Masteroppgave

NTNU
Norges teknisk-naturvitenskapelige universitet
Fakultet for ingeniørvitenskap
Institutt for bygg- og miljøteknikk

Andreas Øyehaug

Emission Profile of Norwegian County Roads:

A LCA case study of 49 infrastructure projects built by Trøndelag Fylkeskommune in the years 2010-2022

Masteroppgave i Bygg- og miljøteknikk
Veileder: Rolf A. Bohne
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i. Abstract

Limiting global warming is one of the major global challenges as of the time of writing. To achieve the desired goal, we must limit the amount of greenhouse gases we emit on an annual basis. A key factor to cut emissions is knowledge about what the main contributors of emissions from different activities are. As road construction varies between countries, there have been some challenges to comparing knowledge from different studies. To contribute to the field a study on 49 road infrastructure projects built by Trøndelag Fylkeskommune has been done. The study has built a databank that takes in a portfolio of LCAs made in the LCA tool VegLCA and gives analysis on a portfolio level and a project relative level. The study is a scope 3 study, with a cradle to gate perspective. The main benefit of this study is that all projects are assessed by the same assessor and within the same goal and scope, making comparisons viable. By interpreting the results from the LCA databank, we have gained insights in what contributors cause the most to emissions from road construction and what differences there are between road projects, tunnels, and bridges. Overall, the non-road construction equipment was found to be a major contributor to emissions, with diesel consumption being the major cause of emissions. For projects that include tunnels and/or bridges steel, and concrete also contributed a lot to emissions, explosives, asphalt, and transportation of masses were the final 3 largest contributors, and the 6 contributors made up 80-95% of emissions in most projects. The study then looked at ways to cut emissions and found that two of the national goals, transitioning away from fossil fuels, and demanding low-carbon concrete, would have reduced scope 3 emissions from the portfolio with about 26.4%.

ii. Sammendrag

Å begrense global oppvarming er en av de store globale utfordringene verden har tatt på seg i skrivende stund. For å få til dette er vi nødt til å redusere mengden av klimagasser vi sender ut i atmosfæren som bidrar til den globale oppvarmingen. En nøkkelfaktor til å kutte i utslippene av klimagasser er kunnskap om hvilke klimagasser som slippes ut som resultat av ulike aktiviteter. Ettersom vegbygging varierer en del mellom nasjoner, så har det vert utfordrende å sammenligne kunnskap mellom forskjellige studier. For å bidra til kunnskapen i fagfeltet har det blitt gjennomført en studie på 49 infrastrukturprosjekter bygget i regi av Trøndelag Fylkeskommune. Studien har laget en databank som tar inn en portefølje av LCAer laget i LCA verktøyet VegLCA, og gir en analyse på porteføljenivå, og mellom individuelle prosjekter. Studien ser på utslipp i ett Scope 3 nivå, med ett vugge til port, perspektiv. En stor fordel denne studien har er at LCAene er laget av samme person, samme verktøy med likt mål og perspektiv, som muliggjør sammenligninger mellom prosjektene. Ved å tolke resultatene fra LCA databanken har vi fått innsikt i hvilke innsatsfaktorer som bidrar mest til utslipp i vegbygging, og hva som er forskjellene mellom rene vegprosjekt og der det også er tuneller og/eller broer. Jevnt over var anleggsmaskiner alltid en stor bidragsyter til utslippene, der dieselforbruket sto for mesteparten av utslippene. For prosjekter som inneholdt tuneller og/eller broer, var betong og stål også store bidragsytere til utslipp. Videre var eksplosiver, asfalt og massetransport de siste tre av de seks store utslippskategoriene. Disse seks kildene til utslipp sto for 80-95% av utslippene for del fleste prosjektene. Studien så videre på muligheten for å kutte i utslippene. Ved å oppnå to av nasjonale målene om kutt i fossile energikilder, og bruk av lavutslipps-betong, kunne Scope 3 utslippene for porteføljen vert redusert med 26.4%.

iii. Acknowledgements

It is said that it takes a village to raise a child and writing a master's thesis is also very well a project that requires support from people around one for the process to be successful.

The last months I have been dedicated almost all my time to finishing my civil engineering degree, which has included skipping birthday parties, family vacations, game night with friends, given up potential extra responsibilities at work, in short, I have prioritized the thesis over a lot of things, and I would like to thank everyone for their understandment of my priorities.

I would like to thank the people around me that have encouraged me to allow myself to make such priorities. Especially in a world that has been eager to get back to the way things used to be after the pandemic, it has at times felt particularly wrong to prioritize self-improvement to doing long sought activities with friends and family.

I would also like to thank everyone who has set aside some of their time to aid me in the process of writing the masters. My supervisor has guided me towards the finish line, and even set aside time in his vacation to give some directions, which have been very helpful. Ever since I started my studies, I have always thought of the process of writing a masters as an impossible project, but tips and guidance along the way has made the process much better than I had dreaded.

I would like to thank my family, and the people close to me, who have cheered me on, and made the commitment to finishing the degree easier to maintain, even though it meant giving up a lot of things I would have liked to participate in.

Finally, I would like to thank myself. It is very much not in my nature to decide to do something as selfish as dedicating half a year to fulfil something I want to do for my own, rather than to join people in their endeavours. I have shown myself that when I am dedicating myself to something, I can achieve my goals, even though they seem daunting and even though it did not work last time, and I am very glad that I let my self prioritize this.

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1. Introduction

1.1. Why this theme for the thesis

As of 2022 when this thesis was written, the world at large has mitigating global climate change as one of the major agendas for policymakers. Corporations, public offices, nation states all claim to look for sustainable ways to operate in the future. This also applies to the public road sector. A part of mitigating global climate change is to cut emissions, a leading cause of global climate change. Having ambition of cutting emissions is one thing, but being certain that actions taken leads to emissions cuts, that is a different problem.

In the pamphlet "Roadmap for green construction-sector" it is sited that major public offices such as the Norwegian state road agency, Statens Vegvesen (SVV), and the railroad agency Bane NOR are using a newly developed tool called VegLCA to analyse emission impacts from construction (SINTEF, 2021). For large national public governance offices such as SVV and Bane NOR, it is possible to have several employees working towards optimizing for less emissions within every project. However, for smaller road governance offices, such as the County Road municipalities, and the municipalities, there are longer between large infrastructure projects and worries of additional costs. While they can be eager to reduce their emissions, rarely seeking to cut emissions can result in implementing actions without knowing the theoretical effect of such actions, and one might end up spending a lot of resources on a result that has little or no effect. The idea for the thesis is therefore to do an analysis of a large portfolio of projects typical for a lesser public road office and identify a few actions that can be implemented and say something about how much emissions they will cut and provide this knowledge to policymakers so that they can implement policies based on research.

1.2. Origins of the thesis

In a discussion with employees of Trøndelag Fylkeskommune it was discovered that they had some challenges regarding enacting policies to cut emissions. The data overarching data they had was only on a surface level, they had some LCAs they had made for their roads, but they had no systemic use of them, and they lacked precise insight in their own emission profile for road projects, so they had little information on how different policies for emission cuts would actually affect their emissions, and they did not know how far off their goals for 2030 they were.

I thought that doing an analysis of the entire portfolio of these data would give good insight in the emission profile, and thus give good insight in what policies to enact to cut emissions. In addition, by setting it up in a database it would be possible to compare average data for the portfolio before and after actions were taken, if it continually was added assessments to the database.

I therefore proposed to make such a database where assessments done in VegLCA, a LCA tool that Trøndelag Fylkeskommune has experience with and is the industry standard for LCAs in Norwegian road construction, can be added to and automatically added to the overarching analysis.

Trøndelag fylkeskommune liked the idea and my supervisor at NTNU thought a LCA analysis of a portfolio of LCAs was a good subject for a master thesis so I decided to do it.

1.3. Motivation

My motivation for this study is to provide data driven advice for policy makers on how to do emission cuts, so that politicians responsible for road networks can have more information available on what to do to cut emissions, and to what effect such actions will have.

The idea is to produce a databank to analyse the assessments and provide accessible easily digestible information about emissions from the road infrastructure projects. Further, the database will be produced in such a way that it is possible to expand upon it in the future and compare emissions from road-infrastructure projects year for year to show the actual effect on emission cuts from policies.

Further my motivation includes providing a step-by-step instruction on how to create such a databank for others to do similar work in the future, should they be inspired.

Hopefully, through this research knowledge would be gained that leads to faster emission cuts in the road construction sector.

1.4. Research Goal

1.4.1. RQ1: Overarching Research goal

Is it possible to do an analysis of a portfolio of recently built road construction projects, gain insight into the emission profile of those projects of that portfolio and use that insight to suggest good actions and policies to enact to cut emissions for future road construction projects?

1.4.2. RQ2: Life Cycle Assessment (LCA) databank

As a part of this study, I will make a databank for LCAs, the databank will be able to take in several assessments made with the LCA-tool VegLCA and provide analysis of them. The idea being that by analysing a group of several projects that are typical for a road governance office, the risk of the results being skewed by outliers are lowered and one should get a comprehensive insight in the emission profile of the kind of projects one builds, and that should make it easier to cut future emissions.

After finishing this study, the databank should be made available for other road governance offices, for use at their own discretion. The hopes being that by gathering several datasets from many public offices the collective knowledge about how to cut emissions within road construction.

1.4.3. RQ3: Emission profile

What is the emission profile of the portfolio, and the spread for the emission for individual projects? What are the direct emissions (Scope 1) and the Indirect emissions (Scope 3) associated with the project portfolio? Is it possible to identify large or major emission contributors where action is needed to cut emissions?

1.4.4. RQ4: Identifying good actions to cut emissions

Following the creation of the emission profile and the identification of large, and major emission contributors, what good actions can be identified to achieve emission cuts?

1.4.5. RQ5: Effect of transition from Internal Combustion Engines to Electrical Engines

One of the methods considered by Trøndelag Fylkeskommune to cut emissions from road construction projects, is to demand that construction-sites should be non-fossil by 2025 and electric by 2030. Further in Klimakur 2030 transitioning from construction and transportation vehicles driven by fossil fuels to electric- or hydrogen driven engines is listed as one of many ways to cut emissions, with clear goals for the construction industry by 2030 (Miljødirektoratet, 2020). The study will therefore especially do research around the effect of replacing diesel driven engines by electrical engine, to find out what the reduction of emissions would be for different steps on the way towards transitioning away from Internal Combustion Engines.

1.5. What is to follow in the rest of the thesis

The thesis will start with the background of climate-change, what is happening, how road construction is a contributor to it, what policies are enacted to combat climate change, and how that affects road construction.

Following that we present the concept and framework for LCA, different LCA tools available for road construction, which one we have decided to use and why. Then we look at the state of the art for LCA usage within road-construction, construction in general, and LCAs for different materials that make up large contributors of emissions in road construction projects.

Then we are presenting the methodology, the thinking behind how the LCA databank built by the study should work, how we intend to use that databank to gain more knowledge about the dataset within the LCA framework. We also look at how we are declaring large and major contributors, how to deal with outliers etc. We also discuss different methodologies for allocating scope-2 emissions for electricity.

We then present the case, with the 49 LCAs we got from Trøndelag Fylkeskommune, how they fit within the LCA framework, and what we wish to achieve by the analysis of them.

For the results, we are firstly presenting the LCA databank and what insight into the portfolio emission profiles we get, what major and large emission contributors we find. Then we are looking at subsections to see if there are differences between the subsections of the dataset. Then we are looking at spread for the major and large emission-contributors we identified, to see if we can learn something about what projects have what kind of emission profiles.

Then we are looking at the largest emission contributors, and further investigate within the dataset, compare it with the research done to identify good actions to be taken to cut emissions from future road construction projects.

We then compare the new insights we have gotten, within the dataset and for road construction in general and discuss the way forwards for cutting emissions and try to formulate good actions to cut emissions and why it should work. We discuss the uncertainties and drawbacks within the dataset and how they may have affected the results.

Then we are doing some thought-experiments to see whether road-construction in general can be emission beneficial compared to traffic, even at low trafficked county-roads.

We are then concluding, coming with the suggestions for policy makers, and the references and appendix.

1.5.1. The Excel Databank

A part of the results of this thesis is the Excel Databank made to analyse and present the dataset. It has about 4000 cells of inn-data from the projects, 2 000 cells with calculations, over a hundred graphs that present the data, while being interactive for the reader. Overall, over 10 000 cells are used in the databank altogether. Other offices or companies that have done Assessments with VegLCA, would be able to replace the inn-data from my studies with their own should they want them analysed, or extend the databank to include more datasets for a broader analysis.

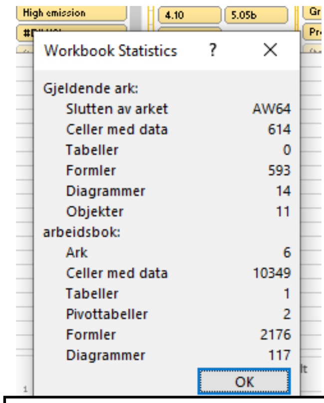


Figure 1: Workbook statistics for the LCA databank.

2. Theory

2.1. Understanding emissions in the atmosphere

As the purpose of the work of this study is to reduce the CO_2eq. impact caused of road construction, it is beneficial to look at the scientific knowledge of *why* we seek to reduce emissions, as a better understanding of the problem should lead to better crafted solutions.

2.1.1. The Greenhouse effect

Already in the late 19th century scientists started to understand the concept that has been called ”*the greenhouse effect.”* (Anderson, Hawkins, Jones, 2016) The Swedish scientist Svante Arrhenius is credited for constructing the quantitative mathematical analysis of what effect the amount of CO_2 in the atmosphere has on the planetary energy-budget (Anderson et al, 2016). In essence, the greenhouse effect is the result of a natural process where a layer of gasses in the atmosphere works as a trapping mechanism for solar radiation. This increase the natural average surface temperature of Earth to be around 14^{o}C, rather than the -21^{o}C it would have been without this layer of gasses in the atmosphere (Anderson et al, 2016).

2.1.2. Global warming

Expanding on the work of Arrhenius, by using weather information from 147 global temperature stations over the five decades from 1980 to 1930, Guy Stewart Callendar calculated a global increase in land temperatures of about 0.3^{o}C over this time period (Anderson et al, 2016). Further calculating a 6% rise in atmospheric CO_2 in this time period, which he found to be consistent with about ¾ of CO_2 released into the atmosphere during the period (Anderson et al, 2016). After linking global temperature rise with increased amounts of CO_2 in the atmosphere (Anderson et al, 2016), Callendar followingly proved that if human made emissions could increase the balance of CO_2 in the atmosphere, we would enhance the Greenhouse effect and contribute to global warming (Anderson et al, 2016).

