115,92741	12,983049	10558,401	3,5477514
Marine ecotoxicity	kg 1,4-DCB	349382,9	102,7286	153,69582	17,212843	15571,081	4,703586
Human carcinogenic toxicity	kg 1,4-DCB	2865271	268,61902	401,89022	45,008859	35311,446	12,299132
Human non-carcinogenic toxicity	kg 1,4-DCB	3937901	1667,1995	2494,355	279,3501	259054,31	76,33528
Land use	m2a crop eq	315220,9	133,3731	199,54411	22,347528	38299,943	6,1066912
Mineral resource scarcity	kg Cu eq	109745,6	14,211786	21,262744	2,3812768	1821,0524	0,65070833
Fossil resource scarcity	kg oil eq	4640952	285,99635	427,88905	47,920544	470037	13,09478
Water consumption	m3	48461,59	2382,0832	3563,9172	399,1335	4810,9375	109,06732

Impact category	2binder course Agb 11 70/100, T=3 cm	2Surface course + wearing course (E39 + side roads),Ab 16 70/100, T=4 cm (E39	2Steel railings road	2Steel railings Bridge	2Bridge piles of steel	2reinforcement B500NC	2Concrete B45, SV-40	2Waterproof membrane	2Bridge bearing varies sizes	2Prefabricated beams type NTB 1200
Global warming	1601586,8	805,08718	548233,68	243253	295180,05	816825	1296445	14373,57	13247,33	1391126
Stratospheric ozone depletion	2,5760483	0,00129493	0,14040688	0,062298971	0,070544142	0,242971	0,368386	0,008706	0,005169	0,436721
Ionizing radiation	89118,22	44,798033	19202,769	8520,3284	10520,249	25338,44	45614,12	1488,783	442,6344	46510,66
Ozone formation, Human health	7338,1074	3,6887269	1330,7293	590,44876	706,23194	2029,432	4560,863	67,22174	43,82047	4645,311
Fine particulate matter formation	3870,5319	1,9456427	971,23017	430,93786	528,7509	1441,706	1161,104	28,68256	22,31189	1474,192
Ozone formation, Terrestrial ecosystems	8182,7602	4,1133178	1405,0811	623,43886	746,51625	2142,868	4610,399	69,0617	45,64686	4727,959
Terrestrial acidification	11430,85	5,7460706	1563,2818	693,633	844,65	2509,806	3092,446	64,35308	40,98691	3492,868
Freshwater eutrophication	1313,8579	0,66045134	292,85577	129,94102	161,18934	411,0115	205,3904	6,606106	5,589348	303,6439
Marine eutrophication	12,116762	0,006090866	25,042907	11,111616	13,898573	36,16881	16,55645	0,345557	0,412354	24,49353
Terrestrial ecotoxicity	4571928,4	2298,2214	3588928,5	1592418,8	1752306	5054469	2145134	116390,2	81755,44	5215851
Freshwater ecotoxicity	23859,62	11,993777	47278,503	20977,619	26202,802	67752,73	14746,31	523,3884	1072,127	32691,02
Marine ecotoxicity	38318,847	19,262155	65793,783	29192,907	36343,085	94662,6	20453,48	752,5411	1475,413	46521,57
Human carcinogenic toxicity	57989,511	29,150223	700198,25	310680,15	390091,56	1002310	38212,56	1454,24	10191,45	318074,8
Human non-carcinogenic toxicity	589224,01	296,1917	606838,42	269256,1	331704,42	872835,6	366918,6	13727,43	18456,07	605072,9
Land use	133723,9	67,22046	13100,476	5812,7222	6431,6496	44707,01	28326,4	834,2826	379,4469	43176,51
Mineral resource scarcity	3002,2113	1,5091545	23699,136	10515,38	13198,752	34808,69	6704,037	63,4412	354,3357	15538,57
Fossil resource scarcity	3283008,3	1650,3058	118312,43	52495,593	62287,607	230946,8	173060,6	6358,459	3458,236	238562,2
Water consumption	5003,5968	2,5152129	5796,8665	2572,0878	3212,399	7144,744	5931,665	333,5831	96,60528	7102,388

7.2.1.3 Level two of impact assessment – P1 Energy and fuel consumption of small cars

Figure 33 shows the characterization of the emissions related to energy and fuel for small cars in terms of percentages for each impact category.

Figure 33 and Table 10 provide that the amount of diesel fuel consumed plays a dominant role over all environmental impacts, so diesel consumption is the primary contributor to environmental impacts, accounting for 99 % of all impacts except for water use. In the case of water use, diesel consumption is responsible for approximately 81% of the total water use impact, with electricity accounting for the remaining 19%.

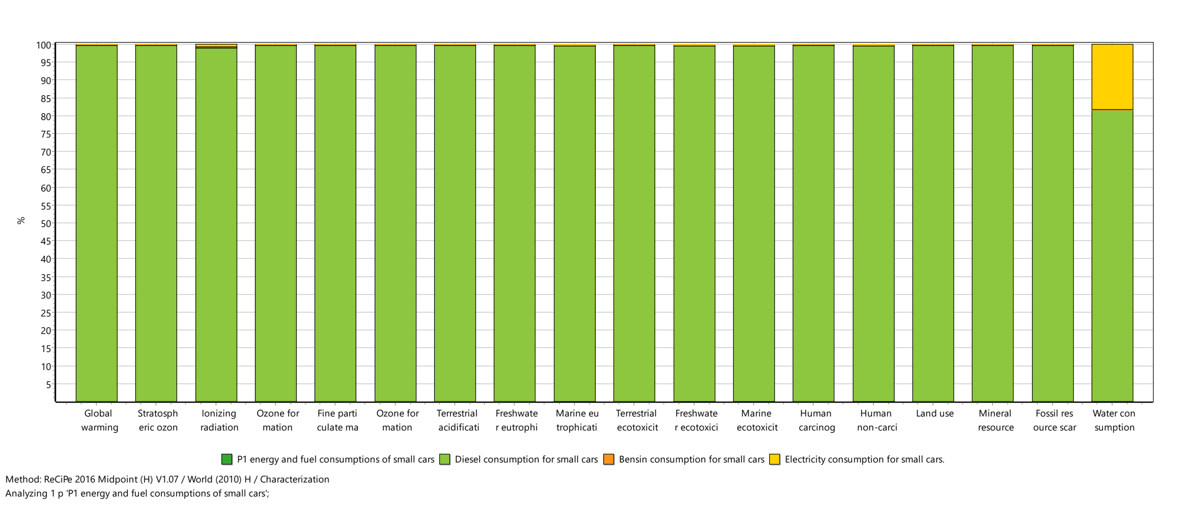


Figure 33 Characterized environmental impacts related to energy and fuel for small cars in the P1 road parcel

Table 10 Categorized environmental impacts of energy and fuel for small cars in the P1 road parcel

Impact category	Unit	Total	Diesel consumption for small cars	Bensin consumption for small cars	Electricity consumption for small cars.
Global warming	kg CO2 eq	70780,18	70533,611	238,74532	7,8272314
Stratospheric ozone depletion	kg CFC11 eq	0,041536	0,04136462	0,000140013	3,11E-05
Ionizing radiation	kBq Co-60 eq	806,8357	798,43715	2,7025857	5,6959216
Ozone formation, Human health	kg NOx eq	862,1872	859,26221	2,9084691	0,016494413
Fine particulate matter formation	kg PM2.5 eq	197,7917	197,11587	0,66720661	0,008599841
Ozone formation, Terrestrial ecosystems	kg NOx eq	876,134	873,16162	2,9555164	0,016839405
Terrestrial acidification	kg SO2 eq	391,7137	390,37393	1,3213551	0,018397392
Freshwater eutrophication	kg P eq	10,47626	10,43715	0,035328132	0,003780619
Marine eutrophication	kg N eq	0,191879	0,19086779	0,000646058	0,000365649
Terrestrial ecotoxicity	kg 1,4-DCB	83346,34	83038,493	281,0724	26,773602
Freshwater ecotoxicity	kg 1,4-DCB	322,7206	321,22325	1,0872908	0,41006253
Marine ecotoxicity	kg 1,4-DCB	503,7397	501,49854	1,6974946	0,54365827
Human carcinogenic toxicity	kg 1,4-DCB	2667,781	2657,3647	8,9947666	1,4215803
Human non-carcinogenic toxicity	kg 1,4-DCB	6685,244	6653,8979	22,522411	8,8231206
Land use	m2a crop eq	968,7477	964,77623	3,2656177	0,70583448
Mineral resource scarcity	kg Cu eq	109,7698	109,32451	0,37004649	0,075211332
Fossil resource scarcity	kg oil eq	22418,37	22341,236	75,621612	1,5135443
Water consumption	m3	69,1853	56,388017	0,19086468	12,606414

7.2.2 P2 Klettelva-Otneselva

This section presents the environmental impacts of road construction processes related to P2 Klettelva-Otneselva and is categorized into three main categories:

1- Earthwork
2- Material consumption
3- Energy and fuel for small cars

(see Life Cycle Inventory for more detailed processes and activities in each category).
Figure 34 illustrates the contributions of each road process to the different environmental categories.
The green color presents the earthwork activities, see 7.1.1 Earthwork for more details.
The orange color presents materials consumption, see 7.1.2 Materials inventory for more details.
The yellow color presents the energy and fuel consumption of small vehicles, see 7.1.3 Energy and fuel for more details.

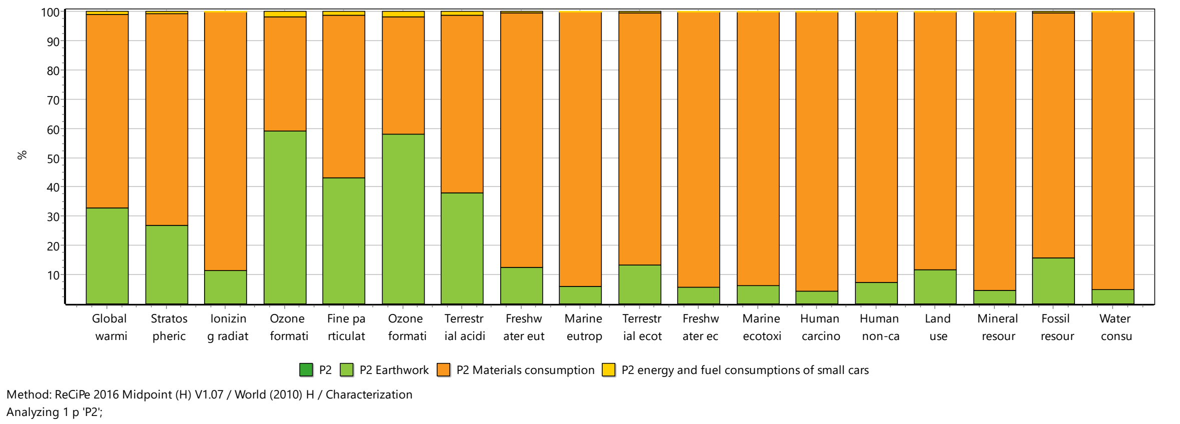


Figure 34 The (P2) environmental impacts of road construction processes in different environmental categories.

According to Table 11 P2-environmental impacts, terrestrial ecotoxicity has the highest environmental impact category with 14182500 kg 1,4- dichlorobenzene (see 3.6.1 Terrestrial ecotoxicology). Terrestrial ecotoxicity impacts are generated during the conversion processes of materials that change their shape or form, such as the production of reinforcement steel, concrete (made of cement, water, aggregate, fly ash, etc.), and asphalt.

The next highest impact is GWP, which is 4878151 kg CO2eq. (see 3.6.2 Global warming).
The main reasons that contribute to the high amount of CO2eq are material production, fuel consumption (burning during earthwork activities), cement production, asphalt, and (steel) reinforcement production, deforestation, and land-use alteration.

Water consumption ranks thirteenth with a total of 26342,7 m3, primarily attributed to material production, which accounts for the largest share of consumed water with a volume of 25006 m3.

Terrestrial acidification ranks fourteenth with a total impact of 23426 kg SO2 eq, primarily attributed to material production, which accounts for the largest share with 14240 kg SO2 eq.

Table 11 P2-environmental impacts

Impact category	Unit	Total	P2	P2 Earthwork	P2 Materials consumption	P2 energy and fuel consumptions of small cars
Global warming	kg CO2 eq	4878151	0	1605560	3218423	54168,84
Stratospheric ozone depletion	kg CFC11 eq	3,496717	0	0,941585	2,523345	0,031787674
Ionizing radiation	kBq Co-60 eq	158891,6	0	18174,86	140099,3	617,46095
Ozone formation, Human health	kg NOx eq	33092,18	0	19559,42	12872,91	659,84143
Fine particulate matter formation	kg PM2.5 eq	10404,98	0	4486,957	5766,649	151,37216
Ozone formation, Terrestrial ecosystems	kg NOx eq	34202,07	0	19875,82	13655,74	670,51508
Terrestrial acidification	kg SO2 eq	23426,88	0	8886,099	14240,99	299,7828
Freshwater eutrophication	kg P eq	1889,778	0	237,5813	1644,179	8,0175852
Marine eutrophication	kg N eq	73,48073	0	4,344732	68,98915	0,14684628
Terrestrial ecotoxicity	kg 1,4-DCB	14182500	0	1890209	12228506	63785,795
Freshwater ecotoxicity	kg 1,4-DCB	126187,1	0	7312,019	118628,1	246,98029
Marine ecotoxicity	kg 1,4-DCB	180826,5	0	11415,63	169025,3	385,51577
Human carcinogenic toxicity	kg 1,4-DCB	1434087	0	60489,71	1371556	2041,6778
Human non-carcinogenic toxicity	kg 1,4-DCB	2058091	0	151463	1901512	5116,2616
Land use	m2a crop eq	189997,9	0	21961,24	167295,2	741,39103
Mineral resource scarcity	kg Cu eq	54000,4	0	2488,559	51427,84	84,007777
Fossil resource scarcity	kg oil eq	3235731	0	508554,5	2710019	17157,025
Water consumption	m3	26342,7	0	1283,563	25006,23	52,905338

7.2.2.1 Level two of impact assessment – P2 Earthwork

Figure 26 shows the characterization of the emissions for each impact category related to earthwork activities in terms of percentages, and it is as follows:

- ‘Rock excavation’ activities are responsible for 35.6 % of the environmental impacts, as indicated by the orange color in the chart.
- ‘Blasted stone from cutting to filling in the line’ activities are responsible for 20.2 % of the environmental impacts, as indicated by the dark red color in the chart.
- ‘Mass replacement Betna and bigs along the line’ activities are responsible for 7.6 % of the environmental impacts, as indicated by the red color in the chart.
- ‘Skytenane masses to fill along the way’ activities are responsible for 6.88 % of the environmental impacts, as indicated by the dark blue color in the chart.
- ‘Another masses’ activities are responsible for 6 % of the environmental impacts, as indicated by the light blue color in the chart.
- ‘Skytebane blasted rock to meadow’ activities are responsible for 1.86 % of the environmental impacts, as indicated by the light gray color in the chart.
- ‘Blasted rock masses to stored for later processing’ activities are responsible for 4.64 % of the environmental impacts, as indicated by the dark purple color in the chart.
- ‘Vegetation clearance and removal of vegetation cover’ activities are responsible for 4.78 % of the environmental impacts, as indicated by the green color in the chart.

- 'Skytebane masses to the meadow activities are responsible for 10.6 % of the environmental impacts, as indicated by the yellow color in the chart.
- 'Masses used to ground leveling' activities are responsible for 1.78 % of the environmental impacts, as indicated by the light violet color in the chart.

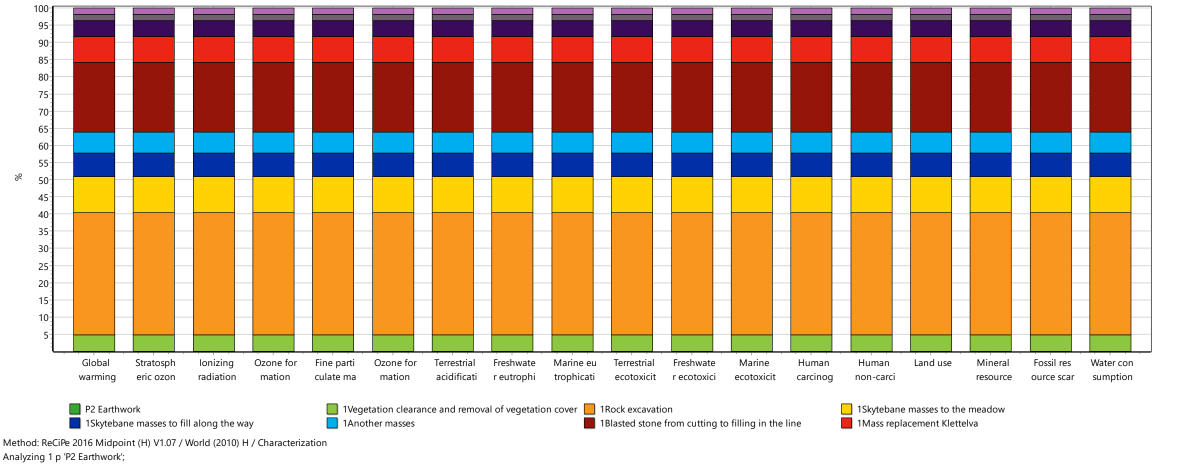


Figure 35 Characterized environmental impacts related to earthwork activities in the P2 road parcel

Table 12 provides numerically the categorized environmental impacts of each earthwork activity in the P2 road parcel.

Table 12 Categorized environmental impacts of earthwork activities in the P2 road parcel

Impact category	Unit	Total	1Vegetation clearance and removal of vegetation cover	1Rock excavation	1Skytebane masses to the meadow	1Skytebane masses to fill along the way	1Another masses	1Blasted stone from cutting to filling in the line	1Mass replacement Klettelva	1Blasted rock masses to stored for later processing	1Skytebane blasted rock to meadow	1Masses used to ground leveling
Global warming	kg CO2 eq	1605560	76745,17	571588,1	169720,3	110451,7	97636,853	324325,98	122156,67	74448,1	29901,286	28585,477
Stratospheric ozone depletion	kg CFC11 eq	0,941585	0,045007	0,335209	0,099533	0,064775	0,057259386	0,19020181	0,071639097	0,043660282	0,017535687	0,016764027
Ionizing radiation	kBq Co-60 eq	18174,86	868,7517	6470,351	1921,226	1250,308	1105,2446	3671,3548	1382,8077	842,74898	338,48115	323,58625
Ozone formation, Human health	kg NOx eq	19559,42	934,9333	6963,263	2067,585	1345,557	1189,4423	3951,0391	1488,1502	906,94972	364,26669	348,2371
Fine particulate matter formation	kg PM2.5 eq	4486,957	214,4749	1597,382	474,3067	308,6724	272,85961	906,37354	341,38361	208,05545	83,563255	79,886045
Ozone formation, Terrestrial ecosystems	kg NOx eq	19875,82	950,0568	7075,9	2101,03	1367,322	1208,6827	4014,9511	1512,2225	921,62053	370,15906	353,87018
Terrestrial acidification	kg SO2 eq	8886,099	424,7523	3163,5	939,3307	611,3037	540,37899	1795,0081	676,08589	412,03898	165,49107	158,20862
Freshwater eutrophication	kg P eq	237,5813	11,3563	84,58026	25,11422	16,34399	14,447729	47,991856	18,076028	11,016393	4,424617	4,2299113
Marine eutrophication	kg N eq	4,344732	0,207677	1,546749	0,459272	0,298888	0,26421063	0,87764373	0,33056259	0,20146061	0,080914506	0,077353855
Terrestrial ecotoxicity	kg 1,4-DCB	1890209	90351,29	672924,8	199810	130033,6	114946,86	381825,63	143813,79	87646,981	35202,476	33653,388
Freshwater ecotoxicity	kg 1,4-DCB	7312,019	349,5118	2603,119	772,938	503,0176	444,65648	1477,0411	556,32431	339,05057	136,17605	130,18361
Marine ecotoxicity	kg 1,4-DCB	11415,63	545,6631	4064,029	1206,722	785,3187	694,20435	2305,9787	868,54184	529,33081	212,60008	203,24459
Human carcinogenic toxicity	kg 1,4-DCB	60489,71	2891,386	21534,67	6394,239	4161,284	3678,4835	12219,031	4602,2714	2804,8437	1126,5356	1076,9623
Human non-carcinogenic toxicity	kg 1,4-DCB	151463	7239,875	53921,66	16010,83	10419,63	9210,7245	30595,796	11523,84	7023,1774	2820,7844	2696,6555
Land use	m2a crop eq	21961,24	1049,739	7818,324	2321,477	1510,786	1335,5011	4436,2112	1670,8892	1018,3196	408,99721	390,99925
Mineral resource scarcity	kg Cu eq	2488,559	118,9522	885,9406	263,0603	171,1961	151,33354	502,69338	189,33836	115,39183	46,345898	44,306442
Fossil resource scarcity	kg oil eq	508554,5	24308,72	181048,2	53758,22	34985,13	30926,078	102728,94	38692,631	23581,134	9471,1114	9054,3341
Water consumption	m3	1283,563	61,35384	456,9555	135,6827	88,30048	78,055674	259,28204	97,658015	59,517451	23,90455	22,852628

7.2.2.2 Level two of impact assessment – P2 Material consumption

Figure 36 shows the characterization of the emissions related to material consumption activities in terms of percentages for each impact category.

Figure 36 and Table 13 provide the following:

- The materials with the highest GWP impact can be identified by looking at the top three materials in Table 9, which are as follows:

  - Binder course Agb 11 with approximately 30 % of total GWP.
  - Prefabricated beams with approximately 25 % of total GWP.
  - Concrete B45, SV-40 with approximately 16 % of total GWP.
- The top three materials with the highest water use are:
  - Steel railings road with approx. 18.3 % of total water use.
  - Reinforcement B500NC with approx. 18 % of total water use.
  - Concrete B45, SV-40 with approx. 15 % of total water use.
- The top three materials with the highest terrestrial acidification are:
  - Binder course Agb 11 with approximately 49 % of total terrestrial acidification.
  - Bearing layer Ag16 with approximately 16 % of total terrestrial acidification.
  - Concrete B45, SV-40 with approx. 14 % of total terrestrial acidification.
- The top three materials with the highest terrestrial ecotoxicity are:
  - Reinforcement B500NC with approx. 25% of total terrestrial ecotoxicity.
  - Binder course Agb 11 with approximately 23 % of total terrestrial ecotoxicity.
  - Steel railings road with approx. 22 % of total terrestrial ecotoxicity.

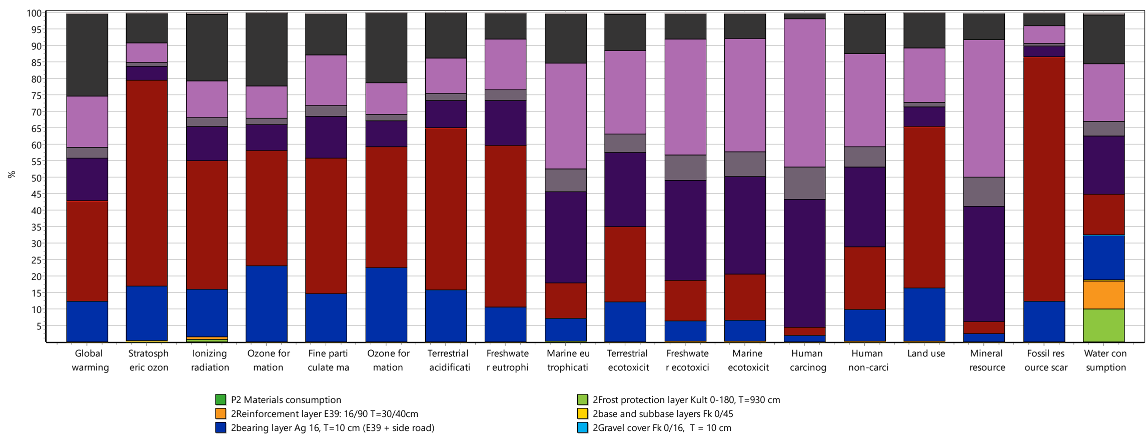


Figure 36 Characterized environmental impacts related to material consumption activities in the P2 road parcel.

Table 13 Categorized environmental impacts of materials consumption activities in the P2 road parcel.

Impact category	Unit	Total	2Frost protection layer Kult 0-180, T=930 cm	2Reinforcement layer E39: 16/90 T=30/40cm	2base and subbase layers Fk 0/45	2bearing layer Ag 16, T=10 cm (E39 + side road)	2Gravel cover Fk 0/16, T = 10 cm	2binder course Agb 11 70/100, T=3 cm	2Surface course + wearing course (E39 + side roads),Ab 16 70/100, T=4 cm (E39	2Steel railings road	2Steel railings Bridge	2reinforcement B500NC	2Concrete B45, SV-40	2Waterproof membrane	2Bridge bearing varies sizes
Global warming	kg CO2 eq	3218423	1564,931	1293,043	59,06471	393083,6	34,996631	980703,52	595,21736	417701,85	105190,48	501784,28	806185,4	6914,322	3311,832
Stratospheric ozone depletion	kg CFC11 eq	2,523345	0,006223	0,005142	0,000235	0,415516	0,000139165	1,5773979	0,000957368	0,10697667	0,026940095	0,14925987	0,229078	0,004188	0,001292
Ionizing radiation	kBq Co-60 eq	140099,3	1138,809	940,9552	42,98173	20275,5	25,467251	54569,977	33,120099	14630,681	3684,4663	15565,671	28364,82	716,1703	110,6586
Ozone formation, Human health	kg NOx eq	12872,91	3,297796	2,724845	0,124468	2975,249	0,073748795	4493,3612	2,727151	1013,889	255,32919	1246,7014	2836,141	32,33662	10,95512
Fine particulate matter formation	kg PM2.5 eq	5766,649	1,719402	1,420677	0,064895	838,5227	0,038451074	2370,0522	1,4384533	739,98489	186,35151	885,65555	722,0245	13,79758	5,577972
Ozone formation, Terrestrial ecosystems	kg NOx eq	13655,74	3,366772	2,781837	0,127071	3067,679	0,075291301	5010,5695	3,0410597	1070,538	269,59518	1316,3863	2866,944	33,22172	11,41172
Terrestrial acidification	kg SO2 eq	14240,99	3,678266	3,039213	0,138828	2233,285	0,082257276	6999,4801	4,2481871	1191,0718	299,9494	1541,8007	1923,016	30,95667	10,24673
Freshwater eutrophication	kg P eq	1644,179	0,755875	0,624551	0,028529	173,6435	0,01690367	804,51779	0,48828514	223,1282	56,19071	252,48871	127,7206	3,177828	1,397337
Marine eutrophication	kg N eq	68,98915	0,073106	0,060404	0,002759	4,758208	0,001634865	7,4194867	0,004503101	19,08031	4,8050232	22,218883	10,29551	0,166228	0,103088
Terrestrial ecotoxicity	kg 1,4-DCB	12228506	5352,956	4422,947	202,0351	1478755	119,70847	2799540	1699,1219	2734421,7	688613,52	3105014,1	1333937	55988,81	20438,86
Freshwater ecotoxicity	kg 1,4-DCB	118628,1	81,98549	67,74153	3,094354	7450,485	1,8334461	14610,019	8,8672435	36021,716	9071,4029	41621,221	9169,889	251,7729	268,0316
Marine ecotoxicity	kg 1,4-DCB	169025,3	108,6958	89,81129	4,102475	10987,66	2,4307711	23463,873	14,240904	50128,596	12623,96	58152,24	12718,85	362,0055	368,8532
Human carcinogenic toxicity	kg 1,4-DCB	1371556	284,2224	234,8423	10,72732	24917,35	6,3560815	35508,859	21,551354	533484,37	134348,17	615729,68	23762,21	699,5535	2547,861
Human non-carcinogenic toxicity	kg 1,4-DCB	1901512	1764,043	1457,562	66,57975	182800,4	39,449389	360800,98	218,98056	462353,08	116435,07	536192,22	228165,8	6603,498	4614,018
Land use	m2a crop eq	167295,2	141,1204	116,6025	5,326265	27026,17	3,1558833	81883,483	49,697457	9981,3152	2513,6096	27463,994	17614,57	401,3268	94,86173
Mineral resource scarcity	kg Cu eq	51427,83	15,03731	12,42477	0,567549	1285,017	0,33628024	1838,3514	1,1157487	18056,484	4547,1915	21383,349	4168,859	30,51802	88,58393
Fossil resource scarcity	kg oil eq	2710019	302,6091	250,0346	11,42129	331679,3	6,7672652	2010292,5	1220,1047	90142,801	22700,797	141873,06	107616,5	3058,699	864,5589
Water consumption	m3	25006,23	2520,452	2082,555	95,12868	3394,815	56,365016	3063,8646	1,8595481	4416,6602	1112,2542	4389,0925	3688,564	160,4682	24,15132

7.2.2.3 Level two of impact assessment – P2 Energy and fuel consumption of small cars

Figure 37 shows the characterization of the emissions related to energy and fuel for small cars in terms of percentages for each impact category.

Figure 37 and Table 14 provide that the amount of diesel fuel consumed plays a dominant role over all environmental impacts, so diesel consumption is the primary contributor to environmental impacts, accounting for 99 % of all impacts except for water use. In the case of water use, diesel consumption is responsible for approximately 81% of the total water use impact, with electricity accounting for the remaining 19%, similar to energy and fuel consumption of small cars in P1 and P3.

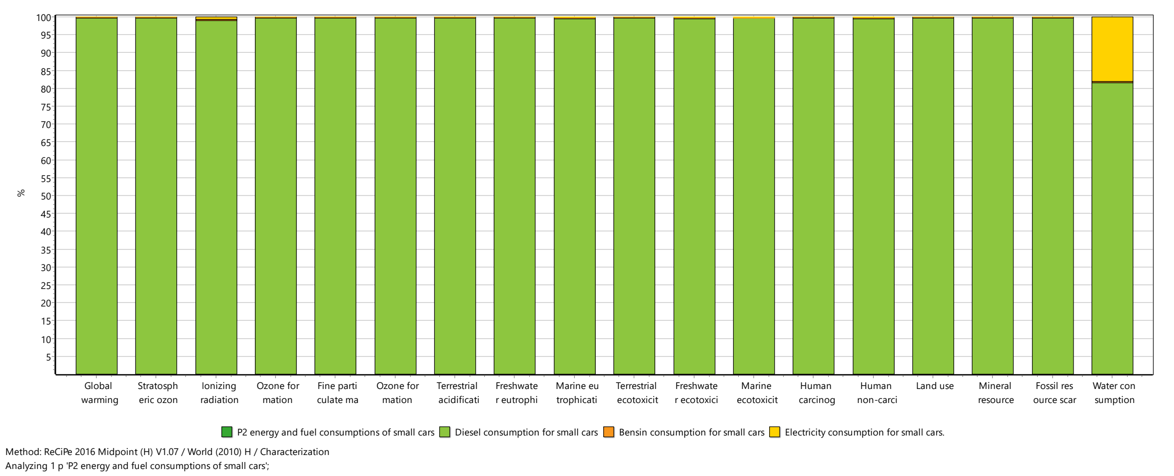


Figure 37 Characterized environmental impacts related to energy and fuel for small cars in the P2 road parcel

Table 14 Categorized environmental impacts of energy and fuel for small cars in the P2 road parcel.

Impact category	Unit	Total	Diesel consumption for small cars	Bensin consumption for small cars	Electricity consumption for small cars.
Global warming	kg CO2 eq	54168,84	53980,98	181,9012	5,963605
Stratospheric ozone depletion	kg CFC11 eq	0,031788	0,031657	0,000107	2,37E-05
Ionizing radiation	kBq Co-60 eq	617,461	611,0621	2,059113	4,33975
Ozone formation, Human health	kg NOx eq	659,8414	657,6129	2,215976	0,012567
Fine particulate matter formation	kg PM2.5 eq	151,3722	150,8573	0,508348	0,006552
Ozone formation, Terrestrial ecosystems	kg NOx eq	670,5151	668,2504	2,251822	0,01283
Terrestrial acidification	kg SO2 eq	299,7828	298,762	1,006747	0,014017
Freshwater eutrophication	kg P eq	8,017585	7,987788	0,026917	0,00288
Marine eutrophication	kg N eq	0,146846	0,146075	0,000492	0,000279
Terrestrial ecotoxicity	kg 1,4-DCB	63785,8	63551,25	214,1504	20,39894
Freshwater ecotoxicity	kg 1,4-DCB	246,9803	245,8395	0,828412	0,312429
Marine ecotoxicity	kg 1,4-DCB	385,5158	383,8082	1,293329	0,414216
Human carcinogenic toxicity	kg 1,4-DCB	2041,678	2033,742	6,853156	1,083109
Human non-carcinogenic toxicity	kg 1,4-DCB	5116,262	5092,379	17,15993	6,722378
Land use	m2a crop eq	741,391	738,3652	2,48809	0,537779
Mineral resource scarcity	kg Cu eq	84,00778	83,66853	0,28194	0,057304
Fossil resource scarcity	kg oil eq	17157,03	17098,26	57,61647	1,153177
Water consumption	m3	52,90534	43,15503	0,145421	9,604887

7.2.3 P3 Otneselva-Hestnes

This section presents the environmental impacts of road construction processes related to P3 Otneselva-Hestnes and is categorized into three main categories:

4- Earthwork
5- Material consumption
6- Energy and fuel for small cars

(see Life Cycle Inventory for more detailed processes and activities in each category).
Figure 38 illustrates the contributions of each road process to the different environmental categories.
The green color presents the earthwork activities, see 7.1.1 Earthwork for more details.
The orange color presents materials consumption, see 7.1.2 Materials inventory for more details.

The yellow color presents the energy and fuel consumption of small vehicles, see 7.1.3 Energy and fuel for more details.

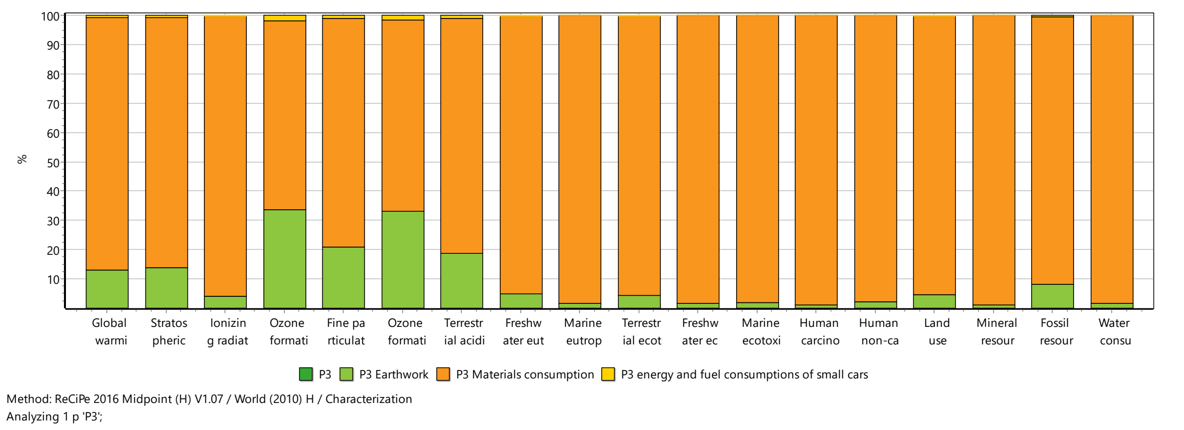


Figure 38 The (P3) environmental impacts of road construction processes in different environmental categories.

According to Table 15 P3-environmental impacts, terrestrial ecotoxicity has the highest environmental impact category with 23124549 kg 1,4- dichlorobenzene (see 3.6.1 Terrestrial ecotoxicology). Terrestrial ecotoxicity impacts are generated during the conversion processes of materials that change their shape or form, such as the production of reinforcement steel, concrete (made of cement, water, aggregate, fly ash, etc.), and asphalt.

The next highest impact is GWP, which is 6415791 kg CO2eq. (see 3.6.2 Global warming).
The main reasons that contribute to the high amount of CO2eq are material production, fuel consumption (burning during earthwork activities), cement production, asphalt, and (steel) reinforcement production, deforestation, and land-use alteration.

Water consumption ranks eleventh with a total of 42191.5 m3, primarily attributed to material production, which accounts for the largest share of consumed water with a volume of 41477.8 m3.

Terrestrial acidification ranks fourteenth with a total impact of 24910 kg SO2 eq, primarily attributed to material production, which accounts for the largest share with 20023 kg SO2 eq.

Table 15 P3-environmental impacts.

Impact category	Unit	Total	P3	P3 Earthwork	P3 Materials consumption	P3 energy and fuel consumptions of small cars
Global warming	kg CO2 eq	6415791	0	839012,3	5532766,4	44012,182
Stratospheric ozone depletion	kg CFC11 eq	3,574745	0	0,492041	3,0568762	0,025827485
Ionizing radiation	kBq Co-60 eq	226769,2	0	9497,579	216769,94	501,68702
Ozone formation, Human health	kg NOx eq	30306,22	0	10221,11	19548,992	536,12116
Fine particulate matter formation	kg PM2.5 eq	11221,21	0	2344,735	8753,4877	122,98988
Ozone formation, Terrestrial ecosystems	kg NOx eq	31427,95	0	10386,44	20496,718	544,7935
Terrestrial acidification	kg SO2 eq	24910,24	0	4643,581	20023,081	243,57352
Freshwater eutrophication	kg P eq	2515,492	0	124,1521	2384,8256	6,514288
Marine eutrophication	kg N eq	140,1739	0	2,270413	137,78415	0,1193126
Terrestrial ecotoxicity	kg 1,4-DCB	23124549	0	987760,5	22084962	51825,958
Freshwater ecotoxicity	kg 1,4-DCB	237175,8	0	3821,019	233154,13	200,67149
Marine ecotoxicity	kg 1,4-DCB	334871,8	0	5965,432	328593,16	313,23156
Human carcinogenic toxicity	kg 1,4-DCB	2945005	0	31609,92	2911736,2	1658,8632
Human non-carcinogenic toxicity	kg 1,4-DCB	3615786	0	79149,53	3532479	4156,9625
Land use	m2a crop eq	249221,3	0	11476,22	237142,72	602,38022
Mineral resource scarcity	kg Cu eq	110558,8	0	1300,438	109190,11	68,256319
Fossil resource scarcity	kg oil eq	3273727	0	265753,7	2994033,4	13940,083
Water consumption	m3	42191,53	0	670,7474	41477,792	42,985587

7.2.3.1 Level two of impact assessment – P3 Earthwork

Figure 39 shows the characterization of the emissions for each impact category related to earthwork activities in terms of percentages, and it is as follows:

- ‘Rock excavation’ activities are responsible for 28.1 % of the environmental impacts, as indicated by the yellow color in the chart.
- ‘Blasted stone from cutting to filling in the line’ activities are responsible for 31.4 % of the environmental impacts, as indicated by the dark red color in the chart.
- ‘Skytenane masses to fill along the way’ activities are responsible for 10.7 % of the environmental impacts, as indicated by the dark blue color in the chart.
- ‘Another masses’ activities are responsible for 9.46 % of the environmental impacts, as indicated by the light blue color in the chart.
- ‘Skytebane blasted rock to meadow’ activities are responsible for 2.9 % of the environmental impacts, as indicated by the dark purple color in the chart.
- ‘Blasted rock masses to stored for later processing’ activities are responsible for 7.21 % of the environmental impacts, as indicated by the red color in the chart.

- ‘Vegetation clearance and removal of vegetation cover’ activities are responsible for 7 % of the environmental impacts, as indicated by the green color in the chart.
- ‘Masses used to ground leveling’ activities are responsible for 2.77 % of the environmental impacts, as indicated by the gray color in the chart.

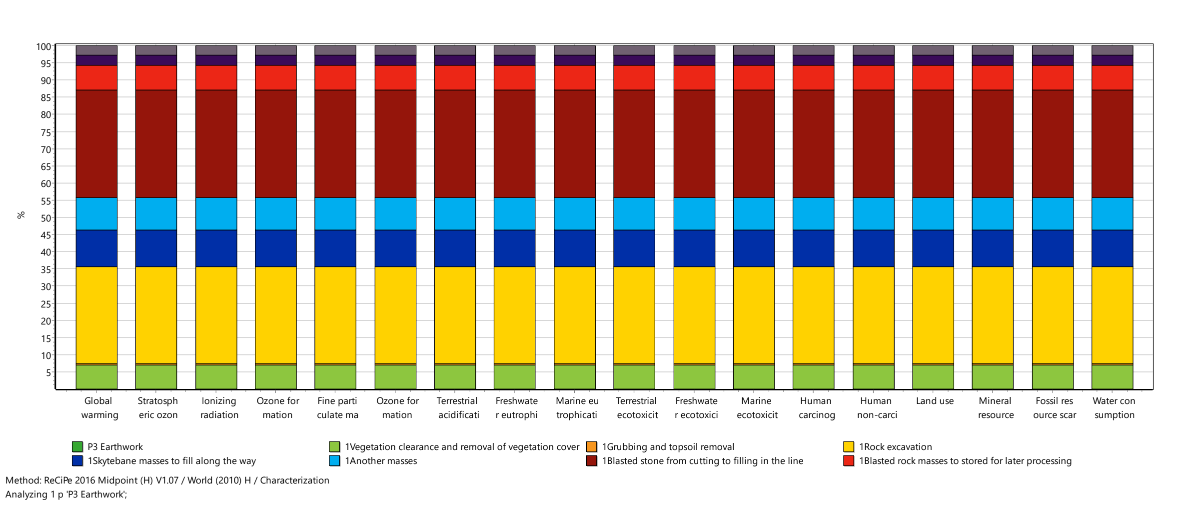


Figure 39 Characterized environmental impacts related to earthwork activities in the P3 road parcel

Table 16 provides numerically the categorized environmental impacts of each earthwork activity in the P3 road parcel.