2.1.3. The fast and the slow carbon cycles

To learn more about the carbon cycle, I read relevant chapters from a book on the topic: “Carbon Sinks and Sources of Climate Change Biology, Second edition” by Hannah Lee, 2015.

“Developing realistic options for reducing CO2 in the atmosphere requires an understanding of the Earth's carbon cycle” (Lee, 2015, Pages 403-422).

In the book the carbon cycle is described as the natural sinks and sources of carbon and how carbon transfers from sources to the atmosphere and to sinks. The book elaborates on the importance of CO_2 as a greenhouse gas, and that the carbon cycle has a major role in climate and climate change:

The carbon cycle plays a major role in climate and climate change. Carbon dioxide and methane are both carbon-containing compounds and major greenhouse gases. CO2 is a major player in the global carbon cycle, as well as the largest component of human greenhouse gas emissions. The burning of fossil fuels releases carbon that has been stored for over millions of years, moving carbon from geologic stores to more rapidly-moving pools in the carbon cycle. Knowledge of these pools and movements can help in the evaluation of ways to safely remove greenhouse gases from the atmosphere and meet international mitigation policy goals. (Lee, 2015, Pages 403-422).

While the book has an entire chapter on the concept of the Carbon cycle, the main takeaway this study takes from it, is the concept of the “*Slow Carbon cycle”* and *“Fast Carbon Cycle.”*

The carbon cycle has two components: the fast carbon cycle and the slow carbon cycle. The fast cycle involves biological processes, such as photosynthesis and decomposition, while the slow cycle involves transitions of inorganic carbon, such as *the weathering of rocks and soils. The slow cycle is implicated in governing climate change on a timescale of millions of years, while the fast cycle participates in decadal to millennial climate changes*. (Lee, 2015, Pages 403-422).

For summary in short for the entire chapter with regards to why the carbon cycle is relevant for this study:

- Both the fast and slow carbon cycles are natural processes (Lee, 2015).
- The burning of fossil fuels releases carbon stored from geological stores, to faster moving pools in the carbon cycle (Lee, 2015). Taking them from the slow cycle to the fast cycle.
- From the Industrial Revolution to the present, the burning of fossil fuels has added about 330 billion metric tons (330 Pg.) of carbon to the Earth's atmosphere (Lee, 2015).
- Human greenhouse gas pollution is rapidly impacting the fast carbon cycle (Lee, 2015).

In conclusion – the burning of fossil fuels is disrupting the natural processes by transferring carbon from the storages of the slow carbon cycle and releasing them into the atmosphere, where they enhance the greenhouse effect and contribute to global warming.

This leads the author of this study into suggesting that when looking at what energy sources to use, with regard to reducing emissions in hopes of reducing global warming, it should be looked at in context of how they affect the Carbon cycle.

- Energy that when harvested releases carbon from the slow carbon cycle into the fast carbon cycle is disruptive to the natural process and should be avoided. Therefore, harvesting fossil fuels and other means of disrupting the slow carbon cycle should be avoided.
- Energy that when harvested releases carbon from the fast carbon cycle into the fast carbon cycle by skipping or reducing the time carbon spends in carbon storage, is better than harvesting fossil fuels but it is still disruptive. If the goal is to be able to reduce the amount of emissions released into the atmosphere it is irrelevant if emissions released come from exploiting the slow or the fast carbon cycle, as burning fuels from either of them disrupt the process of storing carbon from the fast cycle. – Therefore, while not introducing new carbon into the fast carbon cycle, disrupting the storage of carbon is a reason why also fuels that are not fossil, should be avoided if they release carbon into the atmosphere.
- Energy that can be harvested without releasing carbon from either short or long carbon cycle should be prioritized as energy-sources.

2.2. How does road construction disrupt the carbon cycles and contribute to global warming

Road construction is at the core as all other construction and manufacturing, a process where materials are worked and put together to produce something, in our case a place for vehicles or pedestrians to travel. This process produces emissions directly, when fossil fuel sources are burnt to as fuels work the materials together and produce the road, or emissions can be released as by-products when using explosives to do excavation. Emissions can also in-directly be attributed to the road construction if the materials used for the road had emissions through production, as the same materials consumed by a road project no longer can be used elsewhere. This will be expanded upon later in the study.

2.3. How the international community deals with global warming

2.3.1. A brief history of the United Nations Framework Conference for Climate Chance, and the framework around climate change science

Towards the end of the 1980's, the increasing evidence that the global climate was at risk of change, and the consequences were made available for policy makers in member-countries of the United Nations. 6th December 1988 in the 70th plenary meeting, the General Assembly of the United Nations declared that they were convinced that climate change would affect the whole of humanity and determined that necessary actions should be taken to deal with climate change within a global framework (General Assembly, United Nations, 1988).

"Convinced that climate change affects humanity as a whole, and should be confronted within a global framework so as to take into account the vital interest of all mankind" (United Nations, General Assembly, 1988).

In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) was established (UNFCCC, 1992) and entering into force in 1994 (UNFCCC, 2022), This framework has been an important tool for the scientific community as it in addition to pledging action to combat climate change, it defines a framework for communication within the science. Further it set the scene for additional meetings on the topic, such as the Kyoto Protocol where the UNFCCC was operationalized, (UNFCCC, 1997) and the Paris Agreement in 2015 where 196 Parties legally bound themselves to the goal of limiting global warming to below 2^{o}C, compared to pre-industrial levels (United Nations, 2015).

The UNFCCC gave the international community a framework for communication, for example by defining a standardization of emissions that cause global warming to be defined by their Carbon Dioxide equivalent (CO_2eq.), so that emissions could be comparable in their global warming potential. This led CO_2eq., to become the metric for global warming potential, and thus give policy makers a metric for comparison.

Since then, the scientific community followed up the UNFCCC researching to what effect different materials, processes, procedures etc. contributed to global warming. Emissions have then been allocated to different scopes, dependant on where in the production chain they originated. Direct emissions from burning fuels and other actions that directly release emissions with global warming potential into the atmosphere are categorized as scope 1 emissions (United States Environmental Protection Agency, 2022a). Scope 2 emissions are indirect emissions attributed to the production of electricity, steam, heating, cooling etcetera, where emissions are produced in a different facility from where it is consumed but accounted for by the consumer (United States Environmental Protection Agency, 2022a). Scope 3 emissions are indirect emissions that are allocated to products that is consumed by someone that has not produced them (United States Environmental Protection Agency, 2022b). Scope 3 emissions contain the Scope 1 & Scope 2 emissions caused by production, waste-management, transportation etc of a product. To avoid double bookkeeping, each individual organization only reports the Scope 1 and Scope 2 emissions as their own emissions.

2.3.2. Emission cut policy in Norway

The Norwegian state has signed the Paris agreement and is legally bound to cut emissions by 50% compared to the year 1990 by the year 2030 (Norwegian Government, 2021). The Norwegian state has together with the European Union (EU) established a climate-agreement where they are bound to cooperate with the EU about reducing the emissions by at least 40% by 2030, compared with 1990 levels (Norwegian Government, 2021). Norway has ambitions that in 2050 emissions are reduced by 90-95% compared to 1990 levels (Norwegian Government, 2021).

2.3.3. Emission policy in Trøndelag

Trøndelag is a county in Norway, they have also set their own emission goals through a strategy of climate-transition approved by the county council in 2020 (Trøndelag Fylkeskommune, 2020). The strategy states specifically that Trøndelag will reduce greenhouse gas emissions by 50-55% by 2030, compared with 2009 (Trøndelag Fylkeskommune, 2020). As a county governance office responsible for over 6000 kilometres with county-road-infrastructure (Trøndelag Fylkeskommune, 2018a) they are expected to improve and maintain accessibility for the 474 000 inhabitants in 2022 and the expected 523 000 inhabitants in 2050 (Statistisk Sentralbyrå, 2022c) at the same time as they have ambitions to cut emissions. Trøndelag fylkeskommune have provided this study with a portfolio of 49 LCAs of road infrastructure projects they have constructed since 2010. This study seeks to help Trøndelag Fylkeskommune identify good actions to cut emissions within road infrastructure construction.

2.3.4. Klimakur 2030

The Norwegian directory of environment, "Miljødirektoratet", launched in 2020 a 1197-page long document called "Klimakur 2030" with a breakdown of 60 major policies and actions for reaching the goals set by the Norwegian government for how Norway could reach their goal of cutting emissions in accordance with their pledge in the Paris climate agreement, by at least 50% by 2030 compared to 1990-levels (Norwegian Government, 2021). The document describes actions, that if done in accordance with the document, should cut emissions in Norway with 43.6 million tonnes CO_2eq. in the period 2021-2030 (Miljødirektoratet, 2020). 6.0 million tonnes of these should be possible to cut in "Ikke- veigående maskiner og annen transport" ("non-road machines and other transportation") where equipment from road construction is a contributor (Miljødirektoratet, 2020). 11.8 million tonnes of emissions should be possible to cut in "Veitransport", ("road transportation") where heavy trucks transporting goods to construction sites are contributors (Miljødirektoratet, 2020).

The different policies and actions are split into three categories regarding cost, where they are separated into each category by how cheap/expensive cutting 1 tonnes of CO_2eq. are relative to one another. The categories are <500 kr./tonnes CO_2eq., 500-1500 kr./tonnes CO_2eq., and >1500 kr./tonnes CO_2eq., where the costs are in NOK at the time of publishment.

The potential of reduction of emissions from electrifying road transport is especially pointed to as an important potential to exploit. It is expected that the costs will be expensive at first (>1500kr./tonnes) but over the period should be reduced to below 0 kr./tonnes towards the end of the period, making it profitable to cut emissions in this way (Miljødirektoratet, 2020).

As transforming the Norwegian machine-park from a fossil based one to an electricity based one is one of the major actions described in Klimakur 2030, this study will research what impact electrifying the construction equipment and transportation vehicles will have on the emissions attributed to Trøndelag Fylkeskommunes road infrastructure projects.

The specific goals for electrification of non-road machinery and heavy transportation vehicles are:

- 50% of new heavy transportation vehicles are electric or hydrogen based in 2030 (Miljødirektoratet, 2020).
- 70% of new non-road machinery and vehicles are electrical in 2030 (Miljødirektoratet, 2020).

The two goals should cut respectively ~1.1 million tonnes CO_2eq. ~1.75 million tonnes CO_2eq. of emissions allocated to Norway in the period 2021-2030 (Miljødirektoratet, 2020).

Based on these national goals of transitioning away from Internal Combustion Engines (ICEs), the study seeks to investigate the effect of electrification of heavy transportation and non-road machinery.

2.3.5. Cutting emissions within road construction

While Miljødirektoratet supplied a document for cutting emissions in the entire country, there have also been done investigations of how to cut emissions within the road sector in Norway. The state governed road infrastructure builder "Nye Veier" came with a list of possible emission cuts they could do in their projects in collaboration with the Zero foundation in 2020 (Zero, 2020). They cite using recycled materials, materials produced with low carbon impact and optimising project for reducing transportation distances as key actions to reduce emissions from materials used in road infrastructure projects (Zero, 2020). They also point towards electrifying machinery where possible and when electric machinery is far from power infrastructure using hydrogen powered generators if needed, as possible emission cuts from the construction equipment (Zero, 2020). Another institute aiming to contribute knowledge to the construction sector is SINTEF they worked together with major state government offices, and major entrepreneurs in the construction sector to pool the knowledge within the sector. They highlight the importance of starting increasingly use EPDs and LCAs when constructing infrastructure and urge the sector to begin working sooner rather than later to document and implement emission saving measures (Vignisdottir et al, 2021).

2.4. Life Cycle Assessment (LCA)

As a part of the international framework for dealing with global warming, the International Organization for Standardization (ISO) have made standards for principles and framework around environmental management for projects. ISO provides standards ISO 14040, and ISO 14044 for describing the why and how to do an assessment of what environmental impact(International Organisation for Standardization, 2006a; International Organisation for Standardization, 2006b). The framework for the analysis of the environmental impact of a product include all aspects of the environmental impact of a product over the lifecycle, from the resource harvesting of components, to transport and to waste management. Such an assessment (or analysis) over a products life cycle, is thus called a Life Cycle Assessment (or Analysis).

A LCA built on the principles of international framework for ISO 14040 and ISO14044 follow specific protocol for how they are built, so that an LCA done by one assessor, can be investigated by a different assessor, and they should have enough information provided, that they know whether results from a study can be compared with results from another study.

The main parts of a Life Cycle Assessment that are needed for an assessment are the defined "Goal and Scope", a "Inventory Analysis" an "Environmental Impact Assessment" and a "Interpretation." The four parts of a LCA influence one another as shown in figure 2. Following the contents of the different parts of an LCA will be explained.

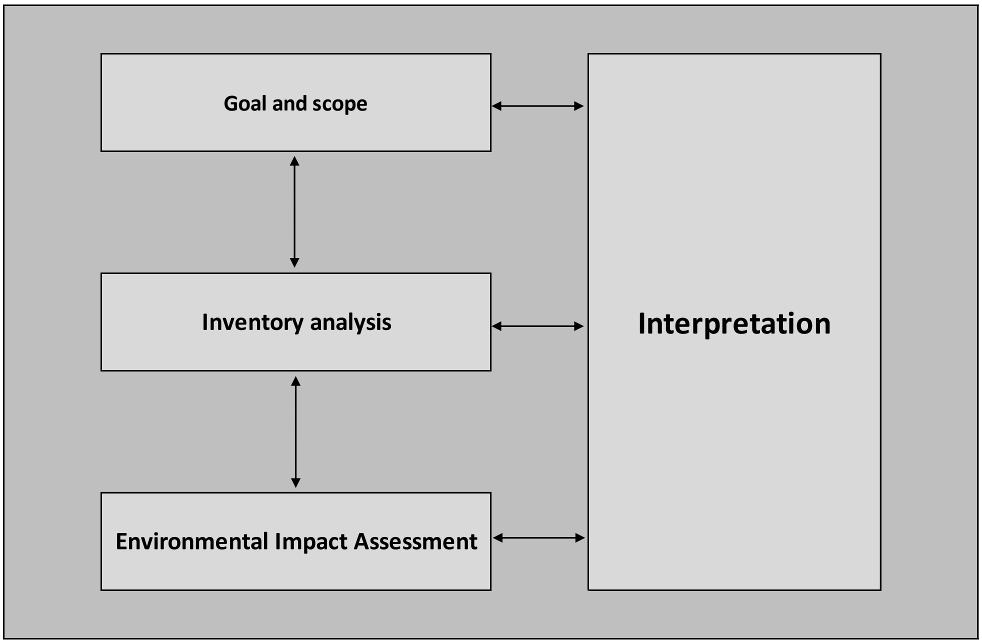


Figure 2: Illustration of the phases in a LCA done within the framework set by ISO 14040.