Table 16 Categorized environmental impacts of earthwork activities in the P3 road parcel.

Impact category	Unit	Total	1Vegetation clearance and removal of vegetation cover	1Grubbing and topsoil removal	1Rock excavation	1Skytebane masses to fill along the way	1Another masses	1Blasted stone from cutting to filling in the line	1Blasted rock masses to stored for later processing	1Skytebane blasted rock to meadow	1Masses used to ground leveling
Global warming	kg CO2 eq	839012,27	58788,827	3749,8307	235876,3	89741,998	79329,943	263514,62	60489,081	24294,795	23226,892
Stratospheric ozone depletion	kg CFC11 eq	0,49204093	0,034476861	0,002199098	0,13833	0,052629428	0,046523251	0,15453883	0,035473979	0,01424775	0,013621471
Ionizing radiation	kBq Co-60 eq	9497,5792	665,48675	42,447906	2670,108	1015,8752	898,0112	2982,973	684,73354	275,01593	262,92732
Ozone formation, Human health	kg NOx eq	10221,106	716,18362	45,681594	2873,518	1093,2647	966,42183	3210,2164	736,89665	295,96669	282,95716
Fine particulate matter formation	kg PM2.5 eq	2344,7351	164,29346	10,479417	659,1887	250,79635	221,69843	736,42783	169,04505	67,895145	64,910743
Ozone formation, Terrestrial ecosystems	kg NOx eq	10386,443	727,7686	46,420539	2920	1110,9493	982,05466	3262,1448	748,81668	300,75424	287,53427
Terrestrial acidification	kg SO2 eq	4643,5807	325,37148	20,753739	1305,476	496,68428	439,05793	1458,4428	334,78167	134,46149	128,5511
Freshwater eutrophication	kg P eq	124,15211	8,6992258	0,55487795	34,90359	13,279494	11,73878	38,993348	8,9508195	3,5950013	3,4369792
Marine eutrophication	kg N eq	2,2704128	0,15908576	0,010147246	0,638294	0,24284672	0,21467114	0,71308488	0,16368674	0,06574304	0,062853232
Terrestrial ecotoxicity	kg 1,4-DCB	987760,49	69211,48	4414,637	277694,7	105652,33	93394,324	310233,04	71213,172	28602,012	27344,78
Freshwater ecotoxicity	kg 1,4-DCB	3821,0187	267,73531	17,07743	1074,225	408,70183	361,28339	1200,0948	275,47858	110,64304	105,77961
Marine ecotoxicity	kg 1,4-DCB	5965,4315	417,99237	26,661539	1677,096	638,07141	564,04103	1873,606	430,08128	172,73756	165,1447
Human carcinogenic toxicity	kg 1,4-DCB	31609,916	2214,8781	141,27545	8886,675	3381,0436	2988,7678	9927,9539	2278,9355	915,31015	875,07673
Human non-carcinogenic toxicity	kg 1,4-DCB	79149,528	5545,9355	353,74611	22251,76	8465,951	7483,7136	24859,062	5706,3316	2291,8873	2191,145
Land use	m2a crop eq	11476,218	804,12816	51,291114	3226,374	1227,5133	1085,0946	3604,4183	827,38466	332,31023	317,70319
Mineral resource scarcity	kg Cu eq	1300,4383	91,120528	5,8121002	365,5996	139,09681	122,9585	408,438	93,75586	37,656042	36,000831
Fossil resource scarcity	kg oil eq	265753,74	18621,123	1187,7437	74712,86	28425,414	25127,438	83467,188	19159,672	7695,2779	7357,0239
Water consumption	m3	670,74743	46,998663	2,997798	188,571	71,744141	63,420235	210,66647	48,357929	19,422447	18,568713

7.2.3.2 Level two of impact assessment – P3 Materials Consumption

Figure 40 shows the characterization of the emissions related to material consumption activities in terms of percentages for each impact category.

Figure 40 and Table 17 provide the following:

- The materials with the highest GWP impact can be identified by looking at the top three materials in Table 9, which are as follows:

- Concrete B45, SV-40 with approximately 28 % of total GWP.
- Reinforcement B500NC with approximately 20 % of total GWP.
- Binder course Agb 11 with approximately 16 % of total GWP.

- The top three materials with the highest water use are:

- Reinforcement B500NC with approx. 23% of total water use.
- Concrete B45, SV-40 with approx. 17 % of total water use.
- Bridge piles of steel with approx. 10 % of total water use.

- The top three materials with the highest terrestrial acidification are:

- Binder course Agb 11 with approximately 32 % of total terrestrial acidification
- Concrete B45, SV-40 with approx. 19 % of total terrestrial acidification.
- Reinforcement B500NC with approximately 17 % of total terrestrial acidification.

- The top three materials with the highest terrestrial ecotoxicity are:

- Reinforcement B500NC with approx. 31% of total terrestrial ecotoxicity.
- Concrete B45, SV-40 with approx. 12 % of total terrestrial ecotoxicity.
- Binder course Agb 11 with approximately 12 % of total terrestrial ecotoxicity.

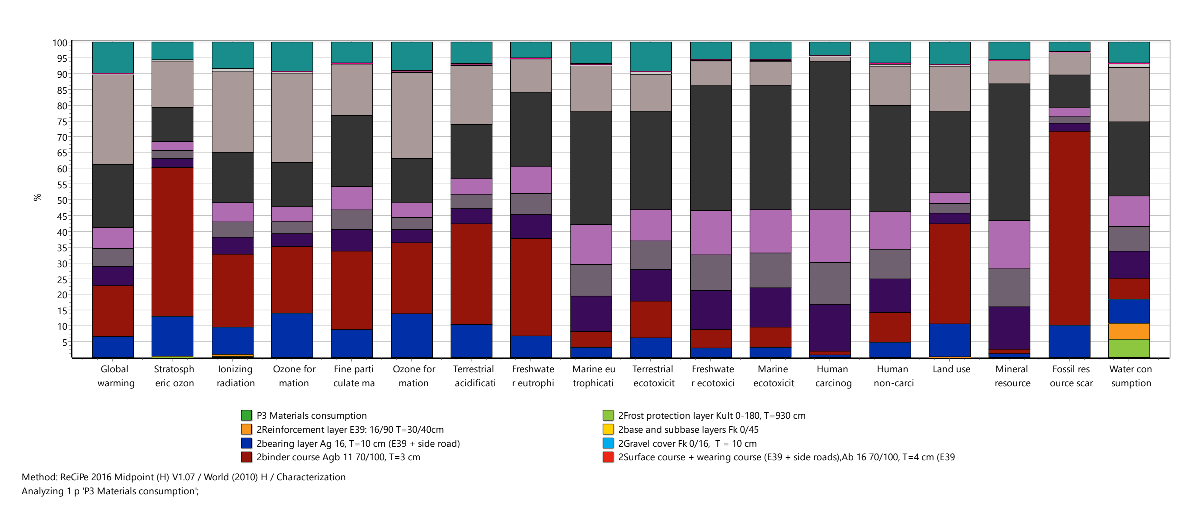


Figure 40 Characterized environmental impacts related to material consumption activities in the P3 road parcel.

Table 17 Categorized environmental impacts of materials consumption activities in the P3 road parcel.

Impact category	Unit	Total	2Frost protection layer Kult 0-180, T=930 cm	2Reinforcement layer E39: 16/90 T=30/40cm	2base and subbase layers Fk 0/45	2bearing layer Ag 16, T=10 cm (E39 + side road)	2Gravel cover Fk 0/16, T = 10 cm	2binder course Agb 11 70/100, T=3 cm	2Surface course + wearing course (E39 + side roads),Ab 16 70/100, T=4 cm (E39	2Steel railings road	2Steel railings Bridge	2Bridge piles of steel	2reinforcement B500NC	2Concrete B45, SV-40	2Waterproof membrane	2Bridge bearing varies sizes	2Prefabricated beams type NTB 1200
Global warming	kg CO2 eq	5532766,4	1483,2507	1233,0943	51,67373	364699,93	13,518554	897403,84	489,30541	339382,75	302422,64	372183,5	1111908	1570778	19787,11	9935,495	540993,6
Stratospheric ozone depletion	kg CFC11 eq	3,0568762	0,005898165	0,004903415	0,000205	0,38551212	5,38E-05	1,4434158	0,000787016	0,08691854	0,077452774	0,088947	0,330746	0,446338	0,011985	0,003877	0,169836
Ionizing radiation	kBq Co-60 eq	216769,95	1079,3701	897,32986	37,60327	18811,455	9,8375302	49934,874	27,226765	11887,428	10592,841	13264,66	34492,11	55266,25	2049,505	331,9758	18087,48
Ozone formation, Human health	kg NOx eq	19548,992	3,125671	2,5985135	0,108893	2760,4132	0,028487802	4111,7009	2,2418865	823,78482	734,07143	890,4664	2762,577	5525,96	92,53956	32,86535	1806,51
Fine particulate matter formation	kg PM2.5 eq	8753,4877	1,6296592	1,3548104	0,056774	777,97482	0,014852942	2168,743	1,1824974	601,23772	535,76058	666,6859	1962,532	1406,799	39,48532	16,73392	573,297
Ozone formation, Terrestrial ecosystems	kg NOx eq	20496,718	3,1910465	2,6528632	0,11117	2846,1687	0,029083643	4584,9782	2,4999388	869,8121	775,08615	941,2596	2916,993	5585,978	95,0725	34,23515	1838,651
Terrestrial acidification	kg SO2 eq	20023,081	3,4862831	2,8983069	0,121456	2072,0248	0,031774471	6404,9533	3,492272	967,74585	862,35453	1064,994	3416,49	3746,821	88,59047	30,74018	1358,338
Freshwater eutrophication	kg P eq	2384,8256	0,71642268	0,595595	0,024959	161,10509	0,006529576	736,18309	0,40140052	181,29166	161,54829	203,2387	559,492	248,8518	9,094173	4,192011	118,0837
Marine eutrophication	kg N eq	137,78415	0,069289953	0,057603913	0,002414	4,4146287	0,000631518	6,7892851	0,003701827	15,502752	13,814442	17,52429	49,23502	20,05986	0,475705	0,309265	9,52526
Terrestrial ecotoxicity	kg 1,4-DCB	22084962	5073,5646	4217,8868	176,7537	1371977,5	46,241177	2561750,7	1396,7831	2221717,6	1979763,9	2209429	6880429	2599054	160226,4	61316,58	2028386
Freshwater ecotoxicity	kg 1,4-DCB	233154,13	77,706346	64,600846	2,707146	6912,5018	0,70822649	13369,063	7,2894215	29267,645	26080,284	33038,32	92228,84	17866,69	720,513	804,0948	12713,17
Marine ecotoxicity	kg 1,4-DCB	328593,16	103,02257	85,647387	3,589117	10194,263	0,93896213	21470,882	11,706902	40729,485	36293,884	45823,89	128860,1	24781,52	1035,972	1106,56	18091,72
Human carcinogenic toxicity	kg 1,4-DCB	2911736,2	269,38772	223,95435	9,384972	23118,124	2,4552373	32492,782	17,716543	433456,06	386250,99	491854,6	1364401	46298,49	2001,952	7643,584	123695,8
Human non-carcinogenic toxicity	kg 1,4-DCB	3532479	1671,9705	1389,9857	58,24838	169600,81	15,238573	330155,01	180,01554	375661,88	334750,83	418236	1188153	444560,1	18897,61	13842,05	235306,1
Land use	m2a crop eq	237142,72	133,75477	111,19647	4,65977	25074,669	1,2190596	74928,407	40,854377	8109,8186	7226,6276	8109,471	60857,71	34320,38	1148,5	284,5852	16790,86
Mineral resource scarcity	kg Cu eq	109190,11	14,252455	11,848719	0,496529	1192,2286	0,12989886	1682,2042	0,91721427	14670,893	13073,176	16641,91	47383,56	8122,639	87,33515	265,7518	6042,777
Fossil resource scarcity	kg oil eq	2994033,4	286,81478	238,44227	9,992099	307729,5	2,61407	1839540,8	1003,0014	73241,026	65264,791	78536,55	314377,8	209680,9	8753,255	2593,677	92774,19
Water consumption	m3	41477,792	2388,9	1986,002	83,22488	3149,6827	21,772768	2803,6239	1,5286634	3588,5364	3197,7307	4050,416	9725,83	7186,829	459,221	72,45396	2762,04

7.2.3.3 Level two of impact assessment – P3 Energy and fuel consumption of small cars

Figure 41 shows the characterization of the emissions related to energy and fuel for small cars in terms of percentages for each impact category.

Figure 41 and Table 18 provide that the amount of diesel fuel consumed plays a dominant role over all environmental impacts, so diesel consumption is the primary contributor to environmental impacts, accounting for 99 % of all impacts except for water use. In the case of water use, diesel consumption is responsible for approximately 81.6% of the total water use impact, with electricity accounting for the remaining 18.4 %.

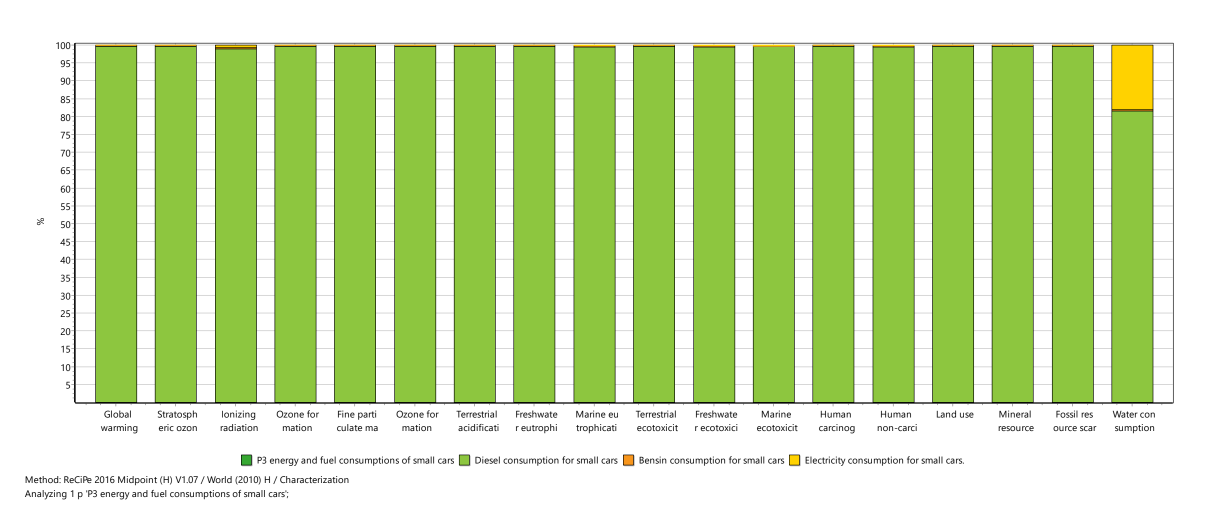


Figure 41 Characterized environmental impacts related to energy and fuel for small cars in the P3 road parcel.

Table 18 Categorized environmental impacts of energy and fuel for small cars in the P3 road parcel.

Impact category	Unit	Total	Diesel consumption for small cars	Bensin consumption for small cars	Electricity consumption for small cars.
Global warming	kg CO2 eq	44012,182	43859,542	147,7947	4,845429
Stratospheric ozone depletion	kg CFC11 eq	0,025827485	0,025721542	8,67E-05	1,93E-05
Ionizing radiation	kBq Co-60 eq	501,68702	496,48795	1,673029	3,5260467
Ozone formation, Human health	kg NOx eq	536,12116	534,31047	1,800481	0,010210827
Fine particulate matter formation	kg PM2.5 eq	122,98988	122,57152	0,413033	0,005323711
Ozone formation, Terrestrial ecosystems	kg NOx eq	544,7935	542,95347	1,829605	0,010424393
Terrestrial acidification	kg SO2 eq	243,57352	242,74415	0,817982	0,011388862
Freshwater eutrophication	kg P eq	6,514288	6,4900778	0,02187	0,002340383
Marine eutrophication	kg N eq	0,1193126	0,11868631	0,0004	0,000226354
Terrestrial ecotoxicity	kg 1,4-DCB	51825,958	51635,387	173,9972	16,574135
Freshwater ecotoxicity	kg 1,4-DCB	200,67148	199,74455	0,673085	0,25384823
Marine ecotoxicity	kg 1,4-DCB	313,23156	311,84418	1,05083	0,33655036
Human carcinogenic toxicity	kg 1,4-DCB	1658,8632	1652,415	5,568189	0,88002589
Human non-carcinogenic toxicity	kg 1,4-DCB	4156,9625	4137,5581	13,94245	5,4619318
Land use	m2a crop eq	602,38021	599,9217	2,021573	0,43694515
Mineral resource scarcity	kg Cu eq	68,256319	67,980683	0,229076	0,046559396
Fossil resource scarcity	kg oil eq	13940,083	13892,332	46,81338	0,93695598
Water consumption	m3	42,985587	35,063462	0,118154	7,8039706

7.2.4 Summary of impact assessment with ReCiPe methodology

The following table shows the environmental impacts of each road parcel and the total sum on chosen damage pathways.

Table 19 The environmental impacts of each road parcel.

	P1	P2	P3	sum	unit
GWP	8579937,4	4878151,1	6415790,9	19873879.4	kg CO2 eq
Water use	49911,438	26342,699	42191,525	118445.6	M3
Terrestrial acidification	36862,959	23426,875	24910,235	85200	kg SO2 eq
Terrestrial ecotoxicity	28347341	14182500	23124549	65654390	kg 1,4-DCB

By comparing the chosen environmental impacts (GWP, Water use, Terrestrial acidification, and terrestrial ecotoxicity) in each road parcel as illustrated in Figure 42, the findings are as follows:

- With a length of only 3400 m, P3 is the shortest road parcel. Despite its relatively small size, it has the second-highest terrestrial ecotoxicity and acidification impact, accounting for 35% and 29% of the total terrestrial ecotoxicity and acidification impacts, respectively. In addition, it should be noted that the P3 road parcel has the second-highest GWP impact with 32% of the total GWP impacts.

- The comparison chart of the chosen environmental impacts (GWP, water use, terrestrial acidification, and terrestrial ecotoxicity) reveals that the P1 road parcel, which spans 5400 m, is accountable for around 43% of these impacts on average. Hence, it can be inferred that the P1 road parcel plays a substantial role in contributing to the environmental impacts.
- The comparison chart of the chosen environmental impacts (GWP, water use, terrestrial acidification, and terrestrial ecotoxicity) reveals that the P2 road parcel, which spans 4100 m, is accountable for around 25% of these impacts on average.

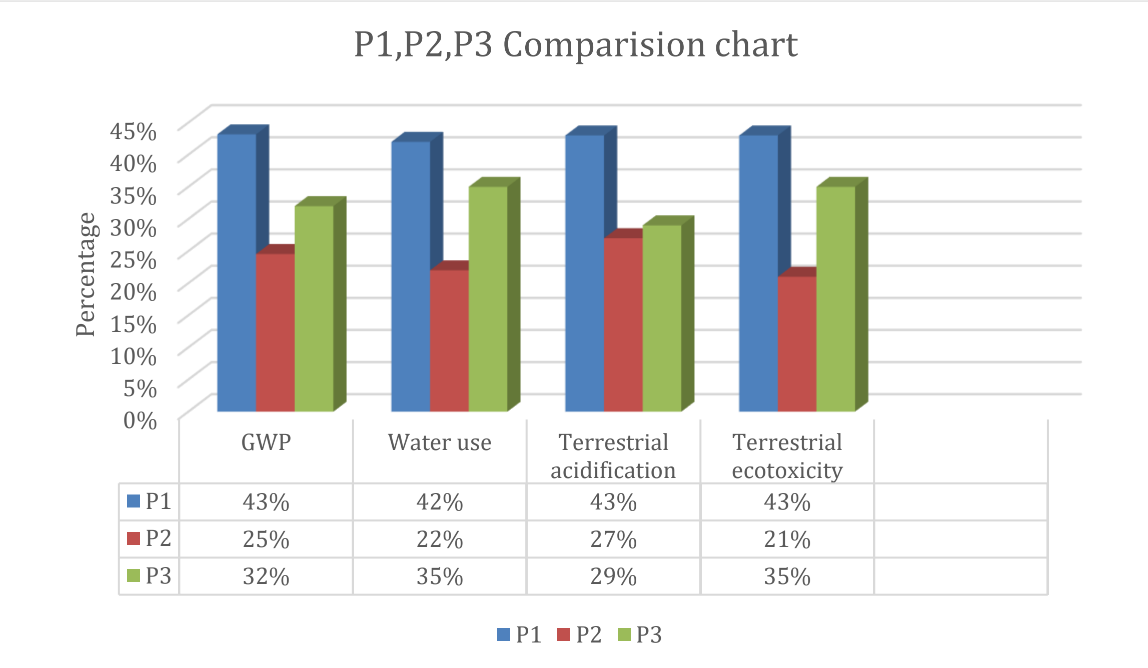


Figure 42 shows the comparison of total environmental impact shares for each road parcel.

Figure 43 illustrates the chosen environmental impacts (GWP, water use, terrestrial acidification, and terrestrial ecotoxicity) caused by earthwork activities in each parcel of the road. The figure indicates that each road parcel produces the same proportion of chosen environmental impacts. The environmental impacts resulting from earthwork activities in each road parcel were found to be relatively similar, with P1 being responsible for 41% of GWP, 41% of water use, 41% of terrestrial acidification, and 41% of terrestrial ecotoxicity. P2 is responsible for 38% of GWP, 38% of water use, 38% of terrestrial acidification, and 38% of terrestrial ecotoxicity. P3 is responsible for 20% of GWP, 20% of water use, 20% of terrestrial acidification, and 20% of terrestrial ecotoxicity.

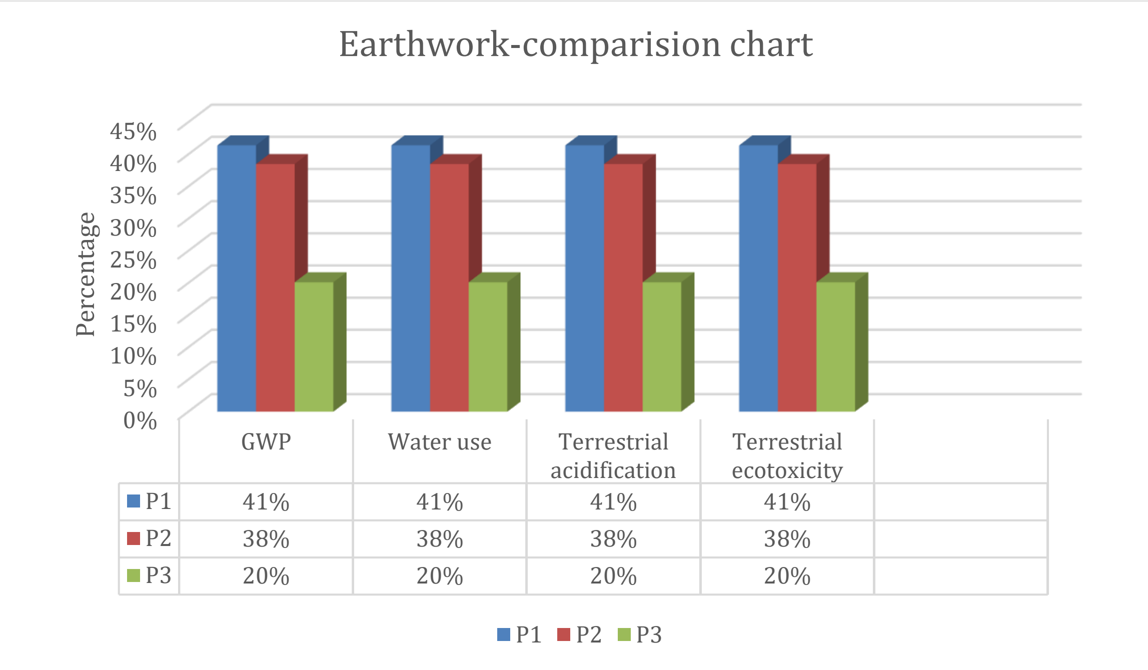


Figure 43 shows the earthwork comparison of total environmental impact shares for each road parcel.

Figure 44 illustrates the chosen environmental impacts (GWP, water use, terrestrial acidification, and terrestrial ecotoxicity) caused by material consumption activities in each parcel of the road.
The environmental impacts resulting from material consumption activities in each road parcel were found to be on average as follows:

- P1 has on average 43% in each chosen environmental impact.
- P2 has on average 22% in each chosen environmental impact.
- P3 has on average 35% in each chosen environmental impact.

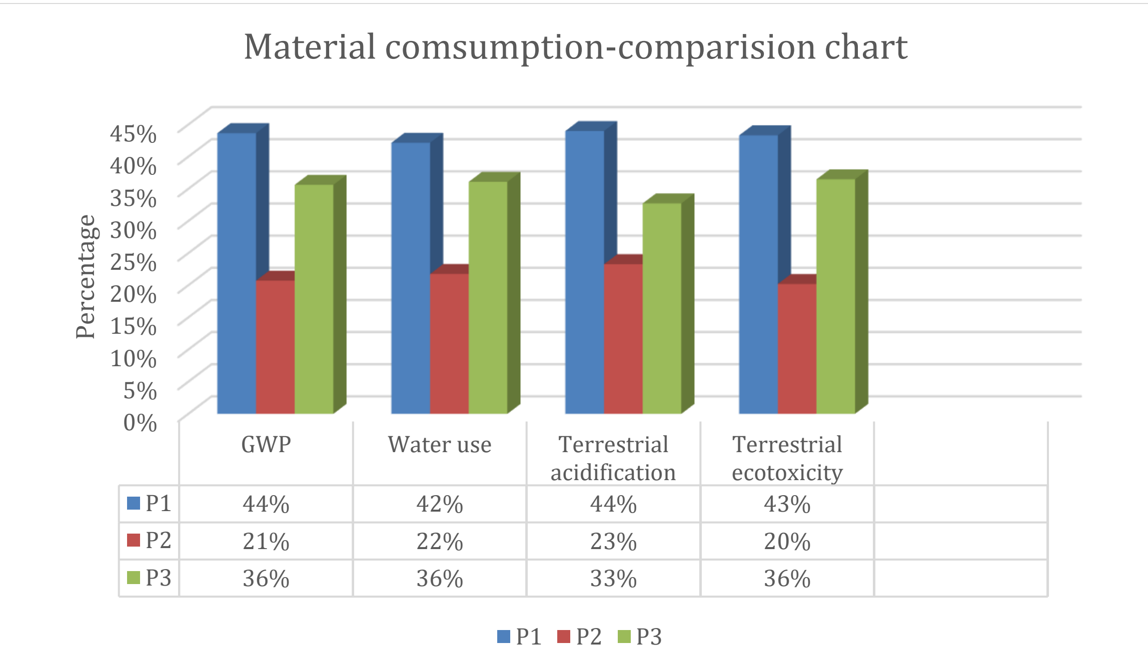


Figure 44 shows the material consumption comparison of total environmental impact shares for each road parcel.

Figure 45 illustrates the chosen environmental impacts (GWP, water use, terrestrial acidification, and terrestrial ecotoxicity) resulting from the consumption of energy and fuel for small cars. The figure indicates that each road parcel produces the same proportion of chosen environmental impacts. The environmental impacts resulting from ‘‘energy and fuel consumption for small cars’’ activities in each road parcel were found to be similar, and it is as follows:

- P1 is responsible for 42% of GWP, 42% of water use, 42% of terrestrial acidification, and 42% of terrestrial ecotoxicity.
- P2 is responsible for 32% of GWP, 32% of water use, 32% of terrestrial acidification, and 32% of terrestrial ecotoxicity.
- P3 is responsible for 26% of GWP, 26% of water use, 26% of terrestrial acidification, and 26% of terrestrial ecotoxicity.

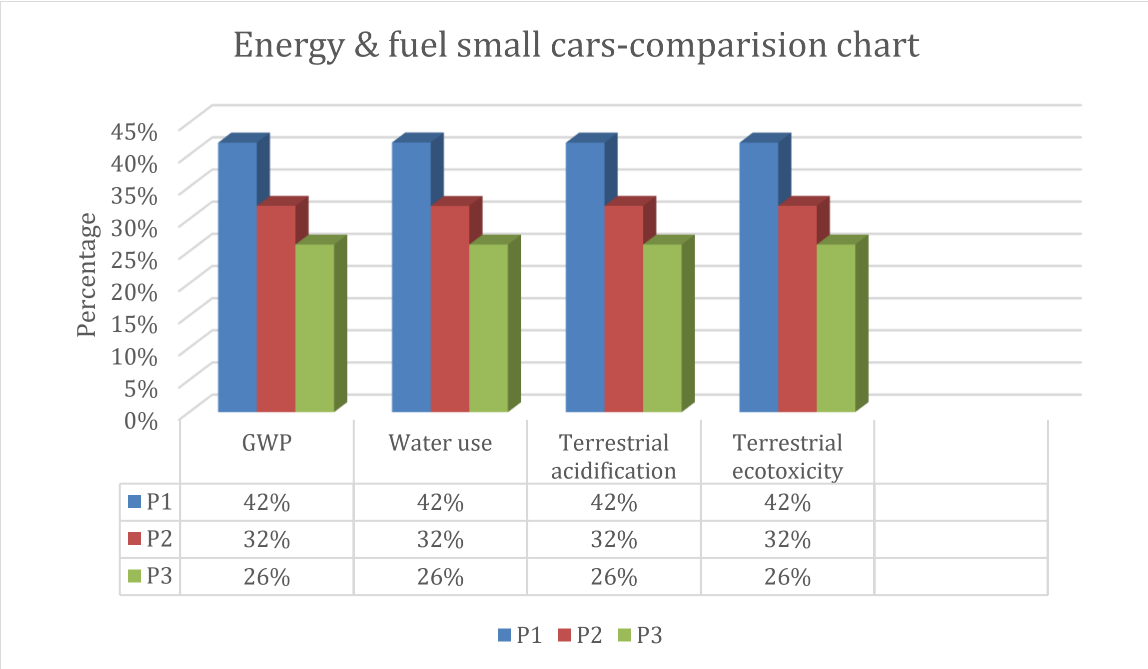
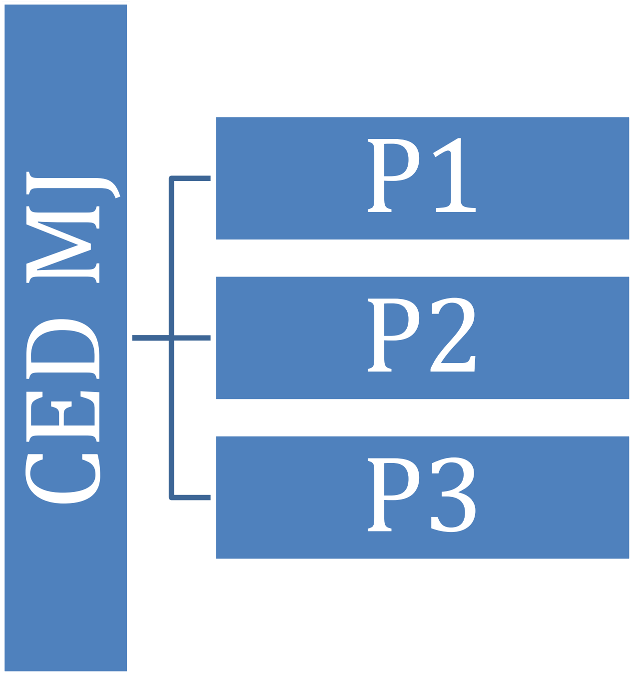


Figure 45 shows the energy & fuel (small cars) comparison of total environmental impact shares for road parcel.

7.3 Cumulative energy demand.

This chapter aims to present the cumulative energy demand (CED) required for the construction of the E39 Betna-Hestnes road project, by using LCA-CED methodology (For more detailed information about CED, please refer to chapter Cumulative Energy Demand CED). The CED values will be provided for each road parcel (P1, P2, and P3) individually to offer a comprehensive analysis (later) of the energy demand required for constructing the road project.
The system is shown bellow



7.3.1 P1 Betna – Klettelva

Figure 46 illustrates the energy demand of each activity in P3 (earthwork, material consumption, and energy consumption for small cars). The figure shows that material consumption activities are the largest and highest contributors to energy demand from multiple and different energy sources.

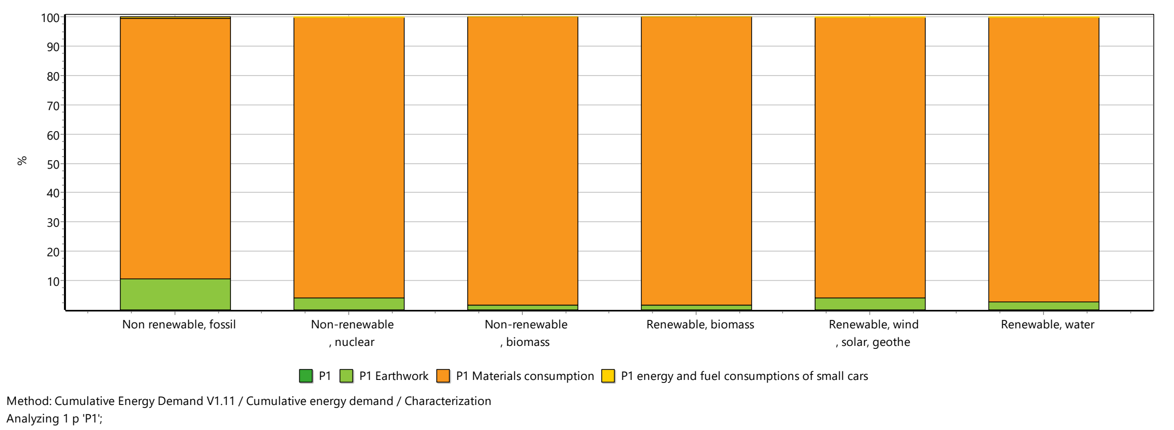


Figure 46 shows the distribution of energy demand for constructing the P1.

Figure 47 shows that most of the energy demand in material consumption activities is derived from non-renewable (fossil and nuclear) sources, with 96% from fossil and 2 % from nuclear of the total energy demand.

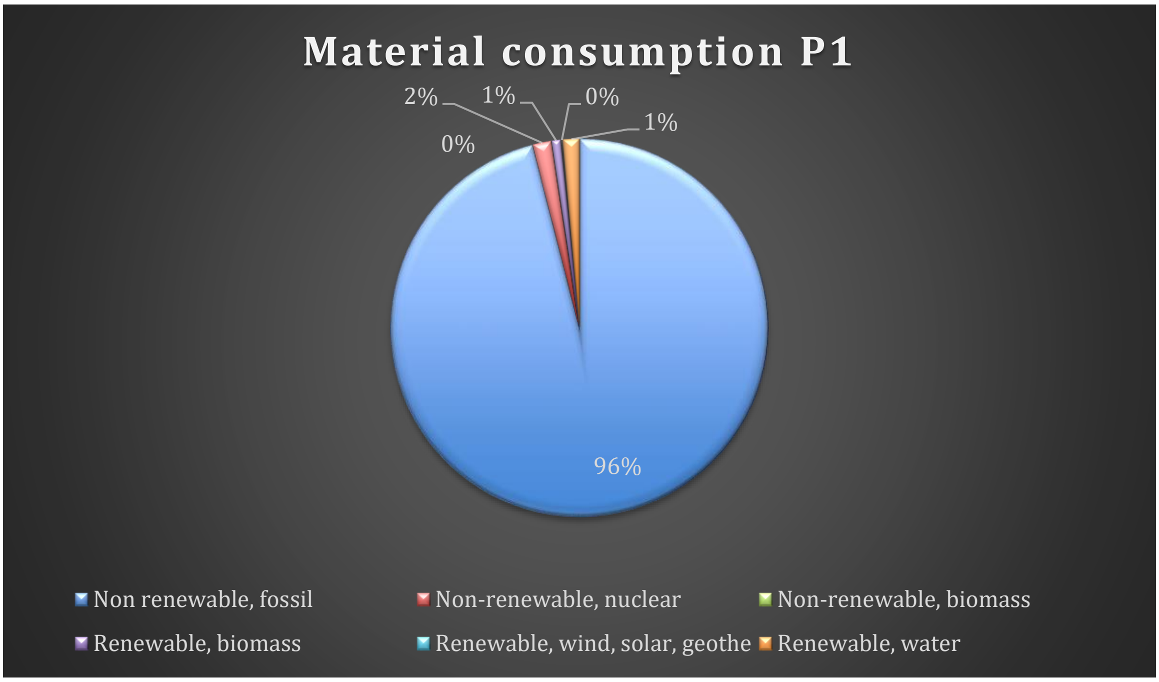


Figure 47 Energy demand for material consumption activities in P1.

Earthwork activities, such as rock excavation, vegetation removal, and clearness, are known to have a significant impact on energy demand, especially from non-renewable sources. According to Figure 46, earthwork activities contribute to approximately 10% of the total energy demand from non-renewable fossil sources and 4 % from nuclear sources.

Table 20 presents numerical data that represents the energy demand of each activity involved in constructing P1.

Table 20 shows the cumulative energy demand of constructing P1

Impact category	Unit	Total	P1 Earthwork	P1 Materials consumption	P1 energy and fuel consumptions of small cars
Non renewable, fossil	MJ	2,39E+08	25053654	2,13E+08	1026755,9
Non-renewable, nuclear	MJ	3735525,5	156041,8	3572986	6497,678
Non-renewable, biomass	MJ	8125,7651	127,43622	7993,096	5,2329025
Renewable, biomass	MJ	1698652,8	29723,779	1667696,1	1232,9237
Renewable, wind, solar, geothe	MJ	510634,76	20449,778	489280,98	903,99341
Renewable, water	MJ	3166549,6	83958,263	3077512,6	5078,7626

7.3.2 P2 Klettelva-Otnes

Figure 48 illustrates the energy demand of each activity in P2 (earthwork, material consumption, and energy consumption for small cars). The figure shows that material consumption activities are the largest and highest contributors to energy demand from multiple and different energy sources.

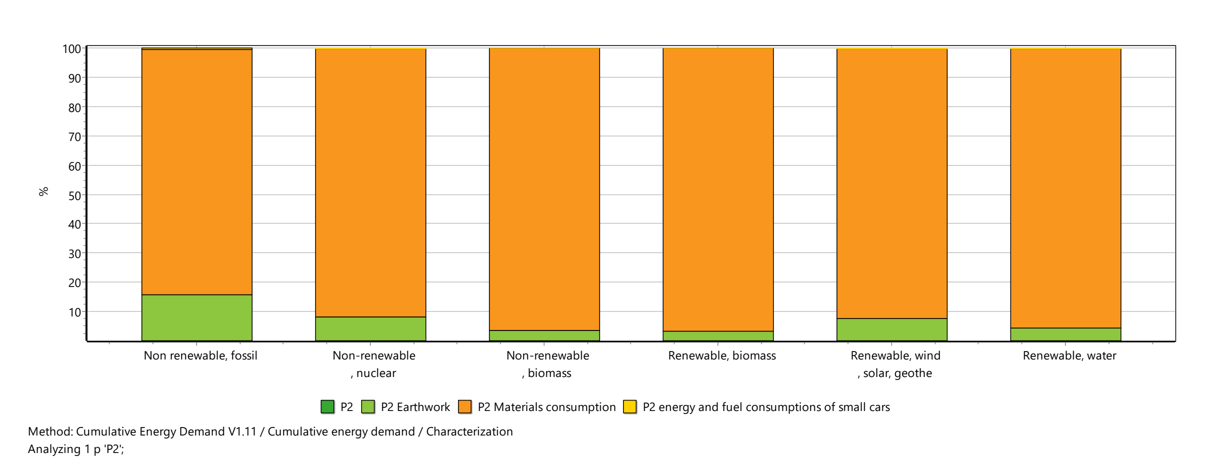


Figure 48 shows the distribution of energy demand for constructing the P2.

Figure 49 shows that most of the energy demand in material consumption activities is derived from non-renewable (fossil and nuclear) sources, with 95% from fossil and 2 % from nuclear of the total energy demand.