2.4.1. Goal and scope

The goal and scope set the background and context for the assessment. What are the boundaries set by the assessment? What is the intended use for the assessment? Who is the intended reader/user of the assessment? Is the study going to limit itself geographically? What assumptions are being made? What process stages are the assessment going to contain? What are we measuring, what ware we measuring against? Where are the data coming from? What Environmental Product Declarations or Industry Standards are we using?

2.4.2. Inventory analysis

The Inventory Analysis is the process where the quantifiable data for the assessment is gathered with regards to the boundaries set by the goals and scope. Here all the data for quantifiable materials, energy consumption are collected and documented. How much of a material is consumed for each work process, how many times are the work processes done? What kind of materials are used? What energy source are used? What quality of materials are used?

2.4.3. Environmental Impact Assessment

The Environmental Impact Assessments takes in the data produced in the Inventory Analysis and aggregates up the environmental impact for each of the materials used and gives an emission profile for the assessed project.

2.4.4. Interpretation

Interpretation is the process where the assessor does what they intended to do with the assessment. Was the goal to find significant contributors? Then the assessor analyses the Environmental Impact Assessment and looks for signs for such contributors. Was the goal to identify whether product based on material A or material B has less emissions? The assessor can conclude by comparing two studies.

2.4.5. Environmental Product Declaration (EPDs)

Environmental Product Declarations (EPDs) have been developed to give precise and comparable datasheets for environmental-related information about products, such as the Global Warming potential of emissions released into the atmosphere as the result of producing a product. EPDs are based on international standards such as ISO 14025, EN 15804 and EN 55942, that give structure, protocol, principles, and what data to contain in an EPD, so that they may be compared and used cross countries and organisations.

EPDs are made by doing a LCA of a material or a product consisting of many materials. As EPDs are made within the same international standard, a LCA of a product containing other products and materials, can take in EPDs from the components. While we in this study mainly focus on EPDs from an emission point of view, the EPD also declares other environmental impacts besides global warming.

Having access to EPDs for products means that the process of assessing the environmental impact of emissions related to an Inventory Analysis goes much faster, as there is verified data backed numbers to aggregate for. Taking this process one step further, it gives the opportunity for the creation of assessment-tools that are built on the same principles, that take in data from research done by the scientific community on how different materials and manufacturing processes impact the environment and give an assessor the ability to sum their amounts of emissions caused directly and indirectly by a project or a product.

2.4.6. LCA tools available for road construction

VegLCA is the tool of choice for my study, more on that later. VegLCAs provider SVV also has another assessment tool available for the use within road construction EFFEKT. EFFEKT is not a tool primary for looking at LCAs with regards to carbon impact, but as a tool for choosing between different potential routes for new roads where emissions is a part of the consideration in addition to traffic-economics, traffic safety and environment (Vegdirektoratet, 2018). In Trøndelag fylkeskommune this tool is primary used in the very early part of the planning period. There have also been developed tools by other organisations than Norwegian road offices, Joulesave (National Road Agency (Ireland), 2006) a consortium effort between European Union member countries in 2006 has focus on translating road construction processes to the amount of Joules required to do the work. A joint research programme between The Netherlands, Norway, Sweden, Denmark, Germany, Ireland, and the United Kingdom produced LICCER, that focused on the construction of the road infrastructure including tunnels and bridges (Brattebø et al, 2013). The Swedish traffic governance Trafikverket have their own LCA tool for infrastructure called Klimatkalkyl which is publicly accessible, it provides the emissions from construction, use and operation & Maintenance (Toller, 2018). Finally, HERMES CO_2 is a product of the joint research programme HERMES, that as of the time of writing take in data about the pavement part of the road (Barbieri et al, 2021).

As the portfolio of 49 LCAs that was gathered for the assessment, were in entirety made in VegLCA, VegLCA had to be chosen as the assessment tool of choice when going back and interpreting each individual project assessment, as projects analysed within different road assessment tools is subject to different scopes and will might have harmonization challenges (Hoxha et al, 2021). This is not unique for the road sector, whether it is LCAs for building construction (Kamali, Hewage and Sadiq, 2019), Electric Batteries (Dieterle et al, 2022) or research on emerging technology (Kawajiri et al, 2020) the importance of doing apples-to-apples comparisons between datasets is highlighted. Even though the dataset in the portfolio is all done in VegLCA, there is still some harmonization issues, as they are made in different versions of the tool.

2.4.7. VegLCA

VegLCA is a LCA tool provided and maintained by Statens Vegvesen, which is the Norwegian road governance office (Statens Vegvesen, 2022a). VegLCA works by submitting data for process codes used by a road infrastructure project, and the assessment tool calculates how much work done, materials needed, transport distances etc. which is caused by the road infrastructure project based on the input data, and indistry-standards for such projects in Norway.

VegLCA gives Scope 1 and Scope 3 emission data of the project and allocates emissions to different parts in the lifecycle according to the A1 – A3, A4, A5, B1 - B5 processes.

VegLCA is the chosen assessment tool for this thesis, as the portfolio of road infrastructure analysed in this thesis had been assessed in VegLCA.

2.4.8. How VegLCA works

VegLCA works by taking in inputs from the assessor for a project, with the inputs being, how much of each of the 890 different process codes the project consists of any desired quality for components, and any project specifics deemed off-standard for the project. Based on these inputs, and with knowledge about industry standards for Norwegian road construction VegLCA calculates the quantities of 250 different material components needed for the project. The assessor also provides the lifetime and scope to analyse the project for, if the project has any EPDs they can be used to override the pre-set values for industry standards. The tool then takes into account research knowledge about emission contribution for the materials, industry standard maintenance data and calculates emissions for the project and presents it for the assessor.

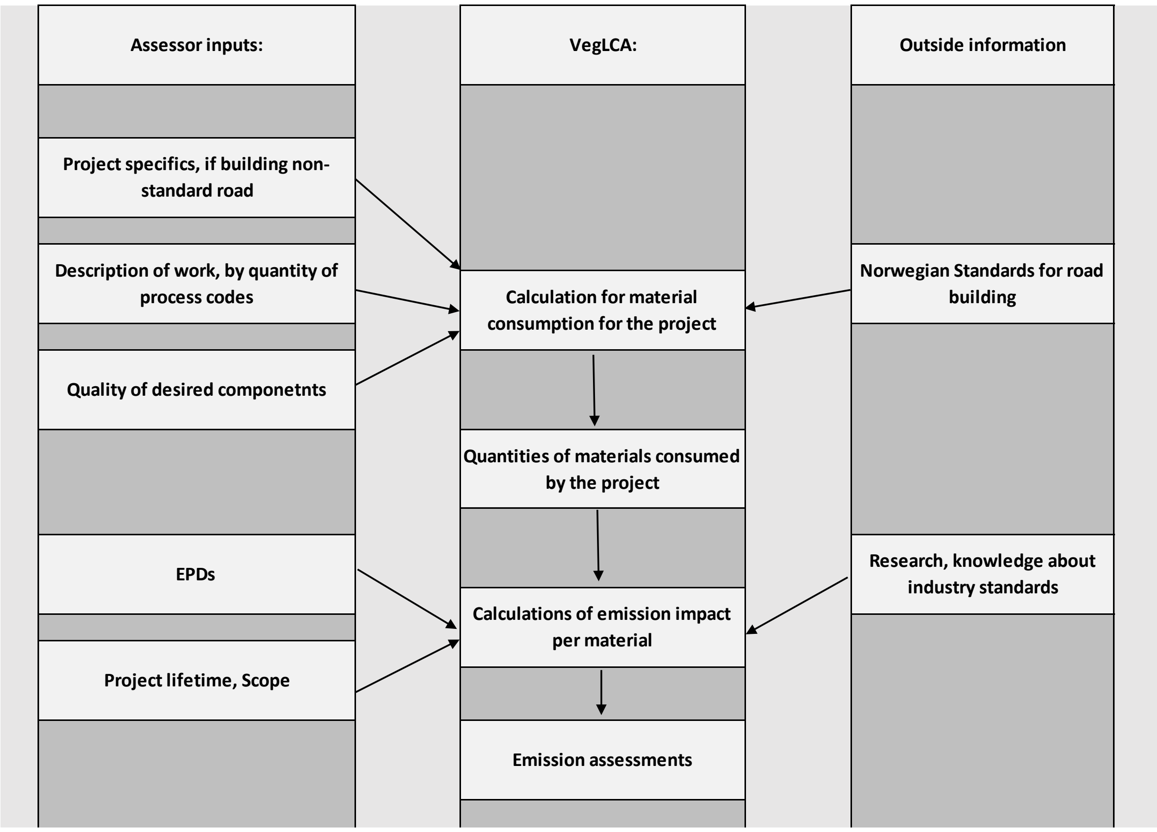


Figure 3: Illustration of how the LCA tool VegLCA takes in inputs from the assessor, what the Tool does, and what outside information is updated between versions.

As all the 49 LCAs in the portfolio is made with the same system, and the same scope, we can be more confident that we are looking at apples-to-apples comparisons between the LCAs in the portfolio. This is great as it will provide insight into how projects compare with one another, based on what kind of infrastructure they consist of. However, as the assessments have been amassed over few years, the "outside information" in figure 3 has improved over time, making the comparison between project more a comparison between old-apples-to-new-apples. When possible fixing harmonization issues between assessments done with different versions of VegLCA has been tried, but some of the changes between versions were hard to quantify.

2.4.9. VegLCA versions used v4.06 – v5.06b

The assessments studied in the study have been assessed over three different years, the assessments are from 2020 to 2022, over this period the VegLCA tool has been upgraded several times to reflect updated knowledge and to correct errors. A consequence of this could be that input data in one version would yield different output data. Therefore, adjustments are needed to correct mistakes made by earlier versions.

The oldest version used in this study is v4.06, and the newest is v5.06b. In the next section the study will go through the changes between the versions, whether the changes will cause our dataset to need adjustments, and what those adjustments are.

Table 1: Summary of the changelogs for VegLCA, and the consequences they have on the dataset.

Version	What is different – that influences the databank.	Adjustments needed to be made on our dataset.
5.06B	Correction in calculation of direct emissions from building site – previous versions did not add explosive usage correctly.	All datasets from versions prior to this one need to add explosive usage to direct emissions.
5.05B	Correction in calculating concrete in process 44.4, after fixing the calculated amounts should increase by 0% - 3%.	Hard to estimate a good fix for this update, without doing all the assessments again.
5.04B	Update has no impact on the databank	
5.03B	Correction of process 32.21,	No mentions of how it will impact datasets. Hard to estimate how to correct for it.
5.02B	Update has no impact on the databank.	
5.01B	Total update of all calculating factors based on new data available for 2021.	No mentions on how it will impact datasets. Hard to estimate how to correct for it.
4.10B	Added a column that is not in use for the datasets in the databank.	No corrections needed.
4.10	Updated process codes to norm of 2018. With some minor error fixing and adjustments	No mention on how it will impact datasets. Hard to estimate how to correct for it.
4.07	No changes in parts of the tool that is used for this study.	
4.06	This is the oldest version used in this study, and therefore we need no further adjustments.	

Not mentioned in the change log, is that for the newer versions there is a split in the amount columns for diesel usage. – It is assumed that since it is split into two columns where only one of them contain a non-zero number, the zero-number rows can “be “included”” in a mother diesel usage number as before the split. There are also a few extra informative descriptions added to some of the fields in the newer versions.

Based on the findings the study will in the different versions manually add the explosive usage column to the direct emissions column, for assessments made in versions 5.05B and older.

2.5. Climate in Norwegian Standards Contract for Road Construction

Statens Vegvesen (SVV) provides drafts for road construction contracts for below (Statens Vegvesen, 2022b) and above (Statens Vegvesen, 2022c) EØS threshold-values, suggesting actions to be put into contracts for projects of specific sizes. For the period 2022-2024 this threshold value is 56 MNOK (Norwegian Government, 2022). For contracts of all sizes there are demands for EPDs for asphalt, construction concrete, and steel armament used in the projects, and that these EPDs should be in accordance with NS-EN 15804:2012 (Statens Vegvesen, 2022b; Statens Vegvesen, 2022c). For projects above the EØS-threshold there is also a paragraph in the contract draft dedicated to emission gas-budgeting and accounting, suggesting that entrepreneurs should use VegLCA and assess the projects. There are also bonus & malus incentives for emission control suggested in the contract draft, and specific demands for class B35 and B45 concrete used for construction to not surpass respectively 280 $kgCO_2eq./m^3$ & 290 $kgCO_2eq./m^3$ (Statens Vegvesen, 2022c).

2.6. State of the art

2.6.1. LCAs within the sector

Before doing the analysis of the dataset, a literature study was performed to explore what was done in the field, and similar fields with regards to Life Cycle Assessments (LCAs).

Already before the Kyoto-protocol was signed (United Nations, 1997) the first cradle to grave assessment of asphalt and concrete pavements were published (Häkkinen, 1996). The following years more studies within the field emerged in Japan (Inamura, Piantanakulchai and Takeyama, 1999), Sweeden (Stripple, 2001) and according to a study (Santero, Masanet and Horvath, 2011) also in the U.S., Canada, Korea & Australia had LCAs during the first few years of the 2000s*[1]. In 2000 LCAs was shown to be feasible tools for decision-making when looking to minimize environmental impacts (Schenck, 2000). In 2003 it was proposed that LCAs should be a part of civil-engineering studies (Roudebush, 2003) and a few years later an assessment of replacing virgin materials in road construction with ashes from incinerators was done (Birgisdottir, 2005).

In 2011, a study of 15 of the at the time available LCA studies was performed (Santero et al, 2011), they criticised the field of research of working too independently of one another, focusing over different time frames, including different processes such as material production and waste management etc. Causing the field of research to be even though bountiful, to be bearing different fruits making apples-to-apples comparisons between studies hard.