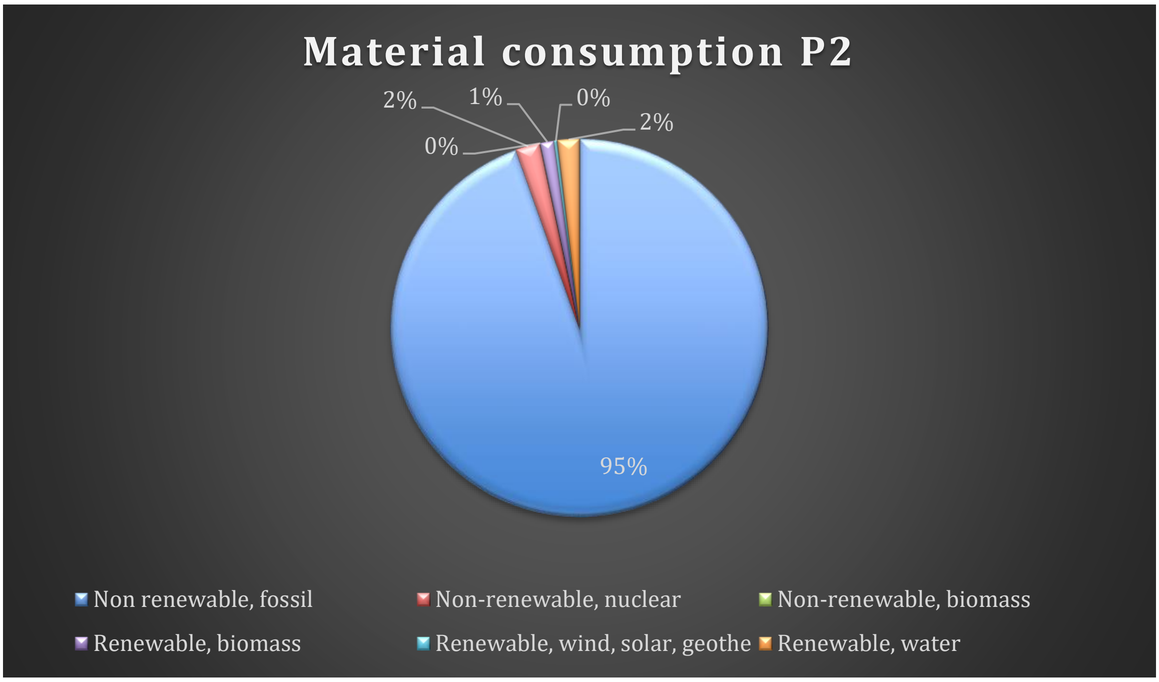


Figure 49 Energy demand for material consumption activities in P2.

According to Figure 48, earthwork activities contribute to approximately 16% of the total energy demand from fossil non-renewable sources and 4 % from nuclear sources.
Table 21 presents numerical data that represents the energy demand of each activity involved in constructing P2.

Table 21 shows the cumulative energy demand of constructing P2.

Impact category	Unit	Total	P2 Earthwork	P2 Materials consumption	P2 energy and fuel consumptions of small cars
Non renewable, fossil	MJ	1,48E+08	23291669	1,24E+08	785787,53
Non-renewable, nuclear	MJ	1789068,6	145067,62	1639028,6	4972,3942
Non-renewable, biomass	MJ	3482,18	118,47383	3359,7014	4,0047626
Renewable, biomass	MJ	818059,06	27633,352	789482,18	943,51969
Renewable, wind, solar, geothe	MJ	250901,25	19011,577	231198,06	691,61154
Renewable, water	MJ	1770603,6	78053,608	1688668,7	3881,2534

7.3.3 P3 Otneselva-Hestnes

Figure 50 illustrates the energy demand of each activity in P3 (earthwork, material consumption, and energy consumption for small cars). The figure shows that material consumption activities are the largest and highest contributors to energy demand from multiple and different energy sources.

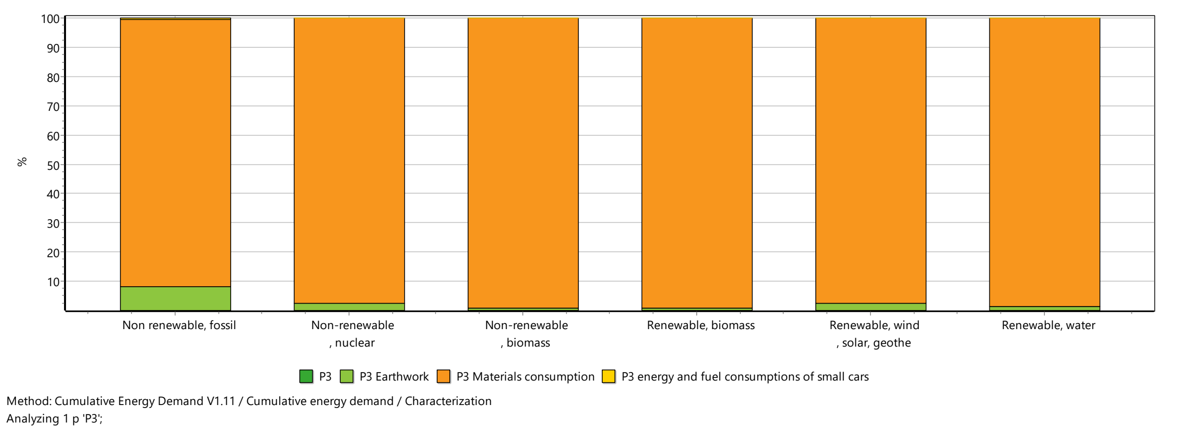


Figure 50 shows the distribution of energy demand for constructing the P3.

Figure 51 shows that most of the energy demand in material consumption activities is derived from non-renewable (fossil and nuclear) sources, with 97% from fossil and 1 % from nuclear of the total energy demand.

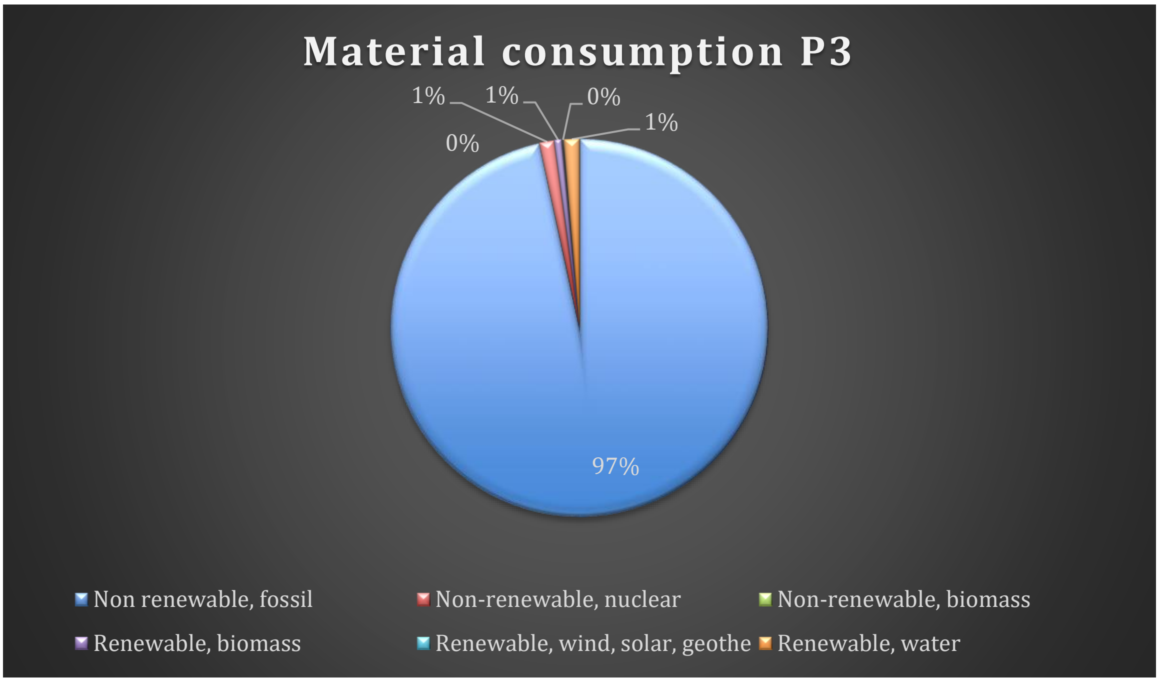


Figure 51 Energy demand for material consumption activities in P3.

According to Figure 50, earthwork activities contribute to approximately 8% of the total energy demand from fossil non-renewable sources and 2.5 % from nuclear sources.
Table 21 presents numerical data that represents the energy demand of each activity involved in constructing P3.

Table 22 shows the cumulative energy demand of constructing P3.

Impact category	Unit	Total	P3 Earthwork	P3 Materials consumption	P3 energy and fuel consumptions of small cars
Non renewable, fossil	MJ	1,50E+08	12171455	1,37E+08	638452,37
Non-renewable, nuclear	MJ	3144135,1	75807,529	3064287,5	4040,0703
Non-renewable, biomass	MJ	6851,6482	61,910496	6786,4839	3,2538696
Renewable, biomass	MJ	1723340,1	14440,274	1708133,2	766,60975
Renewable, wind, solar, geothe	MJ	431098,94	9934,8199	420602,19	561,93438
Renewable, water	MJ	2747058,4	40788,229	2703116,6	3153,5184

7.3.4 Summary of Cumulative Energy Demand

The following table shows the cumulative energy demand of each road parcel and the total sum of energy demand and energy sources:

Table 23 The total energy demand of the E39 Betna-Hestnes Road Project.

Total energy demand of E39 Betna-Hestnes Road Project					
Impact category	Unit	P1 Total	P2 Total	P3 Total	Sum
Non renewable, fossil	MJ	2,39E+08	1,48E+08	1,50E+08	5,37E+08
Non-renewable, nuclear	MJ	3,74E+06	1,79E+06	3,14E+06	8,67E+06
Non-renewable, biomass	MJ	8,13E+03	3,48E+03	6,85E+03	1,85E+04
Renewable, biomass	MJ	1,70E+06	8,18E+05	1,72E+06	4,24E+06
Renewable, wind, solar, geothe	MJ	5,11E+05	2,51E+05	4,31E+05	1,19E+06
Renewable, water	MJ	3,17E+06	1,77E+06	2,75E+06	7,68E+06

According to the CED analysis above conducted on each road parcel of the E39 Betna-Hestnes Road project, the consumption of materials is a major contributor to the energy demand from non-renewable sources, accounting for an average of 98 percent. The reason behind this is the production process of consumed materials that contain asphalt and cement, which require a significant amount of energy.

Figure 52 presents the Cumulative Energy Demand (CED) analysis focused just on the material consumption activities related to the P1 road parcel,(the figure is similar to P2 and P3 road parcels) and it shows the following:

1- Binder course Agb accounts for a significant proportion. Specifically, it is responsible for 70.7 % of total energy demand from non-renewable fossil sources and 10 % from non-renewable nuclear sources.
2- Bearing layer Ag16 is responsible for 10.1 % of total energy demand from non-renewable fossil sources and 10.1 % from non-renewable nuclear sources.
3- Concrete B45. SV-40 is responsible for 4 % of total energy demand from non-renewable fossil sources and 22.7 % from non-renewable nuclear sources.
4- Prefabricated beams are responsible for 5.15 % of total energy demand from non-renewable fossil sources and 22.8 % from non-renewable nuclear sources.

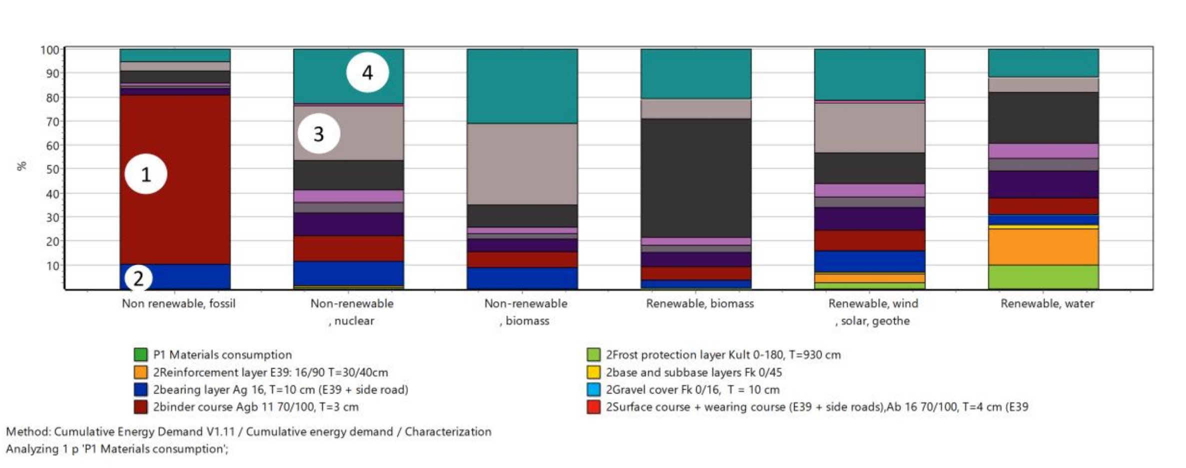


Figure 52 shows the energy-demanding materials derived from non-renewable sources is presented, including the most impactful materials.

Upon conducting a comparison of the road parcels P1, P2, and P3 using the CED methodology, as shown in Figure 53, the results indicate that road parcel P1 is the most energy-intensive, followed by P3, and P2 consumes the least energy.
It is worth mentioning that P3 and P2 have almost the same amount and percentage (62.8 % and 62.5 % respectively) of energy demand from non-renewable fossil sources.

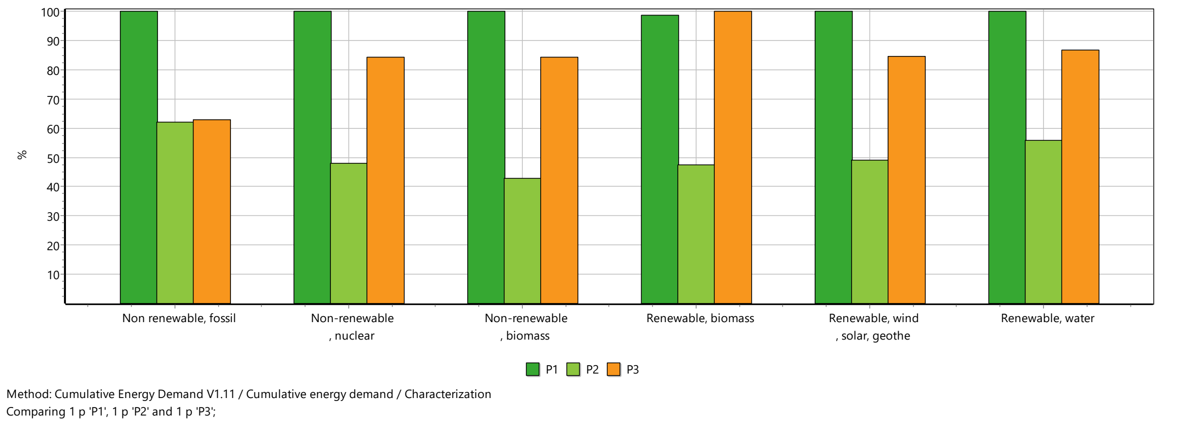


Figure 53 shows the comparison of total energy demand for each road parcel.

8. Discussions

The significance of this master thesis is on conducting a Life Cycle Assessment (LCA) of the E39 Betna-Hestnes road project, and it aims to evaluate and quantify the environmental impacts of constructing the E39 Betna-Hestnes road project. Through the analysis of the environmental impacts and energy demand of constructing the E39 Betna-Hestnes road project, this thesis contributes to expand the existing knowledge base in this field and has the potential to raise environmental awareness among various stakeholders, including road agencies, contractors, and designers. Furthermore, the research conducted in this thesis aligns with global efforts to mitigate climate change, by considering the environmental impacts of road construction activities.
The functional unit in this study is the environmental impacts of each road parcel of the road.

8.1 Discussions on the main findings

8.1.1 GWP

The construction of the entire E39 Betna-Hestnes project results in a total of 19,900 tons of CO2 equivalent greenhouse gas emissions. Breaking it down further, the road parcel Betna-Klettelva contributes 8,580 tons of CO2 equivalent emissions, the Klettelva-Otneselva road parcel accounts for 4,878 tons of CO2 equivalent emissions, and the Otneselva-Hestnes road parcel contributes 6,416 tons of CO2 equivalent emissions.
In order to gain deeper insights into the environmental impact, specifically regarding the GWP (Global Warming Potential), it is necessary to look deeper into Level 2 analysis to identify the primary materials and activities that contribute significantly in the form of high CO2 equivalent emissions. Upon examining the data (from all road parcels) presented in Table 7, Table 8, Table 11, Table 12, Table 15, and Table 16, it becomes evident that materials such as <u>asphalt, concrete, and steel</u> used in road and bridge structures play a substantial role in contributing to the overall CO2 emissions. Furthermore, when considering the earthwork activities, it is worth noting that the rock excavation activity and the use of blasted stone stand out as the two primary contributors to CO2 emissions and subsequently affect the Global Warming Potential (GWP). This outcome can be attributed to the use of a huge amount of fossil fuels during these activities. Energy and fuel consumption will be discussed in the 8.1.4 Energy and fuel consumption chapter.
Based on the findings of the research papers titled:

1- ‘*3.8.6 Life cycle assessment of large-scale timber bridges: A case study from the world’s longest timber bridge design in Norway by Reyn O’born (2018)*’
2- And *<u>Ontario Wood Bridge Reference Guide</u>* by the Ministry of Natural Resources and Forestry 2017 (page 30-1.5.3).

the use of timber bridges offers a more environmentally friendly solution compared to concrete bridges.
Considering the specific context of this E39 Betna-Hestnes road project, which involves constructing of eight bridges with a combined length of approximately 500 meters (with individual bridge lengths ranging from 36 to 117 meters: 36-52-36-65-86-117-35-72 meters), it becomes apparent that these bridges do not necessarily require concrete as their primary construction material.
By using timber as a bridge construction material, provides an opportunity to effectively mitigate carbon emissions. In the context of the E39 Betna-Hestnes road project, by adopting timber as the material of choice for these eight bridges, a substantial contribution can be made towards mitigating carbon emissions and achieving a more sustainable and environmentally friendly road project.
It is very important to mention that each road project is unique, Consequently, the results discussed here (from the literature) in this chapter indicate the potential existence of other alternatives and options that (can be, or) are more environmentally friendly.

8.1.2 Water use

The E39 Betna-Hestnes project had a total water consumption of approximately 118,500 m3. Specifically, 50,000 m3 of water was consumed in activities related to the Betna-Klettelva road parcel, 26,342 m3 of water was consumed in the Klettelva-Otneselva road parcel, and 42,191 m3 of water was consumed in Otneselva-Hestnes road parcel.
In order to gain deeper insights into the environmental impact, specifically regarding Water use, it is necessary to look deeper into Level 2 analysis to identify the primary materials and activities that contribute to high water consumption.
Upon examining the water use throughout the entire construction process, it becomes apparent that the water use in earthwork activities is relatively low, approximately 2.3%, of the total water use compared to the water use in material production activities, which constitutes the remaining 97.7%. (Table 7, Table 8, Table 11, Table 12, Table 15, and Table 16). The water use in material-consumption activities is significantly high, reaching a total of 115,000 cubic meters. This substantial quantity of water is distributed across the three road parcels and it is as follows: 48,461 cubic meters for P1, 25,000 cubic meters for P2, and 41,477 cubic meters for P3.
Upon examining the named tables above, it becomes clearly visible that certain materials, namely Steel rebar, concrete, and asphalt used mainly in bridge constructions, significantly contribute to the overall water consumption. Therefore, in light of the previously suggested solution for mitigating greenhouse gas emissions (GWP), it is a good choice to prioritize the use of timber as a primary construction material in bridges, to mitigate water use. By using timber as an alternative, the requirement for steel rebar and concrete can be significantly reduced, thereby contributing to a substantial reduction in water usage.
Due to time constraints, it is difficult to do an in-depth investigation and analyze the data that results a high water use, which necessitates further seeking.
The significant water use related to steel rebar cannot currently be fully (scientifically) explained or understood. Probably that the cooling process following high-temperature iron refining contributes to this water usage, but further scientific and academic inquiry is required to establish the precise reasons.
Moreover, considering the composition of concrete materials, it is acknowledged that water serves as an essential component. Additionally, the process of washing gravel during the crushing phase also contributes to water consumption. However, these assertions need to be substantiated through rigorous scientific and academic investigation.
As mentioned, due to time constraints, it was not feasible to thoroughly examine every detail encompassed within this thesis.
Despite the named time limitations, it remains highly recommended and efficient to use timber as an alternative to concrete, thereby avoiding the need for steel rebar and concrete consumption.

8.1.3 terrestrial acidification & ecotoxicity

The total <u>terrestrial acidification</u> resulting from constructing the E39 Betna-Hestnes road project is calculated to be 85.2 tons of SO2 equivalent. Breaking it down further in each road parcel, the Betna-Klettelva road parcel contributes approximately 36.8 tons of SO2 equivalent to terrestrial acidification, while the Klettelva-Otneselva road parcel contributes 23.4 tons of SO2 equivalent, and the Otneselva-Hestnes road parcel contributes 25 tons of SO2 equivalent.
In order to gain deeper insights into the environmental impact, specifically regarding terrestrial acidification, it is necessary to look deeper into Level 2 analysis to identify the primary materials and activities that contribute to high terrestrial acidification.
By examining the following tables (Table 7, Table 8, Table 11, Table 12, Table 15, and Table 16), it becomes evident that the acidification of terrestrials is primarily influenced by material consumption activities. The binder course Agb (which is the surface of the road and inc. bitumen) is the main

contributor, accounting for an average of 45 percent of the overall terrestrial acidification(in each road parcel). This contribution is further broken down as follows: P1 Agb contributes 42% to T-acidification, P2 Agb contributes 49%, and P3 Agb contributes 32% to terrestrial acidification. Considering the technical sheet and EPD number EPD-4276-3510-NO, it is observed that the Agb is derived entirely from recycled materials. This finding raises importance regarding the accuracy of the Agb inputs in SimaPro, which need to be addressed and rectified for improved precision (see 12.14 SimaPro's processes).
As mentioned in 3.6.3 Terrestrial acidification, promoting the adoption of fossil-free construction sites holds great potential for mitigating CO2 and NOx emissions.

The total terrestrial ecotoxicity resulting from constructing the E39 Betna-Hestnes road project is calculated to be 65654,3 ton1,4 dichlorobenzene. Breaking it down further for each road parcel, the Betna-Klettelva road parcel contributes approximately 28347,3 ton 1,4 dichlorobenzene to terrestrial ecotoxicity, while the Klettelva-Otneselva road parcel contributes 14182,5 ton 1,4 dichlorobenzene, and the Otneselva-Hestnes road parcel contributes 23124,5 ton1,4 dichlorobenzene.
In order to gain deeper insights into the environmental impact, specifically regarding terrestrial ecotoxicity, it is necessary to look deeper into Level 2 analysis to identify the primary materials and activities that contribute to high terrestrial ecotoxicity.
By examining the following tables (Table 7, Table 8, Table 11, Table 12, Table 15, and Table 16), it becomes evident that the ecotoxicity of terrestrials is primarily influenced by material consumption activities. Notably, the following material is the main and bigger contributor to terrestrial ecotoxicity:

- Reinforcement steel B500NC
- Concrete B45, SV40
- Binder course Agb
- Steel railings (road and bridge)
- Prefabricated beams NTB1200

Based on these findings related to terrestrial ecotoxicity, it is evident that the use of reinforcement steel and concrete continues to bring negative impacts on the terrain and terrestrial ecotoxicity. Terrestrial ecotoxicity impacts are generated during the conversion processes of materials that change their shape or form, such as the production of reinforcement steel, concrete (made of cement, water, aggregate, fly ash, etc.), and asphalt.

The primary aim of seeking terrestrial acidification and ecotoxicity within the context of road construction is to reach insights into how such (road construction) activities can impact the terrestrial environment.
The aim is to identify the key materials and activities that have negative impacts on the terrain along the E39 Betna-Hestnes road. By examining the relationship between road construction and terrestrial acidification and ecotoxicity, we seek to understand the specific factors that contribute to environmental degradation and inform potential mitigation strategies, like the use of timber instead of concrete.

8.1.4 Energy and fuel consumption

While the fuel consumption of small cars is relatively low, it is essential to consider that this is just one aspect of the overall fuel and energy consumption's picture.
It is worth noting that the amount of fuel consumed by construction machinery and for the transportation of masses is remarkably high and huge.
When referring to the data provided in Appendix 12.1, it becomes clear that an enormous quantity of diesel fuel is consumed during the construction process. To be precise, the total amount of diesel fuel consumed reaches **1.2 million liters**, (950,000 liters are being consumed for machinery use and

254,000 liters consumed for mass transport purposes). Additionally, 550,000 kilowatts of electricity are also consumed.
These numbers highlight the enormous fuel and energy demands associated with construction activities, underscoring the need for more sustainable and energy-efficient approaches in order to mitigate environmental impacts and promote resource conservation.
As previously mentioned (in the knowledge background chapter), the Norwegian Public Roads Administration (NPRA) places stringent environmental requirements in tender documents for road construction projects. The NPRA also collaborates with various stakeholders on pilot projects aims at achieving fossil-free construction sites [28], which contribute to achieve more environmentally friendly road projects. The E39 Betna-Hestnes Road Project did not require a fossil-free construction site. Consequently, it is crucial to emphasize the importance of enforcing this option in future road projects to further promote sustainable practices.
According to a report written by DNV-GL titled (In Norwegian: Veileder for tilrettelegging av fossilfrie og utslippsfrie løsninger på byggeplassen 2018), the report highlighted that significant reductions in CO2 emissions, up to 99%, and NOx emissions, up to 96%, can be achieved by implementing alternative energy sources and adopting better and more environmental friendly strategies such as fully electric construction equipment and machinery (SINTEF).

The inventory chapter (7.1.3) provides an allocation (model) of the diesel fuel consumed in machinery and transport activities to specific categories and sub-categories, such as vegetation removal in earthwork activity got approx. 25751-liter diesel (see Table 3, Table 4, Table 5, and Table 6). The allocation model used in this thesis to distribute the high amount of diesel fuel and electricity consumption appears to be relatively equitable, as the fuel consumption is distributed among the relevant activities based on percentages of its own quantities.

From the mentioned findings above, it is clear that the use of environmentally friendly materials, such as timber, in bridge structures instead of concrete, serves as a viable solution and option to reduce and mitigate emissions in E39 Betna-Hestnes Road Project. Furthermore, the implementation of fossil-free construction sites will significantly reduce the environmental impacts. During writing this master's thesis, there are currently E8 Sørbotn-Laukslett pilot (road) project focuses on the implementation of fossil-free zero-emission machines.
Additionally, and due to the lack of time, has not been seeking options and possibilities to reduce the environmental impacts caused by using asphalt.

8.1.5 The Cumulative Energy Demand

The cumulative energy demand of constructing the E39 Betna-Hestnes road project, sourced from non-renewable energy sources including fossil fuels, nuclear energy, and biomass, is calculated to be approximately 545,61 Terajoule [TJ] (equivalent to 545612418 megajoules). The energy demand from renewable sources is calculated to be approx. 13.1 terajoules (equivalent to 13116898 megajoules).

According to the LCA-CED analysis conducted on each road parcel of the E39 Betna-Hestnes Road project, the consumption and production of materials is the major contributor to the energy demand from non-renewable sources, accounting for an average of 98 percent in total. The reason behind this is the production processes of materials that contain asphalt and cement, which require a significant amount of energy.
It is important to mention that Norway does not generate energy from nuclear power [54]. Therefore by discussing the CED-results saying some materials demand energy from non-renewable nuclear sources is inaccurate.

When comparing the energy demand of road parcels (P1, P2, and P3 Figure 53), it becomes apparent that the method of comparison (in this case at least) to reach results, is somewhat inaccurate to identifying the energy-demanding materials during the production stage. Because of

1- The variations in road parcel lengths and amount of structures (bridges) in each road parcel.
2- Norway's energy sources mainly comes from renewable sources (88% hydroelectric power, 9% wind power, and 3% others) [55].

8.2 Discussion on Functional Unit

The chosen functional unit in this thesis focuses on assessing the environmental impacts during the construction and production phases of <u>each specific road parcel</u>, namely P1 Betna-Klettelva, P2 Klettelva-Otneseleva, and P3 Otneselva-Hestnes.
This choice makes it challenging to compare the results among themselves or even with similar road/highway projects.
As mentioned, each road parcel varies in terms of length, number of bridges, quantities of excavated masses, filled masses, removed masses, and materials, etc.
By assessing the environmental impacts with a functional unit 'meter or kilo meter' of E39 Betna-Hestnes road project, may be more suitable as it would facilitate future comparisons with similar road projects.
The choice of a suitable and standard functional unit for assessing the environmental impacts of a road project lacks a clear consensus. The research paper 3.8.4 Life cycle assessment (LCA) to evaluate the environmental impacts of urban roads: a literature review by Rolf Andre Bohne and others (2020). highlights that more than 50 % of the road projects examined used functional units based on their length (meter or kilometer) and width (2-lane road or 4-lane road).
Consequently, it is crucial in the future to assess the environmental impacts by using the 'one meter or kilometer of constructing E39 Betna-Hestnes road project' functional unit.
This approach would align with existing practices and facilitate comparisons with similar projects in terms of their sustainability performance. As mentioned previously, each road project is unique.

8.3 Weaknesses of this LCA analysis

Data collecting poses the biggest challenge and consumes the most time in conducting an LCA analysis, particularly when examining and assessing the environmental impacts on ongoing construction road projects. It is especially difficult to gather accurate, correct, and detailed input data.
The weaknesses of this LCA analysis can be summarized as follows. Firstly, the results of this LCA cannot be compared with similar LCA-road projects, mainly due to the chosen functional unit. As a result, the outcomes of this analysis are not directly comparable to those of other road projects in Norway or internationally.
Secondly, due to the lack of time, certain Material processes in SimaPro could have been built more accurately. For example, it is assumed that the amount of reinforcement rebar in Prefabricated beams is stated to be 0.3 tons, if more time were available, it would be possible to obtain more precise data regarding the amount of reinforcement rebar in Prefabricated beams, rather than assuming that it is 0.3 ton.
Additionally, the type of asphalt purchased from Velde AS was not specified from B&G (see 12.5), resulting to assume that is normal bitumen without any additional inputs in SimaPro.

It is worth noting that obtaining the data from the contractor was a time-consuming process, the quantities and data were received only four days before the Easter holiday. This delay led to low-quality results and getting more challenges. The quantities Excel sheet is attached.

9. Conclusion

The research question in this thesis is:

What are the environmental impacts of constructing the E39 Betna-Hestnes road project?

- The construction of the E39 Betna-Hestnes Road project emits 19,900 tons of CO2 equivalent (greenhouse gas emissions) to the atmosphere.
- There are in total 118,500 m3 of water is consumed, most of the consumed water in the production of materials such as steel rebar, concrete, and asphalt.
- The construction and production activities of the E39 Betna-Hestnes road project contribute to terrestrial acidification, resulting an approx. 85.2 tons of SO2 equivalent emissions. The Binder course Agb 11 is the main contributor with approximately 42 % of total terrestrial acidification.
- The construction and production activities of the E39 Betna-Hestnes road project contribute to terrestrial ecotoxicity, resulting in approx. 65654.3 tons of 1,4 dichlorobenzene equivalent emissions. The Steel rebar, Prefabricated beams, concrete B45-SV40, and Binder course Agb11 is the main contributor to terrestrial ecotoxicity.
- 1.2 million liters of fuel consumed on construction machinery and mass transport is exceptionally high, which indicates a significant dependence on non-renewable energy sources.
- Road parcel P1 Betna-Klettelva stands out as the biggest emission's contributor in terms of greenhouse gas emissions, water consumption, and terrestrial acidification & ecotoxicity. This is primarily due to its length and number of bridges compared to other road parcels.

Overall, these findings highlight the areas of concern in terms of environmental impacts, emphasizing the importance of implementing more sustainable activities and practices in future road projects.

10. Recommendations

1- Recommendations to the client (UiA)

   a. It is recommended to review the inputs in SimaPro to achieve more precise and accurate results. additionally, it is recommended to use the VegLCA software developed by NPRA, as it is specifically built to assess the environmental impacts of road projects in Norway.

   b. In addition, it is recommended to thoroughly evaluate the overall environmental emissions and impacts caused by constructing the E39 Betna-Hestnes road project, not just four of them as it is used in this thesis (GWP, water use, and terrestrial acidification & ecotoxicity).

2- Further work

   a. The Norwegian environment has always been a famous topic in debates on both news and social media platforms. Considering this, it is recommended to research terrestrial acidification and ecotoxicity within road construction projects.

   b. It is recommended to conduct an LCA from cradle to grave of the eight bridges used in the E39 Betna-Hestnes road project. This assessment should explore the feasibility and cost-effectiveness of employing timber as a substitute for concrete, concerning environmental impacts and considerations.

11. References

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12. Appendixes

12.1 Energy consumption in external environment report (Ytremiljø rapport)

4.4 Klimagass og energibruk

Klimagassbudsjettet viser til klimagassregnskapet for anlegget. Tabell 2 viser diesel- og energiforbruk for 2022. Diesel til oppvarming konstruksjoner inngår i "dieselforbruk anleggsmaskiner".

Tabell 2 Diesel- og energiforbruk for 2022.

Energikilde og enhet	Forbruk
Dieselforbruk anleggsmaskiner (liter)	950 424,5
Dieselforbruk massetransport (liter)	254 882,5
Elektrisitetsforbruk (kWh)	556 421,773
Personbil diesel (liter)	48 653
Personbil bensin (liter)	178
Personbil el (kWh)	1065

12.2 Earthwork quantities excel sheet from Sweco.

E39 Betna - Hestnes

Prosess	Beskrivelse	Enhet	Delmengde	Mengde	Enh. Pris	Sum	Kommentar
HP2	**Sprengning og masseflytting**						
21.2/21.31	**Vegetasjonsrydding og fjerning av vegetasjonsdekke**	m3		**175 463**			T=30 cm
	Del 1	m3	69 814				
	Del 2	m3	59 823				
	Del 3	m3	45 826				
21.32	**Avtaking av matjord**	m3		**4 523**			T=30 cm
	Del 1	m3	1 600				
	Del 2	m3	-				
	Del 3	m3	2 923				
22.1	**Sprengning i linja (inklusive dypsprengning)**	m3		**1 009 025**			Fratrukket dypsprengning er det 880.413 pfm3 disponibel
	Del 1 Betna - Klettelva	m3	379 605				
	Del2 Klettelva - Otneselva	m3	445 554				
	Del 3 Otneselva - Hestnes	m3	183 866				
25	**Masseflytting av jord**		476 845				
25.2	Jordmasser til bakkeplanering	m3		**46 845**			
25.4	Skytebane: Jordmasser til voll, uttrauing Klettelva	m3		**89 000**			
25.4	Skytebane: Jordmasser til voll, overskudd langs linja	m3		**181 000**			
25.7	Myr og andre ubrukbare masser (Betna + langs linja)	m3		**160 000**			Lagres mellom Motorcrossbanen og E39
26	**Masseflytting av sprengstein**		880 824				
26.1	Sprengt stein fra skjæring til fylling i linja	m3		**531 481**			
26.1	Masseutskiftning Betna og myrer langs linja	m3		**114 285**			
26.1	Masseutskiftning Klettelva	m3		**64 058**			
26.3	Sprengt stein til lager for senere bearbeiding	m3		**122 000**			Masser til overbygning, omfylling grøft mm
26.4	Skytebanen: Sprengt stein til voll	m3		**49 000**			

12.3 Materials quantities excel sheet from Sweco.

HP 5	**Vegfundament**				
52.3	**Frostsikringslag**				
	E39: Kult 0-180, T=930 cm	m3		**71 666**	
	Del 1	m3	23 413		
	Del 2	m3	24 773		
	Del 3	m3	23 480		
53	**Forsterkningslag**				
53.2	E39: 16/90 T=30/40cm	m3		**75 018**	
	Del 1	m3	35 029		
	Del 2	m3	20 469		
	Del 3	m3	19 520		
53.3	**Forkiling av forsterkningslag med AK (E39)**	m2		**132 743**	
	Del 1	m2	55 775		
	Del 2	m2	42 127		
	Del 3	m2	34 841		
54	**Bærelag**				
54.2	Fk 0/45	m3		**5 676**	
	Del 1	m3	3 923		
	Del 2	m3	935		
	Del 3	m3	818		
55.1	**Ag 16, T=10 cm (E39 + sideveger)**	m2		**128 780**	
	Del 1	m2	54 560		
	Del 2	m2	38 500		
	Del 3	m2	35 720		

HP 6	**Vegdekke**			
61.1	Grusdekke, Fk 0/16, T = 10 cm	m3		**1 840**
	Skogsbilveger, del 1	m3	1 072	
	Skogsbilveger, del 2	m3	554	
	Skogsbilveger, del 3	m3	214	
63.1	Riving av asfaltdekke, Betna	m2		**3 850**
63.1	Riving av asfaltdekke, Hestnes	m2		**4 550**
65.1	**Bindlag**			
65.11	Agb 11 70/100, T=3 cm	m2		**135 315**
	Del 1	m2	62 165	
	Del 2	m2	38 330	
	Del 3	m2	34 820	
65.2	**Slitelag**			
65.21	Ab 16 70/100, T=4 cm (E39)	m2		**120 876**
	Del 1	m2	51 507	
	Del 2	m2	38 069	
	Del 3	m2	31 300	
65.21	**Agb 16 70/100, T=4 cm (sideveger)**	m2		**4 592**
	Del 1	m2	1 072	
	Del 2	m2	-	
	Del 3	m2	3 520	
67.1	Belegning på skulder	m2		4 875
HP7	**Vegutstyr og miljøtiltak**			
75.232	Rekkverk av stål på stålstolper, side	m		6 500

12.4 Quantities related to bridge constructions.

Quantites bridges							
		part of the road section	process code	description	Unit	quantity	comment
K10 bridge Gurålivegbrua, L=36 m . W=8m . A=288 m2	axis 1	1-Betna-Klettelva	84.2	formwork	m2	90	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	12	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	70	
	exis 2	1-Betna-Klettelva	84.2	formwork	m2	90	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	12	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	70	
	road Superstructure	1-Betna-Klettelva		Prefabricated beams type NTB 1200 (7 pcs), KTB 1200 (2 pcs); L= 36m	LM	324	
		1-Betna-Klettelva	84.31	Reinforcement B500NC (cast on)	t	32	
		1-Betna-Klettelva	84.4	Concrete B500NC, SV-40 (cast on)	m3	160	
		1-Betna-Klettelva	87.1	Waterproof membran	m2	288	
	equipment	1-Betna-Klettelva	87.2	bridge railing	m	76	
		1-Betna-Klettelva	87.3	Bridge bearing type pot bearing (assumed 1 fixed + 3 movable; Max V = approx. 4000kN).	item	4	
		1-Betna-Klettelva	87.4	welding fleas	m	0	
K30 bridge våglandselvbrua, L=52m . W=10.70 m . A=556,40 m2	axis 1	1-Betna-Klettelva	84.2	formwork	m2	100	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	12	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	70	
	axix 3	1-Betna-Klettelva	84.2	formwork	m2	90	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	10	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	60	
	column axis 2	1-Betna-Klettelva	84.2	formwork	m2	140	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	14	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	70	
	road Superstructure	1-Betna-Klettelva	84.2	formwork	m2	800	
		1-Betna-Klettelva	84.31	Reinforcement B500NC	t	170	
		1-Betna-Klettelva	84.36	Tension reinforcement (assumed 12 cables a27tau As=4050mm2)	mMn	3 700	
		1-Betna-Klettelva	87.1	Moisture insulation	m2	556	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	820	
	equipment	1-Betna-Klettelva	87.2	bridge railing	m	108	
		1-Betna-Klettelva	87.3	Bridge bearing type pot bearing (assumed 1 fixed + 3 movable; Max V = approx. 6000kN).	item	4	
		1-Betna-Klettelva	87.4	welding fleas	m	0	