Five years later, similar difficulties were found in a study over road construction LCAs in 2010-2015 (Jafari, Yahia and Amor, 2016). The diverse material options available for road construction, different

*1 The studies are referenced in N. Santero’s 2011 study; however, they are not accessible through my university access.

national strategies for maintenance and expected life span for materials, have led to an increased, but diverse amount of available LCAs within the road sector (Jafari et al, 2016). The inconsistencies between assessments make it difficult to compare them, which will limit their usefulness in a decision-making process (Jafari et al, 2016).

A more recent study of LCAs within road construction (Hoxha et al, 2021), took in data from 94 papers, spanning 417 road case studies. They (Hoxha et al, 2021) found that the scientific field still had the same harmonization challenges as was criticised ten years earlier (Santero et al, 2011). They (Hoxha et al, 2021) found it was difficult to compare assessments done between countries as only 18% of the road case studies produced the source material in addition to an assessment of the Life Cycle Climate impact. This means that for the remaining 82% of the road case studies the results were non-reproduceable. They pointed to the lack of transparency regarding the source material as barriers to identifying low carbon solutions for road construction. As a result of this, this paper aims to improve the amount of data available to the scientific community on the topic of Life Cycle Analysis of Road Constructions, by seeking to provide the data and metadata desired by the study (Hoxha et al, 2021).

2.6.2. Recent LCA studies on road infrastructure

A Chinese study analysed an urban road in Xi'an, China (Li et al, 2020), and found that the material components of the concrete made up 61.75% of emissions in their study. However as this was an urban road the analysis also covered drainage, water supply-systems and power-pipelines as a part of the road infrastructure. The road itself had emission characteristics of 84.49 $kgCO_2eq./m^2$ road, with material components making up 89% of the emissions and construction & transportation the remaining 11%. They state better technology and replacing lime-fly ash with stabilized gravel as a cause of greatly reducing emissions in the future, they also hail electrifying machinery as a possible way of reducing emissions in the future (Li et al, 2020). A study of highways in Michigan suggested that using more prefabricated elements of concrete, rather than cast in place concrete could be beneficial with regards to construction time (Chan, 2007). A reduction of construction time should reduce the impact on the wear and tear on construction equipment. A study on a single highway construction in China (Luo et al, 2021) found concrete and steel to be the main materials that contributed to carbon emissions and because of heavy usage of small electric equipment's electricity was found to be the highest emission contributing fuel (Luo et al, 2021).

2.6.3. LCAs in similar sectors

With the lack of desired data from similar road construction assessments to compare with, this study chooses to look to a similar sector within construction for inspiration on how to perform a LCA study. Building construction have enough similarities to road construction to be used for inspiration. Similarities include what kinds of materials that are used, the need for movable heavy-duty machinery doing work and the excavating of masses to mention some. However, this study expects the results from findings in LCAs of building construction to differentiate somewhat from the findings in LCAs of road construction, as it is expected that the ratio of materials for road construction and building construction are different.

A LCA study of 969 urban buildings and some rural building infrastructures in China found that 80% of the energy spent in the pre-occupancy stage was allocated to the building materials used in the construction process (Zhang et al, 2019). Of the energy spent to manufacture building materials, 51% was spent making steel and 33% was spent making cement, as seen in figure 4.

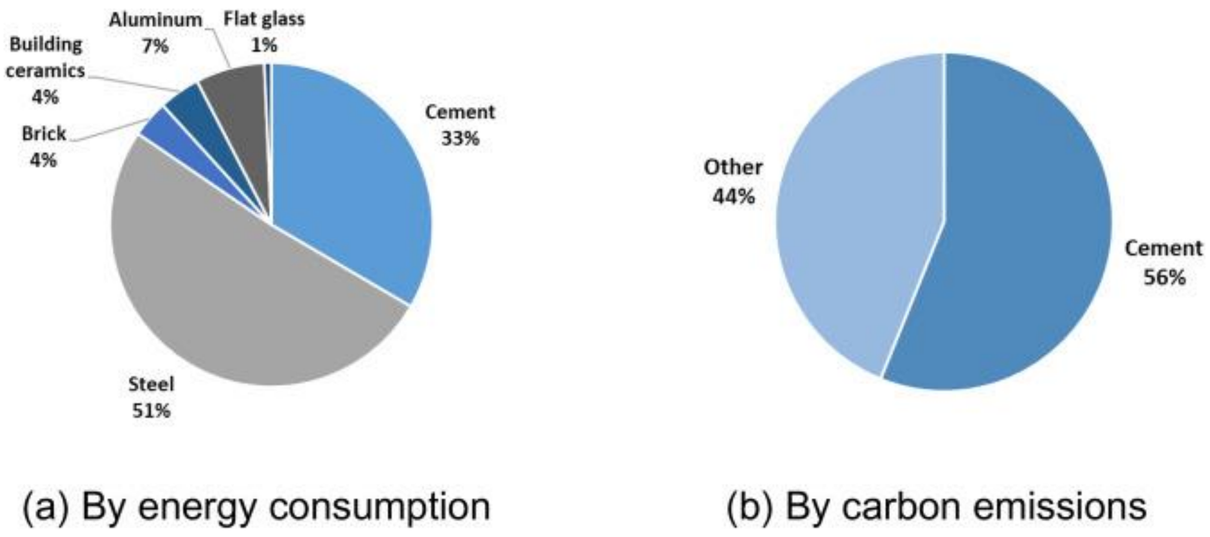


Figure 4: Share of production energy consumption and emissions by material type (Zhang et al, 2019).

By identifying large contributors to emissions from a sector, good actions to cut emissions can be found. For example, optimizing for less materials and resources used will result in less emissions. If the building portfolio assessed (Zang et al, 2019), could have optimised steel consumption and overall used 10% less steel, 5.10% less emissions would have been needed to produce the building materials. The same effect would be achieved with a 10% reduction in emissions from steel manufacturing, and both in effect at same time would give emission cuts of 9.69%.

Being able to allocate where the emissions have come from in infrastructure projects is key to finding good actions to take to cut emissions from future similar infrastructure projects. Which is why this study seeks to fin the emission-profile of the road projects.

2.7. Impact of construction equipment being electrical versus fossil powered

A recent study has shown that adding hydrogen to the combustion process can significantly impact the performance of ICEs (Bakar et al, 2022). Another study shows that adding ammonia to the combustion process could reduce Greenhouse Gases by significant amounts. (Yousefi et al, 2022) It is therefore possible in the future that the typical combustion engines are more efficient than they are today. However, such technology is probably far from able to be used in off the shelf construction machinery as the Norwegian department of Environment has attributed such technology to primary be used by large marine vehicles in their assessment of emission cuts (Miljødirektoratet, 2020).

Transportøkonomisk institutt (Norwegian Transport-Economics Institute, (TØI)) published a report on early adopters of heavy-duty zero-emission vehicles in Norway in 2019 where they briefly reference the efficiency gap between combustion engines and electrical engines (Hovi et al, 2019).

"The efficiency of the conversion from electrical to mechanical energy is high at between 70-95% (Andwari et al, 2017) compared to the ~25-40% for ICE engines" (Andawari et al, 2017, cited in Hovi et al, 2019).

They cite research (Andwari et al, 2017) for the efficiency of electrical engines while the efficiency for ICEs is left uncited. A study on typical non-road heavy duty machinery uses 40% efficiency for diesel engines as default for their comparison of diesel engine efficiency (Tan et al, 2021).

The efficiency rate is how efficient an engine is in converting the fuel to work. For ICEs this fuel is diesel and some of the energy is lost as heat during the combustion process. For electrical engines the fuel is electricity, where some of the energy is lost to friction in the engine, and some of the energy is lost over the transport and electricity storage. The European Federation for Transport and Environment AISBL operate with a 17% efficiency loss from electricity-production to charged battery, based on data from their own research and the world bank (European Federation for Transport and Environment AISBL, 2020, cited The World Bank, 2020).

When comparing the efficiency when estimating how much energy is needed to replace a ICE with an electrical engine doing the same workload, 40% efficiency rate for diesel engines and 95% efficiency rate for electrical engines are used. The reasoning behind choosing 40% for the diesel engine is that it is used as a default efficiency rate for typical ICEs in 2021 (Tan et al, 2021). The reasoning behind choosing 95% for the electrical engine is that it is reported that electrical engines with 95% efficiency are possible (Andawari et al, 2017), and when looking at alternatives to replace fossil driven ICEs we assume that the market will produce the most efficient alternatives. As 95% efficiency was chosen as the efficiency for electrical engines, it means that that is the efficiency-level needed for electrical engines to cut emissions by the amount the study finds. Potential future better performing engines will cut more emissions, and worse performing engines will cut less emissions than this.

A study done on the lifecycle emissions of electric cars (European Federation for Transport and Environment AISBL, 2020) claims that:

Electric cars outperform diesels and petrols in all scenarios, even on carbon intensive grids such as Poland, where they are about 30% better than conventional cars. In the best-case scenario (an EV (Electric Vehicle) running on clean electricity with a battery produced with clean electricity), EVs are already about five times cleaner than conventional equivalents (European Federation for Transport and Environment AISBL, 2020).

The study also notes that:

*In the scenario of 100% of the remaining car demand met by battery electric cars, and with average transmission losses over the electricity grid across Europe of 5%, the amount of additional clean electricity required to power the fleet of cars in Europe in 2050 is 475 TWh, or 14.7% of the electricity generated in the EU in 2015. (*European Federation for Transport and Environment AISBL, 2020).

Which points to the enormous scale of how much electricity is needed should ICE driven vehicles be all replaced by electrical engine driven vehicles. In addition, this electricity should this energy come from only clean and renewable energy-sources to have an environmental impact. The study concludes that not only should one seek to replace fossil powered ICEs with clean technology, but to achieve a full decarbonisation of the car fleet by 2050 a rapid demand reduction for personal mobility is also needed (European Federation for Transport and Environment AISBL, 2018).

This means, that should electricity be used as means to cut emissions from heavy-duty construction equipment, and transportation vehicles in Norway, there must be enough surplus electricity to handle the transition.

2.7.1. Calculating the emission cuts of replacing diesel with electricity

When replacing ICEs with Electrical Engines (EEs), we are transitioning from Scope 1 emissions to Scope 2 Emissions. To calculate the emission cuts of replacing diesel with electricity we first need to calculate how much work is done by the ICE, then calculate how much electrical energy is needed to do the same amount of work, and finally calculate the Scope 2 Emissions for that electrical energy.

2.8. Biofuels

An alternative to fossil fuels, are biofuels. Biofuels are options to fossil fuels that are produced by harvesting biomass. The first biofuels were based on edible biomass, the second generation on food production waste and wood there also exists variants produced by algae (Khan et al, 2022). A study that claims that biofuels are a part of the solution to climate change, suggests that between 50 and 150 EJ (Exajoules, EJ= 10^{18}J) in biofuels can be produced annually by forestry and agricultural residues and other organic wastes (Popp et al, 2014). Biofuels have the same emission issues as other energy-source, that in addition to releasing emissions when used, they have upstream emission through production.

A study of Swedish Biofuel production, where the clean renewable energy is used for production, production they found production emissions of the biofuel to be around 0.4 $gCO_2eq./MJ_{MeOH}$ (Basile et al, 2022). There is also a need to consider that while not necessarily emitting global warming emissions, biomass-production demands freshwater and takes up valuable arable land, and such land usage conversion must be taken into account (Maia and Bozelli, 2022).

The major benefit for using biofuels instead of fossil fuels, is that they with regards to the slow carbon cycle, does not release new emissions into the atmosphere, but recycles emissions already present in the fast carbon cycle. Which incidentally also Is a big drawback, since as long the amount of emission in the atmosphere are still cycling, and not being absorbed through the fast carbon cycle the problem of emissions in the atmosphere persists.

2.9. Steel

Steel is an alloy mainly consisting of iron and carbon. There are different ratios of carbon to iron in different kinds of steel dependant on what usage it is supposed to endure. Since we are seeking to cut emissions in this study, it is important to distinguish between lowcarbon-steel, which is a steel type appropriate for welding, while low-emission-steel is steel that is produced with low emissions.

Steel has been a broadly used material the last centuries because of its desirable properties. It is durable, malleable and have been used for heavy industry, transportation vehicles, railroads, but maybe the most desired property for engineering is the load bearing capacity it offers, relative to how much material is needed (Solberg, Christensen, and Almar-Ness, 2022). Also working in tandem with concrete steel offers better properties for concrete when used as armament.

In road construction steel can be used when the need for the load bearing capacity is needed, like for example plain steel, or reinforced concrete in bridges and tunnels, landslide netting (Maccaferri, 2019) and traffic barriers for some examples.

The iron and steel industry were the second largest energy consuming industry in 2017 and accounted for approximately 6.7% of the total manmade CO_2eq. emissions (Worldsteel Association, 2017). The two dominant methods for steel production is producing steel via reducing iron ore in a blast furnace, or by remelting steel-scrap for new products (Chisalita et al, 2019).

Emissions attributed to steel vary with the production method, but to achieve the high temperatures needed to produce steel with blast furnace (>2000oC) some amount of fuel is needed, and traditionally fossil fuels have been used (Santos et al, 2013). A lot has been done within the industry to reduce the amount of energy needed to produce steel, according to the industry itself, the industry had by 2010 reduced the energy consumption per tonne steel produced by 60% compared to 1960 (Worldsteel Association, 2017). Another way to reduce emissions is by implementing CO_2 Capture and Storge (CCS) technology to reduce emissions from steel production Santos et al in a study from 2013 showed that CCS technology could avoid between 50% and 60% of the emissions to be emitted into the atmosphere, reducing carbon impact (Santos et al, 2013).

To cut emissions from steel using the improved methods in the steel industry, it is important to make use of EPDs, and demand low emission steel when possible, if the desired outcome is to cut emissions from steel consumption. A different approach to reduce emissions from steel would be to look for possibilities to substitute the steel usage with different less emission-intense solutions and materials.

2.10. Concrete

Concrete is a construction material that is made through a chemical reaction based on cement, water, sand, and gravel, that is widely used throughout the world (Thue, 2019). For road construction it is used in tunnel vaults, shotcrete, prefabricated elements, cast in place concrete is used in small and large bridges, it can be used as traffic barriers and some pavements have concrete-asphalt. Concrete has good load-carrying capacities, especially when combined with steel armament, and is therefore often used where such properties is sought (Thue, 2019). Research on LCAs for road construction suggest that concrete should be a major emission contributor for road projects (Li et al, 2020; Luo et al, 2021).

Studies of concrete has shown that it is possible to produce concrete, with significantly reduced emissions than the CEM-I types, without sacrificing much in durability (Limbachiya, Bostanci and Kew, 2014). Suggestions to use such low-emission concrete are already in place in the standard contracts produced by Statens Vegvesen, (Statens Vegvesen, 2022b; Statens Vegvesen, 2022c), Nye Veier and Zero have the suggestions to use low-emission concrete where possible in their projects, and suggest using concrete produced with CCS technologies when that comes to the market, also stating that substituting concrete with less emission-intensive materials when possible could be beneficial (Zero, 2020). Such a product will come to the market quicker if the public offices demand them a study have found (Stokke et al, 2022).

3. Method

3.1. The literature study

For the scientific literature study, I mainly used sciencedirect.com as my search engine. I knew I was going to use LCAs, so I started the search by searching generally for LCAs about road construction, and then expanding the search to also include the building sectors. When I found interesting studies that matched well with what I was looking for, I started snowballing from them and looked at what articles and studies they have cited and been cited by.

I also searched for studies looking for information on the different materials of road construction with regards to LCAs, carbon impact, emission cuts etc, also here looking at what articles were cited by them and cited them when interesting articles were found. Such searches for material LCAs were keyworded on the form were on the form "_____+LCA" or "_____+LCA+road" or "____+LCA+construction", as shown by the example in figure 5.

I also found that quite a few of the articles that were useful came from the same journals, so to make sure that I had gotten insight in all the newer published materials in the field, I used the same keywords I used with sciencedirect and looked at the results from the last two years within those Journals as a part of snowballing. The "*Journal of Cleaner Production*", "*Construction and Building Materials*", and "*Science of the Total Environment*" journals were the journals that such searches were done in.

The literature study was limited to papers written in the English language, but as one of the goals of the study is to identify emission cuts within road construction in Norway, the non-scientific study included sources of Norwegian authorities and administrations written in Norwegian.

As mentioned, in addition to the scientific literature study, google has also been used as a search engine to access information outside the scientific community, such as information from governmental institutions, the European Union, the United Nations, Norwegian public offices, encyclopaedias etc.

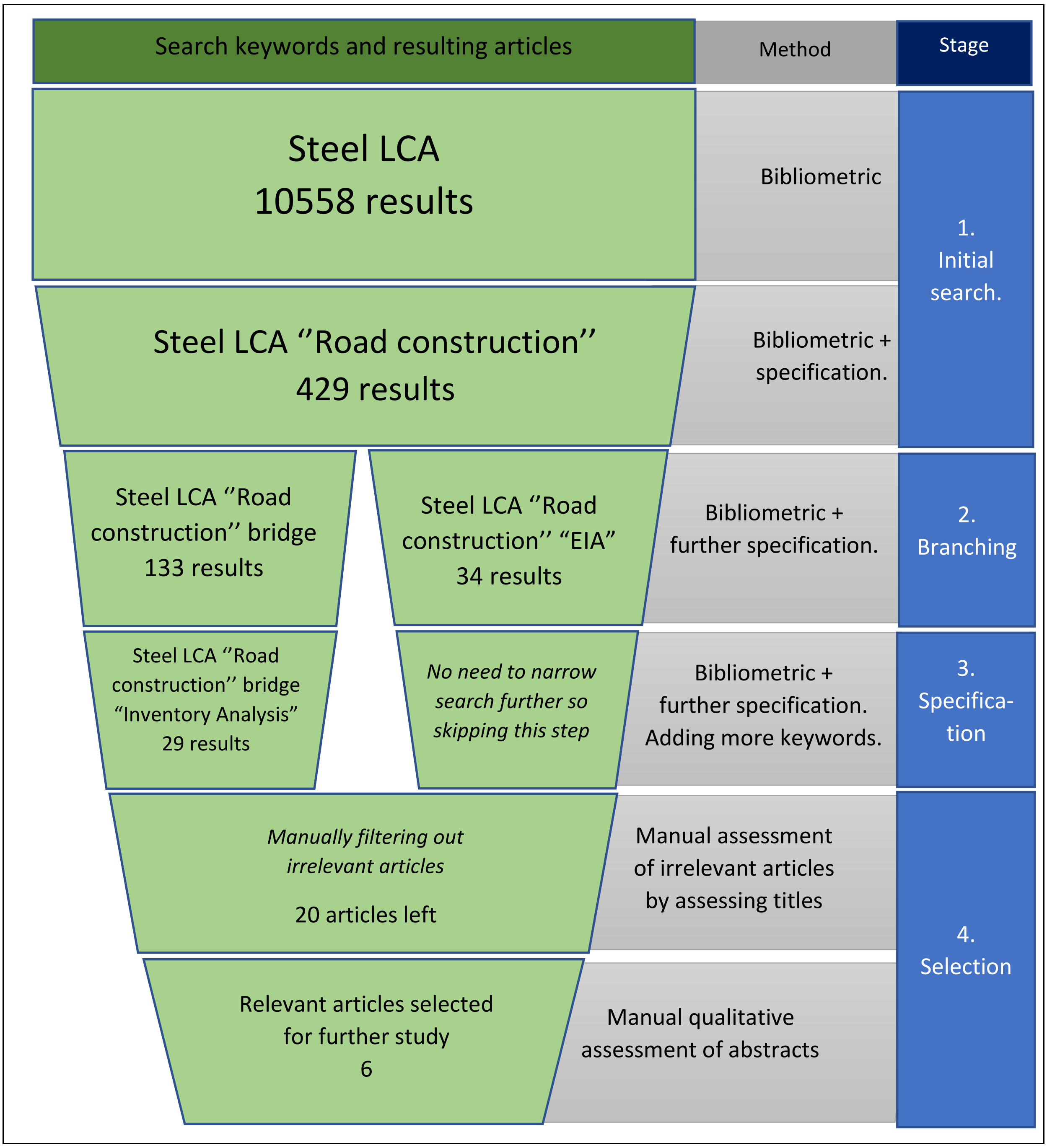


Figure 5: Example of the search procedure for how to find LCAs for Steel that are relevant for road construction, in the sea of other journal entries available.

3.2. How the LCA of the portfolio will be conducted

This study will be doing a standard LCA approach within the ISO 14040 and ISO 14044 guidelines. We will establish a scope and goal for the study, which in short is to gain more insight into a portfolio of 49 infrastructure projects, so we can identify good actions that can be taken to cut emissions in the future. We are doing that up by setting up a database that takes in the data from the LCAs of the portfolio, including metadata about road width, length, traffic, infrastructure type etc. It will take in all the Inventory Analysis from the portfolio and the Environmental Impact Assessments from the portfolio and organise it for analysis over the entire portfolio and as individual projects. These will then be interpreted to establish what has been the major emission contributors for the portfolio as a whole & what are the major emission contributors for typical projects.

By analysing and interpreting this data in the databank we will gain insight into where the potential emission cuts are. After the major emission contributors are established, we will go back to the Inventory Analysis and Investigate where the major contributors to individual materials come from, are they the optimal solutions and try to suggest policies to enact to either reduce the amount of such materials needed or reduce the carbon intensity of the material chosen. The Goal and Scope will be presented in further detail in the section for the case. The Inventory Analysis and the Environmental Impact Assessments will be done with the excel database as described under and how the data-interpretation will lead us to suggestions for emission-cuts will be explained later in this chapter.

3.3. The Excel database

As a part of the thesis, I wanted to make a database of the LCAs. While there exist tools better suited for statistical analysis than Excel, they can seem daunting for someone that lacks the experience with such programs. As there is a secondary goal besides to be able to use it for statistical analysis for my own thesis, I wanted to provide intuitive and easily accessible data and graphics for other people fresh to the LCAs on roads, the general public and research. As Excel spreadsheets are in my opinion the least daunting option for providing such a database, Excel was chosen as the software for the database.

The database will consist of six datasheets working together to provide information to the reader: A sheet to take in the data from the LCAs, a sheet to turn the data into a interactive pivotable, a sheet to take in information from the input data-table and the pivo-table and do calculations and make charts and graphs, a front page that lets the user interact with the dataset and give visual feedback of the overview of the emission profile for select sources, a second pivotable to be used with a sheet for statistical analysis and a final sheet for statistical analysis. A walkthrough of how the databank is set up is provided in Appendix A, and an overview of its workings can be seen in figure 6.

3.3.1. Input datatable

A datasheet where the raw data from the LCAs will be input. The data in the datasheet will mainly be the raw data for Environmental Impact Assessment, and Inventory Analysis produced by the LCAs provided, but it will be made in such way that it is possible to expand the dataset in the future if more LCAs made with VegLCA are provided. Most inputs in the datasheet will come from the LCAs, but some inputs will be calculated within the dataset.

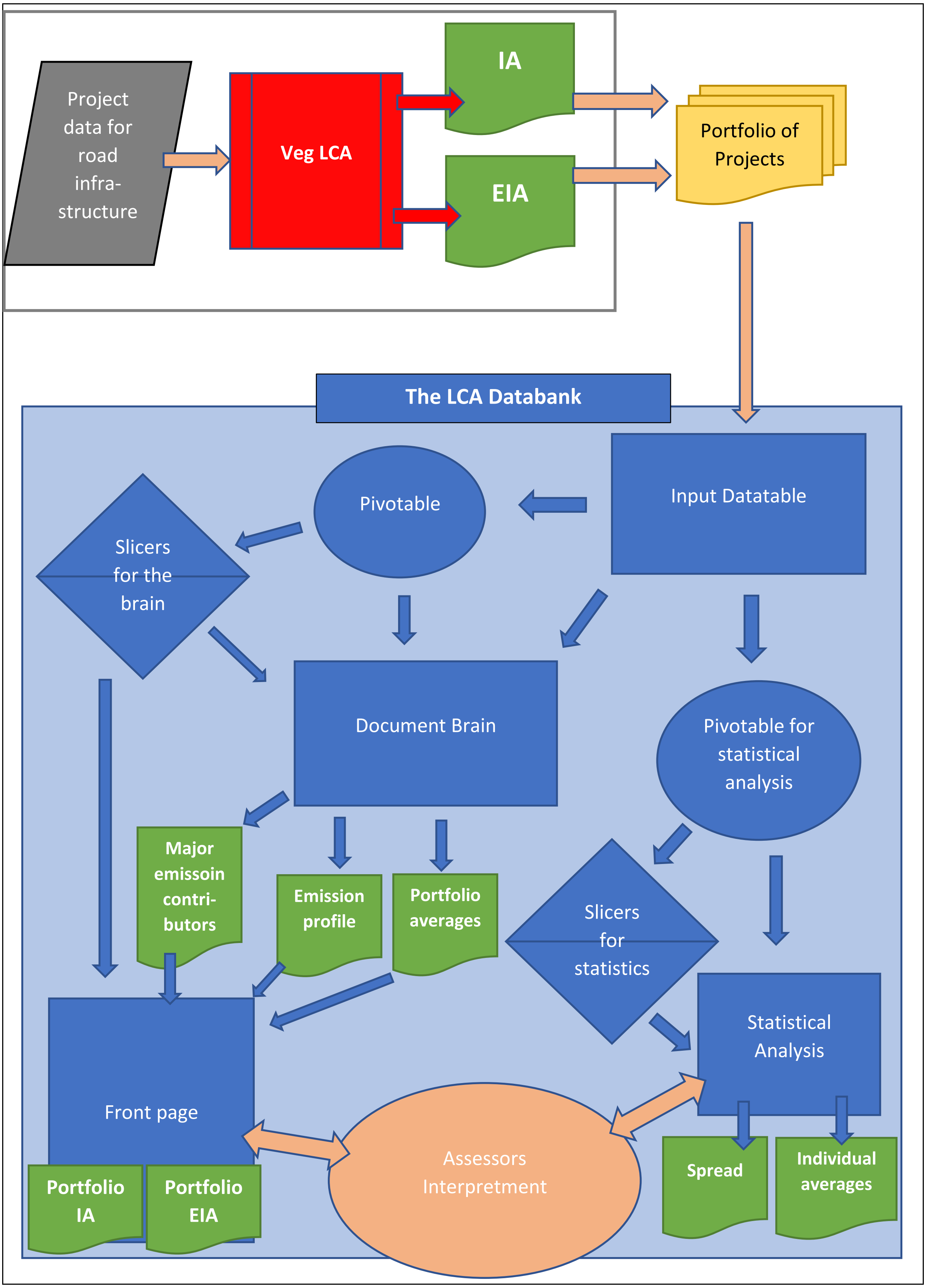


Figure 6: Overview of the workings of the LCA databank. An assessor that has a portfolio of projects analysed with the tool VegLCA, can use the Databank to navigate the data and gain adittional insights. Red indikates Processes done by VegLCA, blue indicates processed done by the LCA databank, and beige indicates work that has to be done by an assessor. Green indicates information to be gained.

3.3.2. Pivotable

The pivotable will be a sheet dedicated to summing up all the values in the input data-table for the projects selected by the user. The projects should be able to be selected within by clicking different buttons that selects different selections of projects. Such a functionality can be provided with slicers, and these should be made to control the pivotable.

3.3.3. Document Brain

The document will need a brain where it can take in numbers from the input data-table and the pivotable and do calculations on them and create graphs and charts. By putting the slicers that control the pivotable in the document brain, they document brain can interact with the dataset in the pivotable and change selections for the calculations. The document brain should provide necessary data analysis for the entire portfolio, and those should be displayed in the front page.

3.3.4. Front page

The database will need a front page, where it is possible to interact with the dataset and gain immediate knowledge about the emission profile of different selections of data. The front page will gather the slicers from the pivotable, and graphs from the document brain sheet, and have it presented in a way that is intuitive and interactive for the user.

3.3.5. Pivotable for Statistical analysis

While the first pivotable has the job of summing projects based on selection criteria, the second pivotable will be used for displaying individual projects so they can be graphed based on selection criteria. Therefore, a secondary group of slicers will be produced from this pivotable to be used with the statistical analysis sheet. To avoid confusion these slicers will have different colours than the ones in the document brain and the front page.

3.3.6. Statistical Analysis

We need a sheet to analyse spread within selected projects, so this sheet will take in the pivotable for statistical analysis, and to make the graphs we need to present the dataset and analyse the spread for individual projects. It should be interactive like the document brain and easy to use.

3.3.7. The Excel database's role in the thesis

The excel database is the source of a lot of the data used in calculations and analytics done for the portfolio and selections of individual projects.