K40 bridge Glåmsvegbrua, L=36m . W=5 m . A=180 m2	axis 1	1-Betna-Klettelva	84.2	formwork	m2	30	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	5	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	30	
	axis 2	1-Betna-Klettelva	84.2	formwork	m2	40	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	5	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	30	
	road Superstructure	1-Betna-Klettelva		Prefabricated beams type NTB 1200 (4 pcs), KTB 1200 (2 pcs); L= 36m	Lm	216	
		1-Betna-Klettelva	84.31	Reinforcement B500NC (cast on)	t	22	
		1-Betna-Klettelva	84.4	Concrete B500NC, SV-40 (cast on)	m3	110	
		1-Betna-Klettelva	87.1	Waterproof membran	m2	180	
	equipment	1-Betna-Klettelva	87.2	bridge railing	m	76	
		1-Betna-Klettelva	87.3	Bridge bearing type pot bearing (assumed 1 fixed + 3 movable; Max V = approx. 4000kN).	item	4	
		1-Betna-Klettelva	87.4	welding fleas	m	0	
K50 bridge Klettelvbrua, L=65m . W=9 m . A=585 m2	axis 1	1-Betna-Klettelva	83.5	bridge peel	m	450	
		1-Betna-Klettelva	84.2	formwork	m2	100	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	15	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	90	
	axix 4	1-Betna-Klettelva	83.5	bridge peel	m	420	
		1-Betna-Klettelva	84.2	formwork	m2	100	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	15	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	90	
	column axis 2 and 3	1-Betna-Klettelva	83.5	bridge peel	m	550	
		1-Betna-Klettelva	84.2	formwork	m2	260	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	40	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	190	
	road Superstructure	1-Betna-Klettelva	84.2	formwork	m2	830	
		1-Betna-Klettelva	84.31	Reinforcement B500NC (cast on)	t	160	
		1-Betna-Klettelva	84.36	Tension reinforcement (assumed 12 cables a27tau As=4050mm2)	mMn	3 500	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	750	
		1-Betna-Klettelva	87.1	Waterproof membran	m2	585	
	equipment	1-Betna-Klettelva	87.2	bridge railing	m	134	
		1-Betna-Klettelva	87.3	Bridge bearing type pot bearing (assumed 1 fixed + 3 movable; Max V = approx. 6500kN).	item	4	
		1-Betna-Klettelva	87.4	welding fleas	m	0	
K720 bridge Hannaelvbrua, L=86m . W=9 m . A=774 m2	axis 1	2-Klettelva-Otneselva	84.2	formwork	m2	120	
		2-Klettelva-Otneselva	84.3	reinforcement B500NC	t	15	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	82	
	axis 4	2-Klettelva-Otneselva	84.2	formwork	m2	120	
		2-Klettelva-Otneselva	84.3	reinforcement B500NC	t	15	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	90	
	column axis 2 and 3	2-Klettelva-Otneselva	83.5	bridge peel	m		
		2-Klettelva-Otneselva	84.2	formwork	m2	250	
		2-Klettelva-Otneselva	84.3	reinforcement B500NC	t	22	
		2-Klettelva-Otneselva	84.4	Concrete B45, SV-40	m3	110	
	road Superstructure	2-Klettelva-Otneselva	84.2	formwork	m2	1 070	
		2-Klettelva-Otneselva	84.31	Reinforcement B500NC (cast on)	t	220	
		2-Klettelva-Otneselva	84.36	Tension reinforcement (assumed 12 cables a27tau As=4050mm2)	mMn	650	
		2-Klettelva-Otneselva	84.4	Concrete B45, SV-40	m3	1 090	
		2-Klettelva-Otneselva	87.1	Waterproof membran	m2	774	
	equipment	2-Klettelva-Otneselva	87.2	bridge railing	m	176	
		2-Klettelva-Otneselva	87.3	movable bridge bearing	item	4	
		2-Klettelva-Otneselva	87.4	welding fleas	m	0	
K001 bridge Otnesbrua, L=117m . W=9 m . A=1053 m2	axis 1	3-Otneselva-Hestnes	83.5	Piles Steel core piles ø150, casing ø273/6.3	m	370	
		3-Otneselva-Hestnes	84.2	formwork	m2	440	
		3-Otneselva-Hestnes	84.3	reinforcement B500NC	t	34	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	210	
	axis 4	3-Otneselva-Hestnes	83.5	Piles Steel core piles ø150, casing ø273/6.3	m	370	
		3-Otneselva-Hestnes	84.2	formwork	m2	90	
		3-Otneselva-Hestnes	84.3	reinforcement B500NC	t	15	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	90	
	column axis 2 and 3	3-Otneselva-Hestnes	83.5	Piles Steel core piles ø150, casing ø273/6.3	m	420	
		3-Otneselva-Hestnes	84.2	formwork	m2	600	
		3-Otneselva-Hestnes	84.3	reinforcement B500NC	t	57	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	270	
	road Superstructure	3-Otneselva-Hestnes	84.2	formwork	m2	3 250	
		3-Otneselva-Hestnes	84.31	Reinforcement B500NC (cast on)	t	280	
		3-Otneselva-Hestnes	84.36	Tension reinforcement (assumed 12 cables a27tau As=4050mm2)	mMn	5 100	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	1 110	
		3-Otneselva-Hestnes	87.1	Waterproof membran	m2	1 053	
	equipment	3-Otneselva-Hestnes	87.2	bridge railing	m	238	
		3-Otneselva-Hestnes	87.3	Bridge bearing type pot bearing (assumed 1 fixed + 3 movable; Max V = approx. 11000kN).	item	8	
		3-Otneselva-Hestnes	87.4	welding fleas	m	10	

K002 bridge Skogvegbrua, L=35m . W=5 m . A=175 m2	axis 1	3-Otneselva-Hestnes	84.2	formwork	m2	30	
		3-Otneselva-Hestnes	84.3	reinforcement B500NC	t	5	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	30	
	axis 2	3-Otneselva-Hestnes	84.2	formwork	m2	30	
		3-Otneselva-Hestnes	84.3	reinforcement B500NC	t	5	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	30	
	road Superstructure	3-Otneselva-Hestnes		Prefabricated beams type NTB 1200 (4 pcs), KTB 1200 (2 pcs); L= 36m	Lm	210	
		3-Otneselva-Hestnes	84.31	Reinforcement B500NC (cast on)	t	18	
		3-Otneselva-Hestnes	84.4	Concrete B500NC, SV-40 (cast on)	m3	90	
		3-Otneselva-Hestnes	87.1	Waterproof membran	m2	175	
	equipment	3-Otneselva-Hestnes	87.2	bridge railing	m	74	
		3-Otneselva-Hestnes	87.3	Bridge bearing type pot bearing (assumed 1 fixed + 3 movable; Max V = approx. 4000kN).	item	4	
		3-Otneselva-Hestnes	87.4	welding fleas	m	0	
K004 bridge Hestnesbrua, L=72m . W=11.10 m . A=799 m2	column axis 2 and 3	3-Otneselva-Hestnes	83.5	Piles	m	0	
		3-Otneselva-Hestnes	84.2	formwork	m2	480	
		3-Otneselva-Hestnes	84.3	reinforcement B500NC	t	52	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	250	
	road Superstructure	3-Otneselva-Hestnes	84.2	formwork	m2	1 030	
		3-Otneselva-Hestnes	84.31	Reinforcement B500NC (cast on)	t	220	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	990	
		3-Otneselva-Hestnes	87.1	Waterproof membran	m2	800	
	equipment	3-Otneselva-Hestnes	87.2	bridge railing	m	148	
		3-Otneselva-Hestnes	87.3	Bridge bearing type pot bearing (assumed 1 fixed + 3 movable; Max V = approx. 4000kN).	item	4	
		3-Otneselva-Hestnes	87.4	welding fleas	m	0	
K005 bridge over Fv.354, L=20.80m . W=9 m . A=187.20 m2	1	3-Otneselva-Hestnes	84.2	formwork	m2	180	
		3-Otneselva-Hestnes	84.3	reinforcement B500NC	t	21	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	130	
	2	3-Otneselva-Hestnes	84.2	formwork	m2	190	
		3-Otneselva-Hestnes	84.3	reinforcement B500NC	t	23	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	140	
	road Superstructure	3-Otneselva-Hestnes	84.2	formwork	m2	270	
		3-Otneselva-Hestnes	84.31	Reinforcement B500NC (cast on)	t	50	
		3-Otneselva-Hestnes	84.36	Tension reinforcement	mMn	600	
		3-Otneselva-Hestnes	84.4	Concrete B45, SV-40	m3	210	
		3-Otneselva-Hestnes	87.1	Waterproof membran	m2	187	
	equipment	3-Otneselva-Hestnes	87.2	bridge railing	m	46	
		3-Otneselva-Hestnes	87.3	Bridge bearing type pot bearing (assumed 1 fixed + 3 movable; Max V = approx. 4000kN).	item	0	
		3-Otneselva-Hestnes	87.4	welding fleas	m	0	

K20 Tractor culvert, L=15m. W=4m. H=5m2	Culvert (elements)	1-Betna-Klettelva	84.3	reinforcement B500NC	t	34	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	210	
	Wings w.fund.	1-Betna-Klettelva	84.2	formwork	m2	220	
		1-Betna-Klettelva	84.3	reinforcement B500NC	t	30	
		1-Betna-Klettelva	84.4	Concrete B45, SV-40	m3	110	
	equipment	1-Betna-Klettelva	87.2	bridge railing	m	10	
K710 Tractor culvert, L=28m. W=4m. H=5m2	Culvert (elements)	2-Klettelva-Otneselva	84.3	reinforcement B500NC	t	50	
		2-Klettelva-Otneselva	84.4	Concrete B45, SV-40	m3	310	
	Wings w.fund.	2-Klettelva-Otneselva	84.2	formwork	m2	220	
		2-Klettelva-Otneselva	84.3	reinforcement B500NC	t	30	
		2-Klettelva-Otneselva	84.4	Concrete B45, SV-40	m3	140	
	equipment	2-Klettelva-Otneselva	87.2	bridge railing	m	0	

12.5 An email with a reply from contractor B&G.

Fra: Muhammad Fadel Murad Kuj <mfkuj17@student.uia.no>
Sendt: Monday, April 24, 2023 10:32:50 AM
Til: Knut Yngve Fidjestøl <knut.yngve.fidjestol@bg.no>
Kopi: Reyn Joseph O'Born <reyn.oborn@uia.no>
Emne: Haster!! anskaffelse av material E39 Betna-Hestnes prosjektet

Hei Knut Yngve, takk for hyggelig samtale

Jeg ønsker å få vite mer om hvor følgende materialer ble skaffet til prosjektet

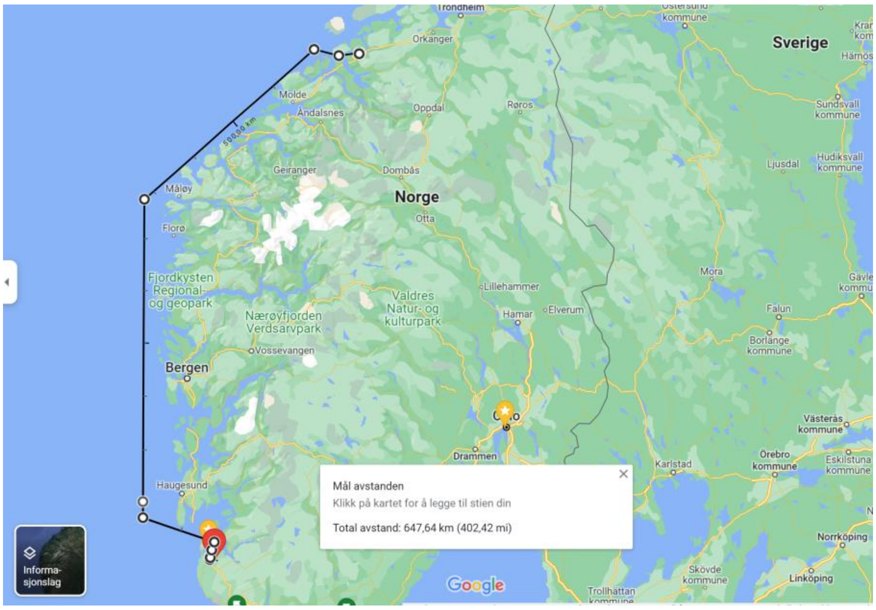
- frostsikringslag 71666 m3
  Denne mengden utgår da steinlaget i jordskjæringer er økt litt for å kompensere for å bruke frostsikringslag. Da ivaretas frostsikringskravet med sprengsteinsfylling
- forsterkningslag 75018 m3
  Produseres ut fra sprengsteinmasser sprengt lokalt på anlegget. Dette utføres med elektrisk steinknuser og elektrisk gravemaskin.
- Bærelag av knuste steinmaterialer, Fk 5676 m3
  Knuses i et nytt trinn som kalles finknusing og det blir brukt masser tilsvarende forsterkningslag som mates inn i denne finknuseren og produserer FK. Dette skjer også elektrisk lokalt på anlegget.
- Bærelag av asfaltert grus, Ag 1840 m3
  Dette blir innkjøpt fra Velde asfalt og fraktes til anlegget med båtfrakt
- Oppgrusing Bindlag (legging av grusdekke) 135315 m2
  Dette produseres også lokalt på prosjektet med finknuser. Samme produksjonslinje som FK bare at det knuses litt finere ned.
- Slitelag 120876 m2
  Kjøpes fra Velde asfalt og fraktes til anlegget med båt
- rekkverk av stål 6500 m
  Kjøpes fra Sirdal vegrekkverk

kunne dere lage innkjøp liste av det nevnte materialer? samt beskrive hvor mye material som ble resirkulert og gjenbrukt fra sprengte masser? Er egentlig bare asfalt som kjøpes av Velde (Bærelag av asfaltert grus og slitelag) og rekkverk som kjøpes inn. Alt annet her produseres av gjenbrukte sprengte masser.

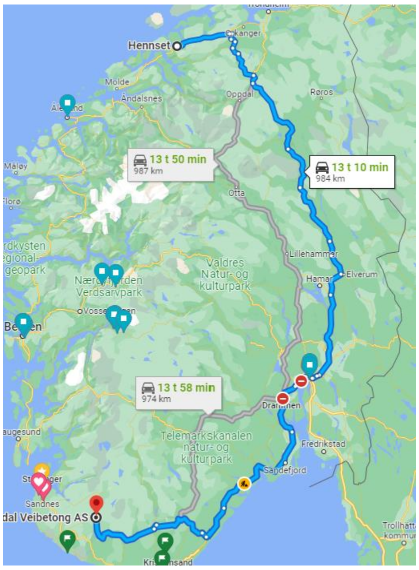
Bare ta kontakt dersom dere trenger noe mer utfyllende informasjon.

...

12.6 Sea transport distance from Velde AS in Sandnes to the construction site (asphalt and B45SV40 concrete)



12.7 The distance between Sirdal and the construction site (steel railings)



12.8 The transport distance from Geo fundamentering & bergboring AS in Trondheim to the construction site (steel bridge piles).

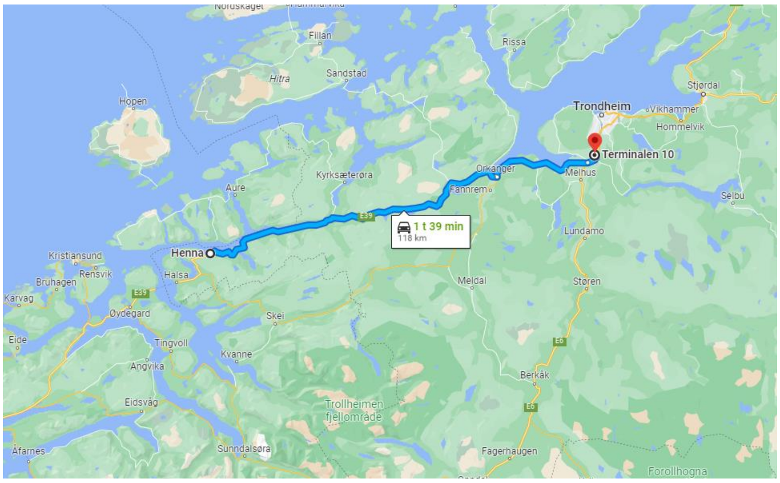
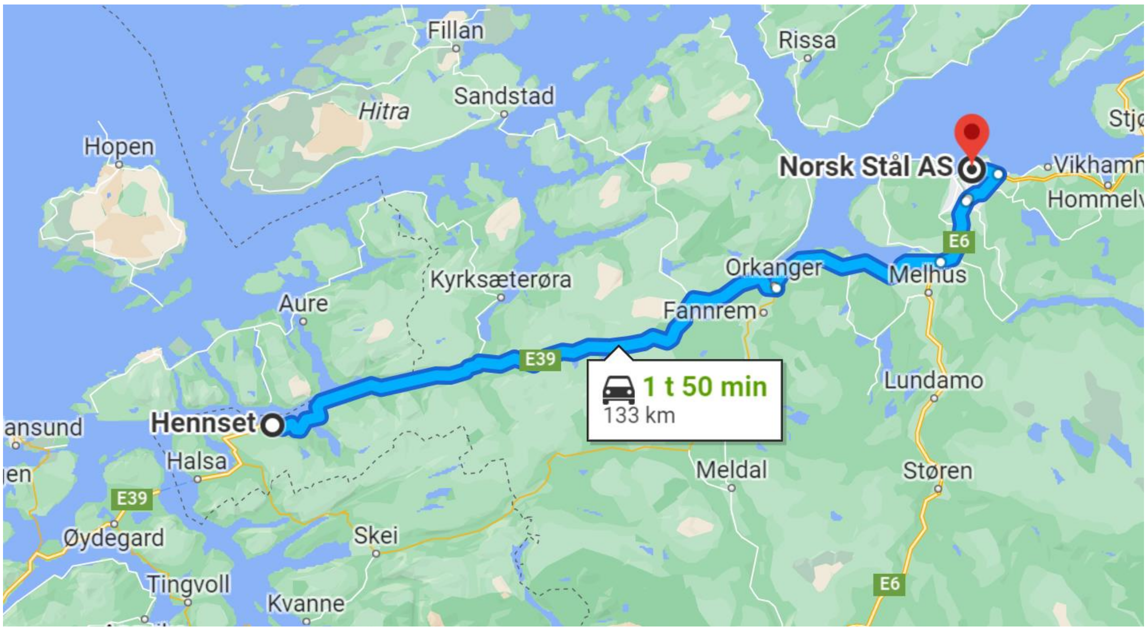


Table showing different steel piles dimensions (D=150 is used in E39 Betna Hestnes see also Figure 28)

Stål-kjerne Ø [mm]	Trykkpelehode bxb [mm]	Trykkpelehode t [mm]	Min. trykkap. N_i [kN]	Borutrustning (alle mål i mm) System	For.rør-dimensjon [mm]	Min. utsparing i magerb.	Over-dekning [mm]	Vekt av pel pr m [kg]	Gyse-masse [liter/m]
Ø70	180	32	1 072	Odex 90	114,3 x 4,0	133	18,2	30,2	5,0
Ø90	200	35	1 718	Odex 115	139,7 x 4,0	162	20,9	49,9	7,3
Ø100	250	45	2 121	Odex 115	139,7 x 4,0	162	15,9	61,7	5,8
Ø110	280	50	2 403	Odex 140	168,3 x 4,5	197	24,7	74,6	10,4
Ø120	310	55	2 860	Odex 140	168,3 x 4,5	197	19,7	88,8	8,6
Ø130	360	60	3 356	Odex 165	193,7 x 5,0	222	26,9	104,0	13,2
Ø150	440	65	4 468	Odex 165	193,7 x 5,0	222	16,9	139,0	8,8
Ø150	440	65	4 468	Odex 190	219,1 x 5,0	247	29,6	139,0	16,7
Ø180	500	80	6 216	Odex 240	273,0 x 6,3	318	40,2	200,0	27,8
Ø190			6 926	Odex 240	273,0 x 6,3	318	35,2	222,6	24,9

12.9 The transport distance from Norsk Stål in Trondheim to the construction site (Reinforcement B500NC rebar).



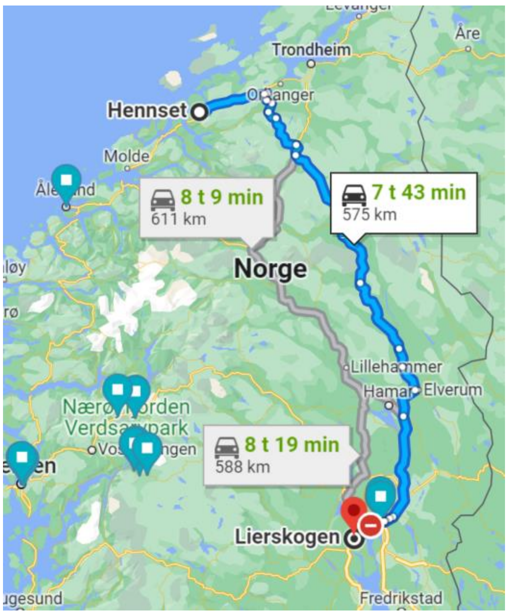
12.10 Product data sheet and distance from Binab (Topeka 4S waterproof membrane)

Tabell 1

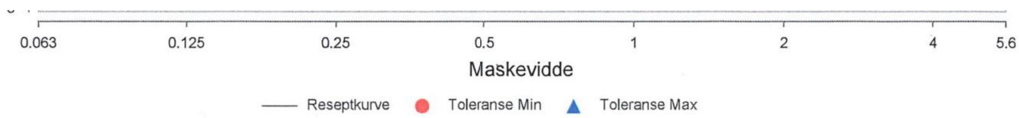
Produktegenskaper for nytt materiale

Egenskap	Prøvingsmetode	Verdier	Enhet
Tykkelse	Intern	5,0	mm
Flatevekt	Intern	6,5	kg/m^2
Bredde	Intern	1	m
Rullengde	Intern	8	m
Vekt av stamme	NS-EN 1849-1	230	g/m^2

The distance from Binab in Drammen to the construction site below.



Material inputs in Topeka 4S



Tilslag	Forekomst	Dens.	FI	LA	Mølle	Sort	Andel
Grus	Lyngås	2.67		20	14.0	0/4	41.0
Steinmel	Lierskogen	2.85		15	7.0	0/4	38.0
Filler	Bitufill	2.74				Filler	21.0

12.11 An e-mail and distance from LAFU (Bridge bearing).

LA Lars Aksnes <lars@lafu.no>
To: Muhammad Fadel Murad Kuj
Tue 5/2/2023 8:33 PM

Hei Muhammed

Har kun levert brulager til Hestnessletta så langt, så det er kun denne jeg kan gi noe input på. Men gjennomsnittsvekten på lagrene der var 120kg, men her er de ensidige lagrene omtrent dobbelt så tunge som de allsidige.

Har ikke levert noen fuger til prosjektet enda.