3.4. Interpreting the Environmental Impact Assessment

3.4.1. Identifying Major and Large contributors to emissions

When the emission profile of the portfolio is done "major" and "large" contributors to emissions will have to be identified. For this study a contributor will be classified as a "major contributor" if more than 15% of the total emissions of the portfolio came from a single contributor. The idea being that at the end of 2022, there is 7 years until 2030 when we should have reduced the emissions by 50%-55%. Reducing half the emissions of a ~15% contributor every year, would get us to the goal.

For this study, a contributor will be classified as a "large contributor" if more than 5% of the total emissions in the portfolio came from that single contributor. The idea being that one can combine actions and policies that reduce emissions by for 2-3 large contributors, combining to ~15% of the total, and they would have the same effect as halving the emissions of a "major contributor," and get us to the goal.

3.4.2. Cut-off

Emission categories that do not make up at least 5% of the total emissions of the portfolio can be mentioned but will not be investigated further by this study.

3.4.3. Grouping similar contributors

As some of the emission contributors are the same materials in the LCAs provided by Trøndelag fylkeskommune, some of the emission categories have been grouped together during analysis of emission contributions. Construction equipment takes in both the Scope 1 emissions from fuel usage and the Scope 3 emissions from wear, maintenance, and reduction of lifetime of used machinery. The Transportation vehicles takes in both the Scope 1 emissions from fuel usage and the Scope 3 emissions from wear, maintenance, and reduction of lifetime of used the transportation vehicles. Concrete-elements, concrete-vaults, Cast-in-place Concrete, and shotcrete have all been grouped together as concrete. Construction steel, steel spunt, steel armament & bolts, steel peeles, steel tensile armament and the steel other categories have been all grouped together as "steel," when looking for major and large contributors.

3.4.4. Spread

In addition to investigating the emission profile for the total portfolio, we also want to investigate the emission-profiles for each individual project and the spread of these. Here we will look at the percentages of emission attributed to the major and large contributors for each individual project. Emissions not allocated to either of the major or the large contributors, will be grouped in a "other" category to analyse to what extent the major and large contributors to emissions make up of emission contributions to the typical projects.

3.4.5. Outliers

The dataset might contain outliers, that offset the results of the analysis. With regards to analysing the total emissions of the portfolio the outliers will be kept in the portfolio. The reasoning is that if a few projects manage to skew the entire portfolio – then those are definitely projects that are necessary to identify good emission cut actions for. For the analysis of the spread we are more interested in finding emissions from a typical project and here might there be worth removing some outlier-data.

If projects seem to have very skewed emission data and have the following characteristics:

- They make less than 300 meters of infrastructure and more than 30% of the project is not a road project.

In addition, the projects considered "minor" projects, that are not expanding the road network will also be removed when looking at the spread within road projects.

3.5. Interpreting the Inventory Analysis

After identifying what contributors are the largest emitters of emissions, by interpretating of the of the Environmental Impact Assessment, we go back to the Inventory Analysis to see what projects that are large contributors to these (if any). After investigating the Inventory Analysis with regards to the large and major emission contributors, it will be researched whether something can be done either to reduce the quantity of materials needed, or the carbon impact of the chosen material if it is irreplaceable.

We want to interpret the data in the Environmental Impact Assessment and the Inventory Analysis to find good actions to cut emissions, we also want to estimate how much emissions would have been cut within such a portfolio of projects, as a reference to what similar projects would have cut in emissions in the future.

3.6. Method for replacing diesel engines with electrical engines

One of the national goals is the one from Klimakur 2030, which has a specific target of transitioning away from diesel engines, towards other energy sources such as hydrogen or electricity. In this study we are going to investigate the effect of doing such a transition from ICE to Electrical Engines (EEs). To do so we need to calculate how much electrical energy is needed to replace the diesel, and then we need to calculate the emissions associated with the production of that electricity.

3.6.1. Calculating how much energy is needed to replace diesel with electricity

To calculate the amount of energy needed to replace the work done by diesel with electricity we need the following information:

- Energy contained in diesel.
- Efficiency of electrical engines and Internal Combustion engines.
- Efficiency loss of electricity from power generation to battery in vehicle.
- By research the study has found the following numbers to be used in the calculations:
- Diesel contains about 36 MJ (Miljødirektoratet 2020).
- The studies researched gives us EE efficiencies of 0.95 (Andawari et al, 2017) and ICE of 0.4 (Tan et al, 2021).
- Efficiency loss from electricity-generation to ready to use in battery driven electrical Vehicles of 17% (European Federation for Transport and Environment AISBL, 2020).

Additionally, we will need to convert Megajoules (MJ) to kilowatt-hours (kWh) to compare with electricity. We use the knowledge of watts being a measurement of Joules per second, and the knowledge that there are 3600 seconds in an hour, to get:

Equation 3.1: Conversion ratio for Watt-hours to Joules:

$$Wh = \frac{J}{\cancel{s}}\cancel{h} * \frac{3600\cancel{s}}{\cancel{h}} = 3600\,J$$

Equation 3.2: Sorting for Joule as standalone factor:

$$J = \frac{Wh}{3600}$$

As we have Joules in MJ, and want Watts in kilo, we must compensate when adjusting to MJ by using the ratio Mega = 1000*kilo.

Equation 3.3: Final ratio of conversion:

$$MJ = kWh * \frac{1000}{3600} \approx 0.2778\, kWh$$

Note: There will also be upstream emissions attributed to the production and transportation of the diesel used in the engines. This will however not be further addressed when calculating the emissions to replace the diesel with electricity. The benefit of not having these emissions as a result of cutting diesel usage will be considered a hidden bonus effect.

Using the information provided by research we get the following formulas for calculating electrical energy production needed to replace a litre of diesel doing construction work:

Work done by 1 litre of diesel with 36 MJ/l energy density, and an ICE with 40% efficiency:

Equation 3.4: Work done by 1 litre diesel:

$$1\, l * 36\, \frac{MJ}{l} * 0.4\, effiency = 14.4\, MJ = 4.00\, kWh$$

Electricity-production needed for an electrical engine to do 4kWh of work, given 95% efficiency and 17% efficiency loss from electricity-generation to battery:

Equation 3.5: Electricity production needed to replace 1 litre diesel:

$$\frac{\left(\frac{4.00\, kWh}{0.95}\right)}{0.83} = 5.07\, kWh$$

To replace work done by an ICE on 1 litre of diesel with work done by a battery electrical vehicle about 5.07kWh of electrical energy would have been had produced to power the vehicle including efficiency losses.

We will also need to be able to calculate the emissions from fuel usage. VegLCA uses a conversion ratio to direct emissions of 2.67 kgCO_2eq. per litre diesel consumed. This conversion ratio is supported by Transportøkonomisk Institutt (TØI) which operates with 2.66 kgCO_2eq. in their calculations (Fridstrøm, 2020). Other studies have operated with 2.64 kgCO_2eq./litre. (McLeod et al, 2020) So this study is confident that somewhere around 2.66 kgCO_2eq. is a peer accepted ratio for calculating emissions from burning diesel.

3.7. Calculating indirect emissions from electrical energy

There are no direct emissions (Scope 1) from electrical d vehicles powered by a battery. However, there are indirect emissions associated with the electricity (Scope 2), as there are emissions from the production of electricity. The production and maintenance of powerplants, production and maintenance of the grid, and what power source the electricity-production is using affects the Scope 2 emissions from electricity. There are arguments to be made for several different ways of how to estimate the scope 2 emissions from electricity usage dependant on what scope one wishes to analyse over. Under the main scenarios used in this study is presented.

3.7.1. Scenario 1: The emissions attributed to the Norwegian electricity-consumption mixture

Reasoning: The Norwegian electricity mixture is suited for calculations on replacing fossil powered ICE with electrical engines in Norway. Norway as a producer and consumer of electricity will face increased domestic demand for electricity caused by the electrification of fossil powered vehicles. The demand for electricity in Norway will in periods be met by Norway's own energy production, and in periods it will have to be supplemented by import. The emissions attributed to the electricity consumed in Norway could therefore be tied to the sum of emissions attributed to electricity production in Norway for the part of the Norwegian electricity demand met domestically + the sum of emissions attributed to the part of electricity production that is of foreign origin. The calculations of the emissions attributed to electricity consumption in Norway is done by the Norwegian Water Resources and Energy directorate, (NVE). The emissions attributed to Norwegian electricity mixture was in 2019: 17 gCO_2eq./kWh, in 2020: 8 gCO_2eq./kWh and in 2021: 11 gCO_2eq./kWh (Norges Vassdrag- og Energi-direktorat, 2022c). Giving an average of 12 gCO_2eq./kWh, which is what will be used as the Norwegian electricity-consumption mixture for Scope 2 emissions.

The Norwegian electricity mixture is the default scenario for the construction phase in VegLCA. The Norwegian electricity mixture is 94% renewable energy sources. (Norges Vassdrag- og Energi-direktorat 2021). In 2021 The Norwegian electrical production surplus was at about 17 TWh (Statistisk Sentralbyrå, 2022a), while the domestic sales of petroleum products in 2021 was 8 731 million litres of those 952 million litres were diesel for construction equipment (Statistisk Sentralbyrå, 2022b). Using the information calculated earlier in the study (Equation 3.5) 1 litre of diesel requires about 5.07kWh, the 952 million litres of diesel for construction equipment would require only:

Equation 3.6: How much electricity production needed to replace all work done by construction diesel:

$$952\ 000\ 000 * 5.07\ kWh = 4\ 826\ 640\ 000\ kWh \approx 4.827\ TWh$$

There is therefore enough energy surplus produced in Norway to cover this extra electricity needs. However, should electricity be used to cover the work done by the additional 3 842 million litres of petrol-products used by fossil driven cars (Statistisk Sentralbyrå, 2022b) we would need:

Equation 3.7: Electricity production needed to cover for all petroleum purchased in Norway:

$$3\ 842\ 000\ 000\ *\ 5.07\ \mathrm{kWh}\ =\ 19\ 478\ 940\ 000\ \mathrm{kWh} \approx 19.478\mathrm{TWh}$$

19.478 TWh are needed in addition to the 4.827 TWh needed for construction vehicles. This is above the power surplus Norway had in 2021.

Emissions attributed to electricity consumed in Norway: 12 gCO_2eq./kWh (Norges Vassdrag- og Energi- direktorat, 2022c).

3.7.2. Scenario 2: The emissions attributed to the European electricity market

Reasoning: Norway is a part of the European energy grid and during the year it exports and imports electricity to and from Europe to help offset production needs. Norway's internal electricity-production is 91.5% hydropower (Statistisk Sentralbyrå, 2022), which is more flexible than many other electricity production methods, as water can be held back in magazines and electricity can be produced when needed. Surplus clean electricity production in Norway can reduce the demand for electricity produced on fossil sources in the European electricity-grid.

Emissions tied to Norwegian electricity-production (not to be confused with the emissions tied to the Norwegian electricity consumption) is very low compared to the European electricity mixture. 38 053 MW in Norway is produced with clean, renewable sources like hydropower or wind-power, while 690MW production capabilities from thermic powerplants represent ~2% of the installed effect. (Norges Vassdrag- og Energi- direktorat, 2022a, Norges Vassdrag- og Energi- direktorat, 2022b). The European electricity mixture is in comparison 9.9% renewable, 24.4% nuclear and 65.7% fossil fuel (Association of issuing bodies, 2022). The European electricity-production is increasingly improving regarding reducing emissions. Estimates from the European Environment Agency suggest it is around 220 gCO_2eq./kWh in 2020 (European Environment Agency, 2021a). However, this only includes European countries that is a part of the European Union. A study of the carbon intensity of electricity produced and consumed in European countries in 2019 (Scarlat, Prussi and Padella, 2022) suggests that it should be somewhat higher for the European union at 296 gCO_2eq./kWh in 2019, (and for Norway, 28 gCO_2eq./kWh), but here some extra factors are considered into the emissions of the electricity production. If we set aside the upstream emissions from fuels and the extra emissions regarding dismantling powerplants we get about the same emissions as NVE had for 2019. Based on data from this study (Scarlat et al, 2022), I will use carbon impact of the electricity produced for Europe 307 gCO_2eq./kWh.

When the 307 gCO_2eq./kWh of Europe is compared to the emissions the study uses for Norwegian emissions 28 gCO_2eq./kWh, every kWh that Norway exports to Europe is a kWh that is not needed to be generated in Europe, thus every exported kWh is 307 gCO_2eq. – 28 gCO_2eq. = 279 gCO_2eq. saved. As electricity consumed in Norway cannot be exported, thus the opportunity cost of using electricity in Norway could be set equal to those 279 gCO_2eq./kWh not saved, in addition to the 28 gCO_2eq./kWh from the electricity consumed.

Emissions attributed to production of electricity in Europe: 307 gCO_2eq./kWh (Scarlat et al, 2022).

3.7.3. Scenario 3: The Scope 2 emissions of electricity should be attributed as if produced by fossil power-plants

Reasoning: For every kWh of demand added to the grid another kWh of electricity has to be produced. The idea is that as long as there is not a surplus of electricity made with renewable or non-fossil sources, every additional electricity demand has to be covered with power created by fossil fuels and is extending the time where electricity-production is dependent on fossil sources. If a litre of diesel is not used in an ICE as it is replaced with electrical engine, but as a result of the increased demand for electricity a litre of diesel is burnt elsewhere, was the intended effect achieved? In addition to that, there is also the efficiency loss over the electrical grid, and the additional efficiency loss for the electrical engine that might suggest that it could be worse to replace ICEs with electrical engines. Batteries can however, charge in periods with low demand and utilize excess capacity and utilizing carbon capture in a single centralized powerplant is easier to achieve than for several individual ICEs, so there are some remedying factors, if they are implemented. For finding numbers for further use, the study uses numbers from the US. Energy Information Administration, that claims the following values for their fossil driven power plants (US. Energy Information Administration, 2021).

Coal: 767 million tonnes CO_2eq. released for 757 763 million kWh produced (US. Energy Information Administration, 2021). Giving an average of:

Equation 3.8: Carbon impact of electricity produced by consuming coal:

$$\frac{767\ 000\ 000\ 000\ 000\ gCO_2eq.}{757\ 763\ 000\ 000\ kWh} = 1012 \frac{gCO_2eq.}{kWh} produced.$$

Natural gas: 576 million tonnes CO_2eq. released for 1,402,438 million kWh produced (US. Energy Information Administration, 2021). Giving an average:

Equation 3.9: Carbon impact of electricity produced by consuming natural gas:

$$\frac{576\ 000\ 000\ 000\ 000\ gCO_2eq.}{1\ 402\ 438\ 000\ 000\ kWh} = 411 \frac{gCO_2eq.}{kWh} produced.$$

Petroleum: 13 million tonnes CO_2eq. released for 13,665 million kWh produced (US. Energy Information Administration, 2021). Giving an average:

Equation 3.10: Carbon impact of electricity produced by consuming petroleum:

$$\frac{13\ 000\ 000\ 000\ 000\ gCO_2eq.}{13\ 665\ 000\ 000\ kWh} = 951 \frac{gCO_2eq.}{kWh} produced.$$

Should the increased energy demand be met with further usage of fossil fuels in electricity-production, then that electricity should be attributed Scope 2 emissions of 950 gCO_2eq./kWh – 1010 gCO_2eq./kWh for petroleum or Coal, or 411 gCO_2eq./kWh if the extra electricity demand is met with natural gas as power source.

3.7.4. Scenario 4 – The assumption of a more carbon neutral future

Reasoning: The International Energy Agency (IEA), claims that to reach the worlds goals of vastly reducing emissions, an enormous increase of available renewable clean energy is needed (International Energy Agency, 2021). In idea four we use the electricity mix for Europe as in idea two, but we assume that the goals set for renewable energy in 2030 and 2050 will be met. The reasoning behind this assumption is that no public office of any country can achieve the immense task of stopping global warming by itself, it must assume that all other public offices and governmental branches work towards reaching goals they have announced. By assuming that the rest of the world will do its part according to announced plans, each public office can concentrate on planning emissions cuts within their own jurisdiction and using other announced plans as future facts for such planning.

According to the European Environment Agency, the share of electrical energy in the EU-27 was 20% in 2019, the goal for the European union is 32% renewables in 2030 and 95% by 2050 (European Environment Agency, 2022a). Assuming the 307 gCO_2eq./kWh found in idea two is correct for an 80% fossil fuelled power grid in 2019, the emissions per kWh should be reduced to:

Equation 3.11: Emissions allocated to 1kWh in Europe in 2030:

$$307 * \frac{68}{80} = 255 \text{ gCO}_2\text{eq./kWh}$$, in 2030 with 68% of electricity based on fossil fuel.

Equation 3.12: Emissions attributed to 1 kWh in Europe in 2050:

$$307 * \frac{5}{80} = 19.2 \text{ gCO}_2\text{eq./kWh}$$ in 2050 with 5% of electricity based on fossil fuel.

Scenario 4 gives us two emission attributes for electricity, 261g CO_2eq./kWh for 2030 and 19.1 gCO_2eq./kWh for 2050.

4. Case

4.1. The LCA databank

4.1.1. Goal

The goal of the LCA databank is to gain insight into the emission profile on a scope 3 level, for a portfolio of road infrastructure projects, to identify major and large contributors to emissions for these projects. Further as a result of this identify good policies and actions that can be suggested to policy makers, to cut emissions in future road infrastructure projects.

4.1.2. Scope

The regional road-network in Trøndelag, «Fylkesvegprosjekter I Trøndelag»

The scope of the study will be limited to infrastructure projects built by Trøndelag fylkeskommune (and the two counties, Sør-Trøndelag and Nord-Trøndelag, which combined to Trøndelag 01. January 2018) since 01. January 2010. The scope is further limited to what LCAs on infrastructure projects that are available for the study.

The scope of the study will also be limited to be looking at ways to cut emissions in the construction-phase, A1-A5, which includes the scope 3 emissions to the manufacture and transportation of materials consumed of the road construction, but will not look at usage, maintenance, or the end of life for road construction. In other words, the scope will be analysis for "cradle to gate".

The dataset

The dataset analysed is a portfolio of 49 LCAs assessed by Trøndelag fylkeskommune, done in 5 different versions of the LCA assessment tool "VegLCA". The projects are some standalone projects, and some are minor & major partial projects of larger infrastructure upgrades.

The dataset contains amongst other details:

- 31 vehicle road projects of total 104 km road infrastructure.
    - Here of 87.8 km road.
    - 8 projects containing tunnels, with a total of 13.7 km tunnels assessed.
    - 15 projects containing bridges, with a total of 2.6 km bridges assessed.
- 7 roads for pedestrians/cyclist of total 12 km pedestrian infrastructure.
- 11 other road infrastructure related minor projects.
    - 3 Reinforcement projects, 2 Ferry Quays, 1 vegetation clearing project, 1 traffic safety project, 1 preparation work, 1 gravel road and one project for maintenance of a cultural heritage bridge.

All the datasets included their Inventory Analysis, and their Environmental Impact Assessments. For the datasets in the portfolio, 16 of them only utilized the standardized values provided by VegLCA. The remainder of the datasets had two types of specified data-inputs. They either had specified thickness of different layers of asphalt other than standardized values, specified transportation distances to depots and quarries or both. Where such data was present in the datasets, such information was marked in the "Project specific data" column in the Climate LCA databank, Input Datatable sheet.

The assessor of the projects, when interviewed about the portfolio commented on the standardized values of "Mur av naturstein, tykkelse" ("wall of natural rocks, thickness"), that he and his colleagues thought that the 2.5 meters set as standard for the earlier versions of VegLCA was way larger than what they considered reasonable, and therefore the value for this was set to in the area of 0.5- 0.7 for most of the assessments where applicable. In some of the projects the desired thickness was documented to be in this area, while in others it was not. In newer versions of VegLCA, the standard for the metric has been reduced to 1.2 meters. The difference in what the assessors in Trøndelag Fylkeskommune considers as a reasonable standard, to what the assessment tool provides as standard numbers might be a source of some error. Emissions attributed to walls of natural rocks are accounted for under the category "other emission." In projects where walls of natural rocks are used natural rocks make up somewhere between 30-60% of the emissions in the "other emissions" category, dependant on whether 2.5 1.2 or 0.7 is used as a multiplicator. The other makes up about 2% of the total emissions of the portfolio. This means that this change in multiplicator value could amount up to about somewhere around 1% error for the total emissions of the portfolio.

A source of error for the entire portfolio could very well be differences in other factors for what is considered "standard" for the roads built by Statens Vegvesen, the public office that publishes VegLCA, and other public offices that construct road-infrastructure projects. Statens Vegvesen build and maintain roads of national and international importance in Norway, while most other public offices that build roads In Norway build roads of municipal or regional importance. Roads that Statens Vegvesen build and considers standard have a much higher traffic than municipal and country roads and must be built accordingly, which could lead to different dimensions in other areas as well.

4.1.3. How the data about the road projects were gathered

Trøndelag fylkeskommune, which is the road owner of all the roads within the scope for this study, has since 2020 been building up a portfolio of LCAs of infrastructure projects they have been building since 2010. To make these carbon footprint assessments they have used a Life Cycle Assessment tool called VegLCA created for use on the Norwegian road network. They have used this assessment tool and used the process descriptions used to describe projects offered to entrepreneurs as the amount of work to be done for each project. The study asked the assessor if it could have access to the assessments that had been done and such access was granted, both for the assessments and the underlying data for them.

Metadata about traffic, lane-width, speed limits etc. was to some degree provided in the assessments provided by Trøndelag fylkeskommune, however it was not provided for all projects. The study also had access to *www.vegkart.atlas.vegvesen.no* which contains detailed information about the road infrastructure in Norway and was able to find some of the lacking metadata there. However, some of the metadata about the infrastructure was either lacking or not updated after new infrastructure had been built.

Some of the metadata was gathered from the project manager of the assessed projects, through attending seminars or by sending them a request for the information.

For some of the metadata where information was not available through the official data systems, it was available through local newspapers. When such a newspaper has been used as a source it has been referenced in the "input datatable" of the Climate databank spreadsheets.

There was some discrepancy found when control checking metadata available from the provided LCAs in the portfolio and when I looked them up. Where such discrepancies have been found the data has been replaces with newfound data and source for that data has been provided in the databank.

The regional projects

Two large infrastructure-upgrade projects have been the main source of infrastructure projects in the portfolio. "Laksevegen" and "Fosenvegene" together make up 94 km out of the 123 km projects in the portfolio. There are also some projects from other regional road infrastructure projects in the portfolio such as "fv 17/720" and some from "Miljøpakken" however there was from "Laksevegen" and "Fosenvegene" most data were provided for the portfolio.

«Laksevegen»

«Laksevegen» - («the salmon road»), is a series of road infrastructure projects, which aim is to improve the accessibility of regional road fv. 714 for heavy transportation vehicles. The 7 projects seen in Figure 7, greatly improved winter accessibility, and made heavy traffic able to hold higher average speeds.

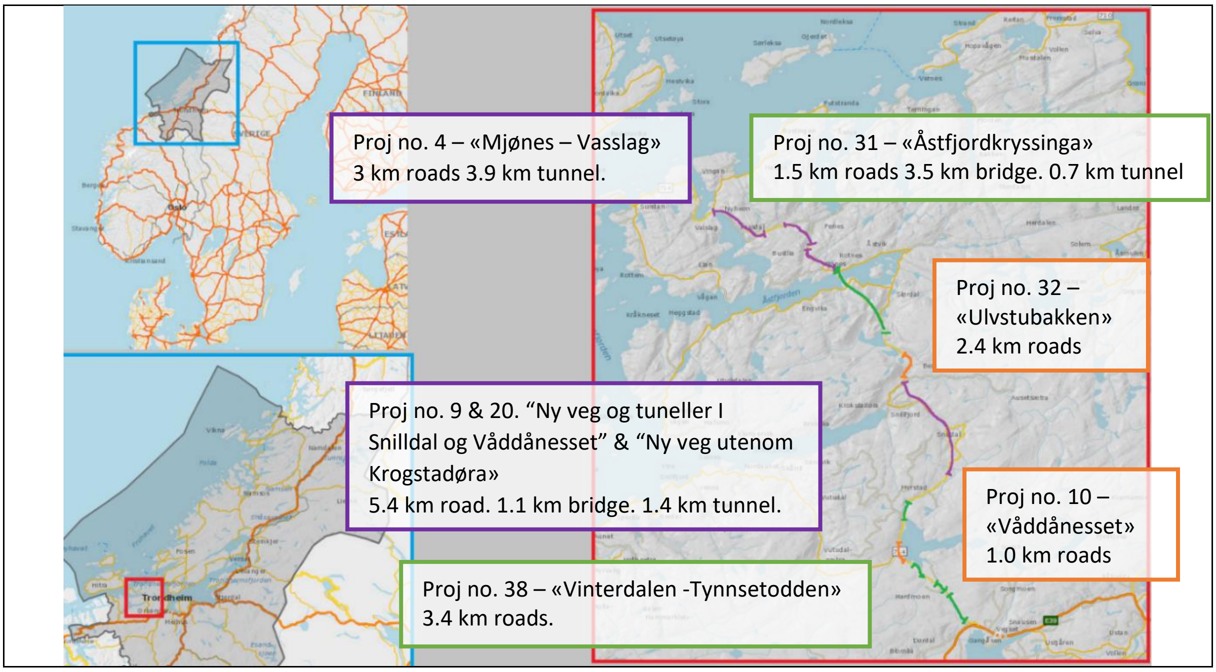


Figure 7: Map over the road projects of Laksevegen, the colour of the box corresponds with information about the same-coloured road.

«Fosenveiene»

20 of the assessed projects in the portfolio was a part of the infrastructure project "Fosenveiene" which is a road infrastructure project in on the Fosen Peninsula. They make up 63 km road, 3.4km tunnels and several bridges, the infrastructure built as of 2021 can be seen in figure 8.

Figure 8: Map over the Fosenveiene infrastructure (figure taken from presentation by Sundet, 2021).

5. Results

5.1. The Excel database

5.1.1. The “front page”

The “front page” is meant as the interactive part of the datatable, where a quick overview of general information about the sets of data available in the database can be gathered for those who access it. The front page is made up from “Slicers” gathered from the “pivotable” page, and graphs and charts based on calculations from the “Document brain” page. For a quick overview of what the front page offers of information see figure 9.

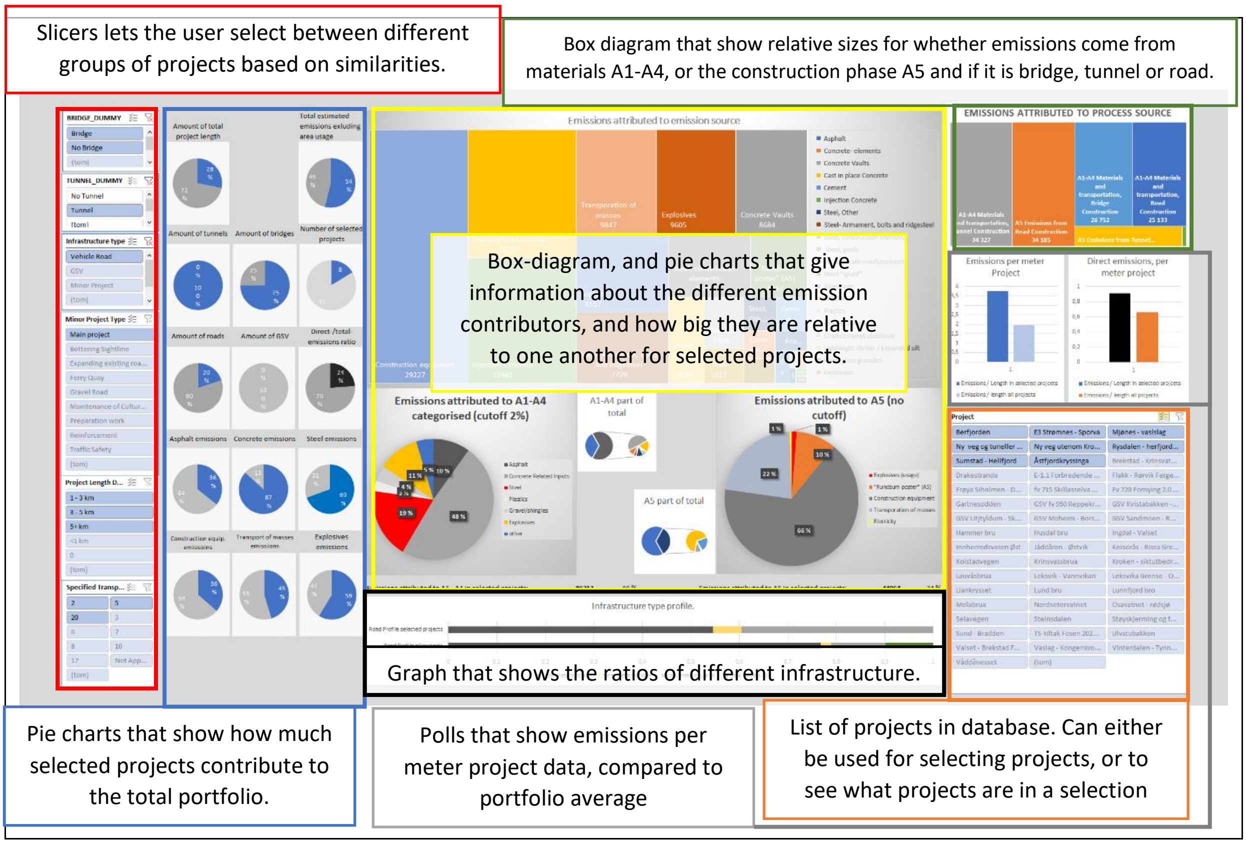


Figure 9: Overview of what each part of the "front page" is showing.