Med vennlig hilsen

Lars Aksnes
Lars@lafu.no
Telefon: +47 971 58 420
LAGER & FUGER AS
www.lafu.no

LA Lars Aksnes <lars@lafu.no>
To: Muhammad Fadel Murad Kuj

Hei Muhammad

Glemte å liste det som var levert til Hestnessletta.

2stk Allsidig glidelager GL 3810_100_40

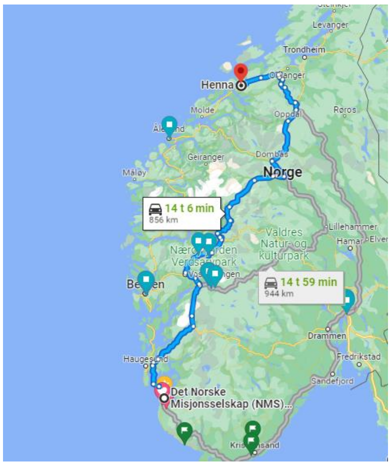
2 stk Ensidig glidelager GG 3720_870_100

Med vennlig hilsen

Lars Aksnes
Lars@lafu.no
Telefon: +47 971 58 420
LAGER & FUGER AS
www.lafu.no

Fikk det, takk. | Ok, takk skal du ha. | Ok, har det.

The distance from LAFU (Lager & Fuger) AS in Stavanger to the construction site



12.12 Prefabricated beams

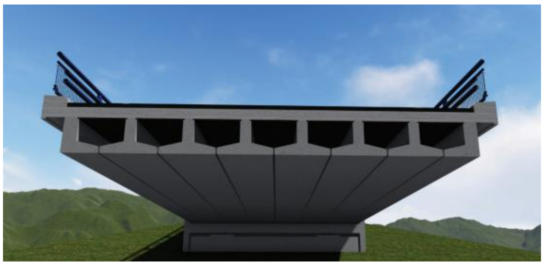
A- The input material is assumed to be B45 SV-40. Source (Prefabrikkerte brubjelker V426) handbook from Norwegian Public Road Administration.

2.4 Materialer

2.4.1 Betong

Generelt gjelder kravene i håndbok R762 Prosesskode 2 \26\. Betongen er forutsatt SV-Standard, bestandighetsklasse MF40 med luftinnhold 4,5 % ±1.5 % for B45 og 3,5 % ±1,5 % for B55.

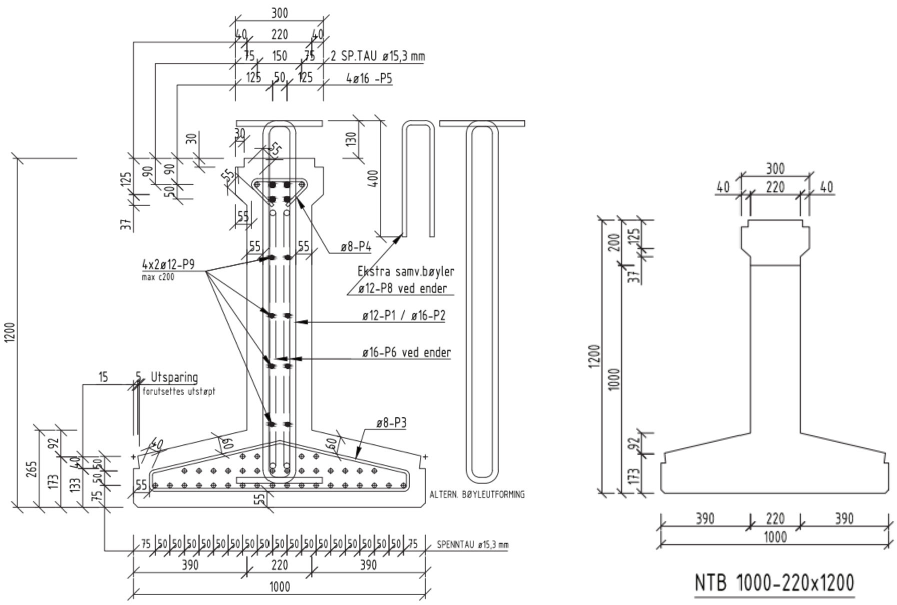
B- Illustration of prefabricated beams type NTB 1200



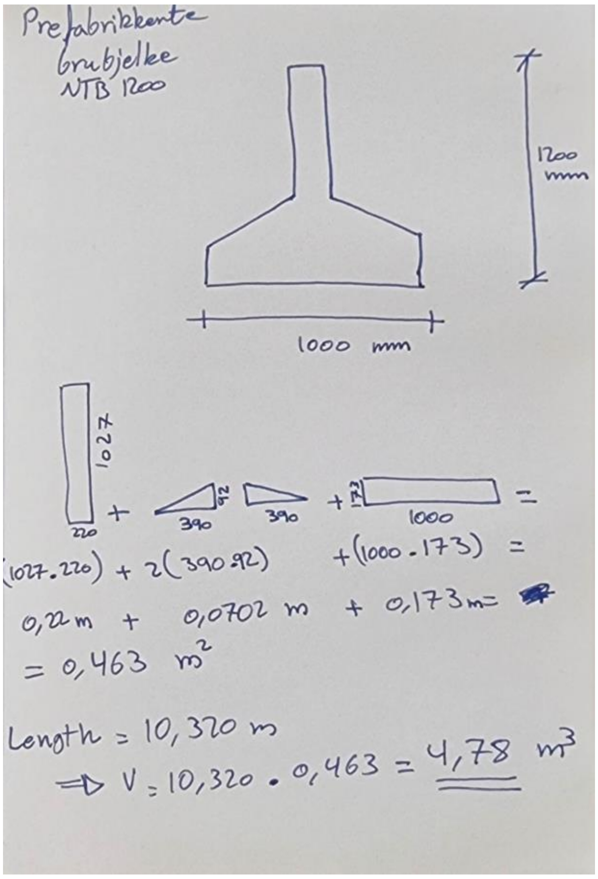
C- Dimension requirements

			Alt. 1		Alt. 2		Alt. 3	
Bjelke	Bjelke-bredde NTB i bunn (mm)	Bjelke-bredde KTB i bunn (mm)	Førings-bredde (mm)	Bru-bredde (mm)	Førings-bredde (mm)	Bru-bredde (mm)	Førings-bredde (mm)	Bru-Bredde (mm)
NTB/KTB 1400	800	570	9140	10220	13240	14320	23080	24160
NTB/KTB 1200	1000	670	9240	10320	13320	14400	23520	24600
NTB/KTB 1000, 800, 600	1200	770	9820	10900	13480	14560	23240	24320

D- Cross section of NTB1200 with reinforcement:



E- Mathematical calculation of the volume



12.13 SimaPro

1- E39 Betna-Klettelva

Inputs from nature | Sub-compartment | Amount | Unit | Distribution | SD2 or 2SD | Min | Max

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2
1Vegetation clearance and removal of vegetation cover	69814	m3	Undefined	
1Grubbing and topsoil removal	1600	m3	Undefined	
1Rock excavation	379605	m3	Undefined	
1Masses used to ground leveling	19675	m3	Undefined	
1Skytebane masses to the meadow	0	m3	Undefined	
1Skytebane masses to fill along the way	76020	m3	Undefined	
1Another masses	67200	m3	Undefined	
1Blasted stone from cutting to filling in the line	223222	m3	Undefined	
1Mass replacement Betna and bogs along the line	114285	m3	Undefined	
1Mass replacement Klettelva	0	m3	Undefined	
1Blasted rock masses to stored for later processing	51240	m3	Undefined	
1Skytebane blasted rock to meadow	50580	m3	Undefined	
2Frost protection layer Kult 0-180, T=930 cm	23413	m3	Undefined	
2Reinforcement layer E39: 16/90 T=30/40cm	35029	m3	Undefined	
2base and subbase layers Fk 0/45	3923	m3	Undefined	
2bearing layer Ag 16, T=10 cm (E39 + side road)	5456	m3	Undefined	
2Gravel cover Fk 0/16, T = 10 cm	1072	m3	Undefined	
2binder course Agb 11 70/100, T=3 cm	1865	m3	Undefined	
2Surface course + wearing course (E39 + side roads),Ab 16 70/100, T=4 cm (E39	2060	m3	Undefined	
2Steel railings road	2730	m	Undefined	
2Steel railings Bridge	407	m	Undefined	
2Bridge piles of steel	920	m	Undefined	
2reinforcement B500NC	573	ton	Undefined	
2Concrete B45, SV-40	2930	m3	Undefined	
2Waterproof membrane	1609	m2	Undefined	
2Bridge bearing varies sizes	16	p	Undefined	
2Prefabricated beams type NTB 1200	540	p	Undefined	
Diesel consumption for small cars	20434	l	Undefined	
Bensin consumption for small cars	74,76	l	Undefined	
Electricity consumption for small cars.	447,3	MJ	Undefined	

Add

Inputs from technosphere: electricity/heat | Amount | Unit | Distribution | SD2 or 2SD | Min | Max

2- E39 Klettelva-Otneselva

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 c
1Vegetation clearance and removal of vegetation cover	59823	m3	Undefined	
1Grubbing and topsoil removal	0	m3	Undefined	
1Rock excavation	445554	m3	Undefined	
1Masses used to ground leveling	14990	m3	Undefined	
1Skytebane masses to the meadow	89000	m3	Undefined	
1Skytebane masses to fill along the way	57920	m3	Undefined	
1Another masses	51200	m3	Undefined	
1Blasted stone from cutting to filling in the line	170074	m3	Undefined	
1Mass replacement Betna and bogs along the line	0	m3	Undefined	
1Mass replacement Klettelva	64058	m3	Undefined	
1Blasted rock masses to stored for later processing	39040	m3	Undefined	
1Skytebane blasted rock to meadow	15680	m3	Undefined	
2Frost protection layer Kult 0-180, T=930 cm	24773	m3	Undefined	
2Reinforcement layer E39: 16/90 T=30/40cm	20469	m3	Undefined	
2base and subbase layers Fk 0/45	935	m3	Undefined	
2bearing layer Ag 16, T=10 cm (E39 + side road)	3850	m3	Undefined	
2Gravel cover Fk 0/16, T = 10 cm	554	m3	Undefined	
2binder course Agb 11 70/100, T=3 cm	1142	m3	Undefined	
2Surface course + wearing course (E39 + side roads),Ab 16 70/100, T=4 cm (E39	1523	m3	Undefined	
2Steel railings road	2080	m	Undefined	
2Steel railings Bridge	176	m	Undefined	
2Bridge piles of steel	0	m	Undefined	
2reinforcement B500NC	352	ton	Undefined	
2Concrete B45, SV-40	1822	m3	Undefined	
2Waterproof membrane	774	m2	Undefined	
2Bridge bearing varies sizes	4	p	Undefined	
2Prefabricated beams type NTB 1200	0	p	Undefined	
Diesel consumption for small cars	15568,96	l	Undefined	
Bensin consumption for small cars	56,96	l	Undefined	
Electricity consumption for small cars.	340,8	kWh	Undefined	

3- E39 Otneselva-Hestnes

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2:
1Vegetation clearance and removal of vegetation cover	45826	m3	Undefined	
1Grubbing and topsoil removal	2923	m3	Undefined	
1Rock excavation	183866	m3	Undefined	
1Masses used to ground leveling	12180	m3	Undefined	
1Skytebane masses to the meadow	0	m3	Undefined	
1Skytebane masses to fill along the way	47060	m3	Undefined	
1Another masses	41600	m3	Undefined	
1Blasted stone from cutting to filling in the line	138185	m3	Undefined	
1Mass replacement Betna and bogs along the line	0	m3	Undefined	
1Mass replacement Klettelva	0	m3	Undefined	
1Blasted rock masses to stored for later processing	31720	m3	Undefined	
1Skytebane blasted rock to meadow	12740	m3	Undefined	
2Frost protection layer Kult 0-180, T=930 cm	23480	m3	Undefined	
2Reinforcement layer E39: 16/90 T=30/40cm	19520	m3	Undefined	
2base and subbase layers Fk 0/45	818	m3	Undefined	
2bearing layer Ag 16, T=10 cm (E39 + side road)	3572	m3	Undefined	
2Gravel cover Fk 0/16, T = 10 cm	214	m3	Undefined	
2binder course Agb 11 70/100, T=3 cm	1045	m3	Undefined	
2Surface course + wearing course (E39 + side roads),Ab 16 70/100, T=4 cm (E39	1250	m3	Undefined	
2Steel railings road	1690	m	Undefined	
2Steel railings Bridge	506	m	Undefined	
2Bridge piles of steel	1160	m	Undefined	
2reinforcement B500NC	780	ton	Undefined	
2Concrete B45, SV-40	3550	m3	Undefined	
2Waterproof membrane	2215	m2	Undefined	
2Bridge bearing varies sizes	12	p	Undefined	
2Prefabricated beams type NTB 1200	210	p	Undefined	
Diesel consumption for small cars	12649,78	l	Undefined	
Bensin consumption for small cars	46,28	l	Undefined	
Electricity consumption for small cars.	276,9	kWh	Undefined	

12.14 SimaPro's processes

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Vegetation clearance and removal of vegetation cover	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ				
Add						

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Grubbing and topsoil removal	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ				
Add						

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Rock excavation	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ			
Add					

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Masses used to ground leveling	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ					
Diesel, burned in building machine {GLO}| market for | APOS, U	0,18*38 = 6,84	MJ					
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Skytebane masses to the meadow	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ				
Diesel, burned in building machine {GLO}| market for | APOS, U	0,18*38 = 6,84	MJ				
Add						

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Skytebane masses to fill along the way	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ				
Diesel, burned in building machine {GLO}| market for | APOS, U	0,18*38 = 6,84	MJ				
Add						

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Another masses	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ				
Diesel, burned in building machine {GLO}| market for | APOS, U	0,18*38 = 6,84	MJ				
Add						

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Blasted stone from cutting to filling in the line	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Co
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ					
Diesel, burned in building machine {GLO}| market for | APOS, U	0,18*38 = 6,84	MJ					
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Mass replacement Betna and bogs along the line	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ					
Diesel, burned in building machine {GLO}| market for | APOS, U	0,18*38 = 6,84	MJ					
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Mass replacement Klettelva	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	(
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ					
Diesel, burned in building machine {GLO}| market for | APOS, U	0,18*38 = 6,84	MJ					
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Blasted rock masses to stored for later processing	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ			
Diesel, burned in building machine {GLO}| market for | APOS, U	0,18*38 = 6,84	MJ			
Add					

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
1Skytebane blasted rock to meadow	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Commen
Diesel, burned in building machine {GLO}| market for | APOS, U	0,37*38 = 14,1	MJ					
Diesel, burned in building machine {GLO}| market for | APOS, U	0,18*38 = 6,84	MJ					
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Frost protection layer Kult 0-180, T=930 cm	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Ma
Electricity, high voltage {NO}| market for | APOS, U	3,61	kWh	Undefined			
Add						

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Reinforcement layer E39: 16/90 T=30/40cm	1	m3	Volume	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min
Electricity, high voltage {NO}| market for | APOS, U	3,61	kWh	Undefined		

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2base and subbase layers Fk 0/45	1	m3	Volume	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min
Electricity, high voltage {NO}| market for | APOS, U	3,61	kWh	Undefined		

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2bearing layer Ag 16, T=10 cm (E39 + side road)	1	m3	Volume	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Transport, freight, inland waterways, barge {RoW}| market for transport, freight, inland waterways, ba	975	tkm	Undefined				650km*1.5t
Bitumen adhesive compound, hot {RoW}| production | APOS, U	60	kg	Undefined				
Gravel, crushed {RoW}| market for gravel, crushed | APOS, U	1320	kg	Undefined				
Inert filler {GLO}| market for | APOS, U	120	kg	Undefined				

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Gravel cover Fk 0/16, T = 10 cm	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Electricity, high voltage {NO}| market for | APOS, U	3,61	kWh	Undefined			
Add						

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2binder course Agb 11 70/100, T=3 cm	1	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Bitumen adhesive compound, hot {RoW}| production | APOS, U	1600	kg	Undefined				
Transport, freight, inland waterways, barge {RoW}| market for transport, freight, inland waterways, ba	1040	tkm	Undefined				1.6 t*650km
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

The ''Binder Course Agb'' and ''surface course'' processes are not fully complete, and an error was identified shortly before the submission deadline. This process requires modification and correction. Additional inputs are necessary to refine this process further, such as aggregate.

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Surface course + wearing course (E39 + side roads),Ab 16 70/100, T=4 cr	2060	m3	Volume	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Bitumen adhesive compound, hot {RoW}| production | APOS, U	1500	kg	Undefined				
Transport, freight, inland waterways, barge {RoW}| market for transport, freight, inland waterways, ba	975	tkm	Undefined				1.5t*650km
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Steel railings road	1	m	Length	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Steel, low-alloyed, hot rolled {GLO}| market for | APOS, U	84	kg	Undefined				0,0105m3*7850 kg
Transport, freight, lorry >32 metric ton, euro5 {RoW}| market for transport, freight, lorry >32 metric to	84	tkm	Undefined				
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Steel railings Bridge	1	m	Length	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Steel, low-alloyed, hot rolled {GLO}| market for | APOS, U	250	kg	Undefined				
Transport, freight, lorry >32 metric ton, euro5 {RoW}| market for transport, freight, lorry >32 metric to	250	tkm	Undefined				

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Bridge piles of steel	1	m	Length	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Transport, freight, lorry >32 metric ton, euro5 {RoW}| market for transport, freight, lorry >32 metric to	16,68	tkm	Undefined				139*120
Steel, low-alloyed, hot rolled {GLO}| market for | APOS, U	139	kg	Undefined				

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2reinforcement B500NC	1	ton	Mass	100 %	not defined	E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Steel, low-alloyed {GLO}| market for | APOS, U	600	kg	Undefined				
Iron scrap, sorted, pressed {NO}| treatment of municipal solid waste, incineration | APOS, U	400	kg	Undefined				
Transport, freight, lorry >32 metric ton, euro5 {RoW}| market for transport, freight, lorry >32 metric to	140	tkm	Undefined				140km*0,001t

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Concrete B45, SV-40	1	m3	Volume	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Cement, alternative constituents 6-20% {Europe without Switzerland}| market for | APOS, U	413	kg	Undefined				1 m3 concrete = approx. 2500 kg
Tap water {RoW}| market for | APOS, U	179	kg	Undefined				
Gravel, crushed {RoW}| market for gravel, crushed | APOS, U	1885,75	kg	Undefined				
Transport, freight, inland waterways, barge {RoW}| market for transport, freight, inland waterways, ba	1625	tkm	Undefined				650km*2.5 ton

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Waterproof membrane	1	m2	Area	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Inputs

Inputs from nature | Sub-compartment | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Bitumen adhesive compound, hot {RoW}| production | APOS, U	0,21*6,5 = 1,36	kg					21%
Gravel, crushed {RoW}| market for gravel, crushed | APOS, U	6,5*79 = 514	kg					79% steinmel, rock flour or glacial
Transport, freight, lorry >32 metric ton, euro5 {RoW}| market for transport, freight, lorry >32 metric to	3,9	tkm	Undefined				600 km*0,0065 tonn

Add

Inputs from technosphere: electricity/heat | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Bridge bearing varies sizes	1	p	Amount	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Inputs

Inputs from nature | Sub-compartment | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Steel, low-alloyed, hot rolled {GLO}| market for | APOS, U	200	kg	Undefined				
Transport, freight, light commercial vehicle {RoW}| market for transport, freight, light commercial veh	190	tkm	Undefined				0.200kg * 950km

Add

Inputs from technosphere: electricity/heat | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
2Prefabricated beams type NTB 1200	1	p	Amount	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Inputs

Inputs from nature | Sub-compartment | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Comment
2Concrete B45, SV-40	4,5	m3	Undefined		
2reinforcement B500NC	0,300	ton	Undefined		assumed to be o.3 kg reinforcement steel i each prefabrucated beam
Transport, freight, lorry >32 metric ton, euro5 {RoW}| market for transport, freight, lorry >32 metric to	12*140 = 1,68E3	tkm			assumed to be 500 km, therefor 11.55t*500km

Add

Inputs from technosphere: electricity/heat | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
Diesel consumption for small cars	1	l	Volume	100 %		E39 Betna-Hestnes	

Add

Outputs to technosphere: Avoided products | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Inputs

Inputs from nature | Sub-compartment | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Comment
Diesel, burned in building machine {GLO}| market for | APOS, U	1*38 = 38	MJ			

Add

Inputs from technosphere: electricity/heat | Amount | Unit | Distribution | SD2 or 2SD | Min | Max | Comment

Add

Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocation	Waste type	Category	Comment
Electricity consumption for small cars.	1	kWh	Energy	100 %		E39 Betna-Hestnes	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Comment
Electricity, high voltage {NO}| market for | APOS, U	1	kWh	Undefined		
Add					

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add							