As can be seen in figure 10, with just a few clicks it is possible to receive information about the overall emission profile of the selection made. If something interesting is found and one wants to explore the data further, the calculations the graphs are based on are available in the “Document Brain” page, and the raw data from the LCAs for each individual project can be found in the “Input Datatable,” and further statistical analysis of the spread of emissions for individual projects within the selection can be found in the “Statistical analysis” sheet.

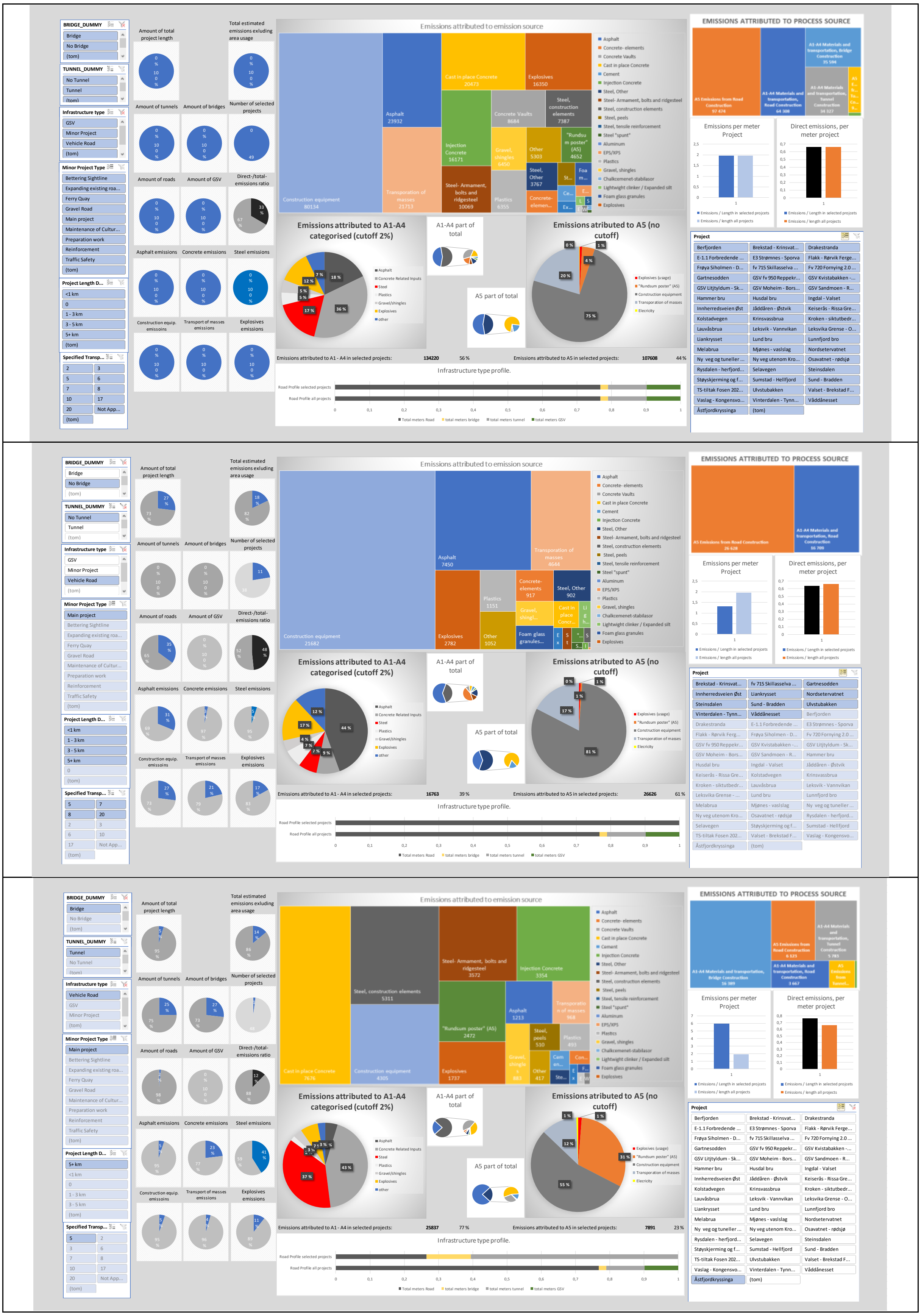


Figure 10: Examples of selections and information that is available for those selections. Top: Emission profile for the entire portfolio. Middle: Emission profile vehicle road projects with no bridge or tunnel. Bottom: Emission profile for specific project; "Åstfjordkryssinga". We can see here that groups of- and individual projects can have huge differences in their emission profiles. A higher resolution of these groups can be reproduced in the LCA-databank by making the same selections.

5.1.2. The "Input data-table"

The raw data from the LCAs of the portfolio has been put into the "input data-table" sheet. Data and metadata for all 49 projects are available from here, and it is possible to sort the columns for either data type if that is desired. By downloading the databank you can find the data here if you want to do your own research with them, or if you have your own set of LCAs you want to have analysed you can use a copy of the databank and replace these data with your own, and the rest of the databank will do the same calculations on your dataset instead of the one I have analysed in this thesis.

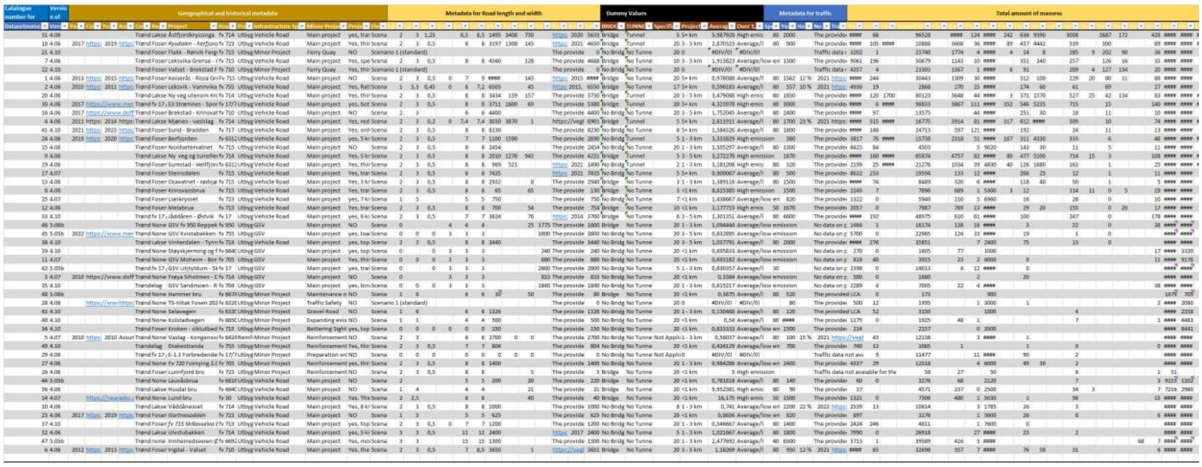


Figure 11: Screenshot of the Input data-table. Each Project has attributed data for 120 different columns with emission-data, emission-related data, and project-related data. A detailed description of the datasheet is provided in appendix A.

Most of the data in the data-table is directly grabbed from the LCAs in the portfolio, some data is gathered about the projects from external sources, and some of the data are values calculated based on the in-data. For example, the dummy-values for Tunnel and Bridge, that checks whether or not the amounts of tunnels and bridges are respectively >0 for either case and return values based on that, and there is the project length category that returns the sum of road, tunnel, bridge and pedestrian/cyclist roads (GSV) for the project length. A description for what column contains what data is provided in appendix A.

5.1.3. The pivotable

A pivotable is a different way to give structure to data than just a regular data-table. Here the data shown can be changed to include or exclude data based on given criteria. For my thesis I have been using slicers to select between different groups of data, as I see them as intuitive to use, and they give constant feedback to the user to what kind of data they have selected. A walkthrough on how the pivotable is set up can be found in appendix A. For this study we have set it up the pivotable in a way that it always sums up all the selected data to row number 9, with the header for what kind of data it is in row 8, which is something used frequently in the next section.

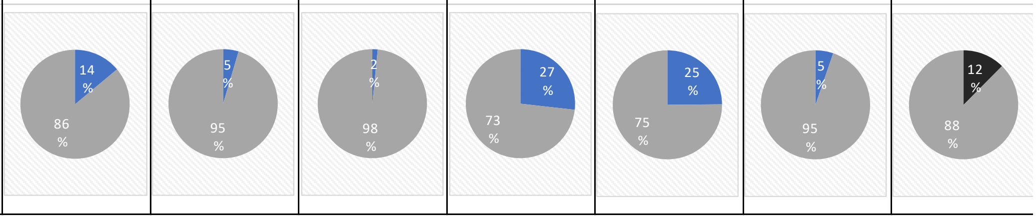
5.1.4. The document brain

The "document brain" sheet is where information from the input datatable, and the pivotable are analysed and graphed. The graphs seen on this sheet are the same that is visible at the front-page, but here all the graphs are placed next to the numbers they represent in addition the text description.

Using that information about a selected group always is found in the row 9 in the pivotable, and information about the entire portfolio is always found in the input data-table, it is possible to make interactive graphs which there are a lot of in the brain sheet. The way it is done, is that the cells in the document brain takes in information from the pivotable or the input data-table, and the graphs illustrate the cells in the brain sheet. When the slicers are used to select a different selection of projects, the cells in row 9 in the pivotable changes, and as long as the cells in the document brain are set to take in values from a specific column-row 9 in the pivotable, they change to the new values, and followingly the graph that illustrates that cell changes to represent the new information.

The Document brain contain over 80 graphs that illustrates different details about the portfolio, and the selection based on the slicer inputs, or individual projects if only one is selected. This information includes quantitative information such as how much different infrastructure is built, how much emissions are attributed to each emission category, quantities of different materials used etc. Averages such as per meter project or per meter specific infrastructure, relative quantities for how the selection of project(s) compared to the entire portfolio, and emission categories compares within the selection. An example of a few such graphs can be seen in figure 12.

Amount data %	Total estimated emissions exluding	Total length of Projects	Total Length of meters in daylight	Total length of Bridges	Total Length of Tunels	Total amount of Direct emissions	Selected direct emissions, as
Total from selected data in pivot-table	33730	5633	1495	730	3408	4289	419
Total from Input datatable	241838	123391,3333	94783	2726	13714	81648,5	3373
Percentage of selected data	14 %	5 %	2 %	27 %	25 %	5 %	12 %
Percentage of unseleceted data	86 %	95 %	98 %	73 %	75 %	95 %	88 %



Aggreagated Materials	Asphalt [tonnes]	Concrete elements [t	Gravel shingels	Cast in place Concrete + Injection Concrete [cubic meters]	Plastics [tonnes]	Cement [tonnes]	All Explosives [tonne	All Steel [tonnes]	W
Selected summed	17138	68	96528	30032	124	242	636	5867	
Rest of sum	*316663*	*2909*	*885035*	*70221*	*923*	*1061*	*5360*	*6947*	
Total all projects	333801	2977	981563	100253	1047	1303	5996	12814	

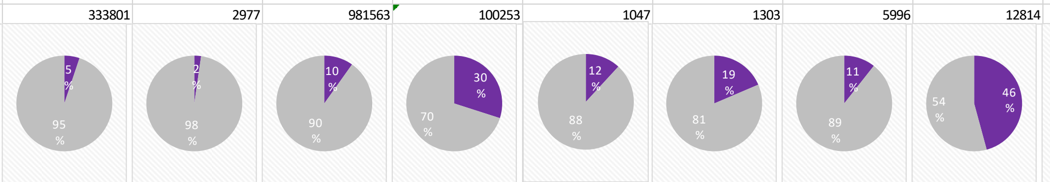


Figure 12: Sample of some of the graphs available in the Document brain, here viewing the data for "Åstfjordkryssinga".

In figure 12, the sample of a graphs we see are from the "Åstfjordkryssinga" project. In the top selection it can be seen that the project itself accounts for 14% of all emissions in the portfolio, and it has about 1/4 of all bridges and tunnels. Direct emissions – Scope 1 emissions from the project only accounts for 12% of the emissions from the project, which means that a lot of scope 3 emissions must come from the materials consumed by the project. When looking at the aggregated quantities of materials used, we see that this one project accounts for nearly half the steel consumed by the entire portfolio, and about a third of the concrete that was measured in m^3!

In the future it could be interesting to expand the databank with another pivotable, with a secondary set of different coloured slicers that lets the user compare two selections of datasets with each other, in addition to against the total portfolio. This will be left for future research when datasets from other portfolios are available. A walkthrough of the document brain can be found in appendix A.

5.1.5. Pivot for statistical analysis

The Pivotable for statistical analysis, has the same function as the other pivotable except that this one only displays the data we want to use for statistical analysis in the last spreadsheet. The two pivotable, while the source is the same data, they are separate instances. Main difference for this pivotable, is that we have de-selected the bottom row, and we have coloured the slicers for this pivotable in different colours than the primary pivotable to highlight that they control separate instances.

5.1.6. Statistical Analysis

The sheet for statistical analysis is set up in the way that an assessor can click the different slicers and change the graphs to only graph desired data. The boxes to the left (red) are intended to show / let assessors select individual projects, the middle (yellow) boxes are for selecting groups with specific criteria, and the green box (right) is meant as a "drag for range" box.

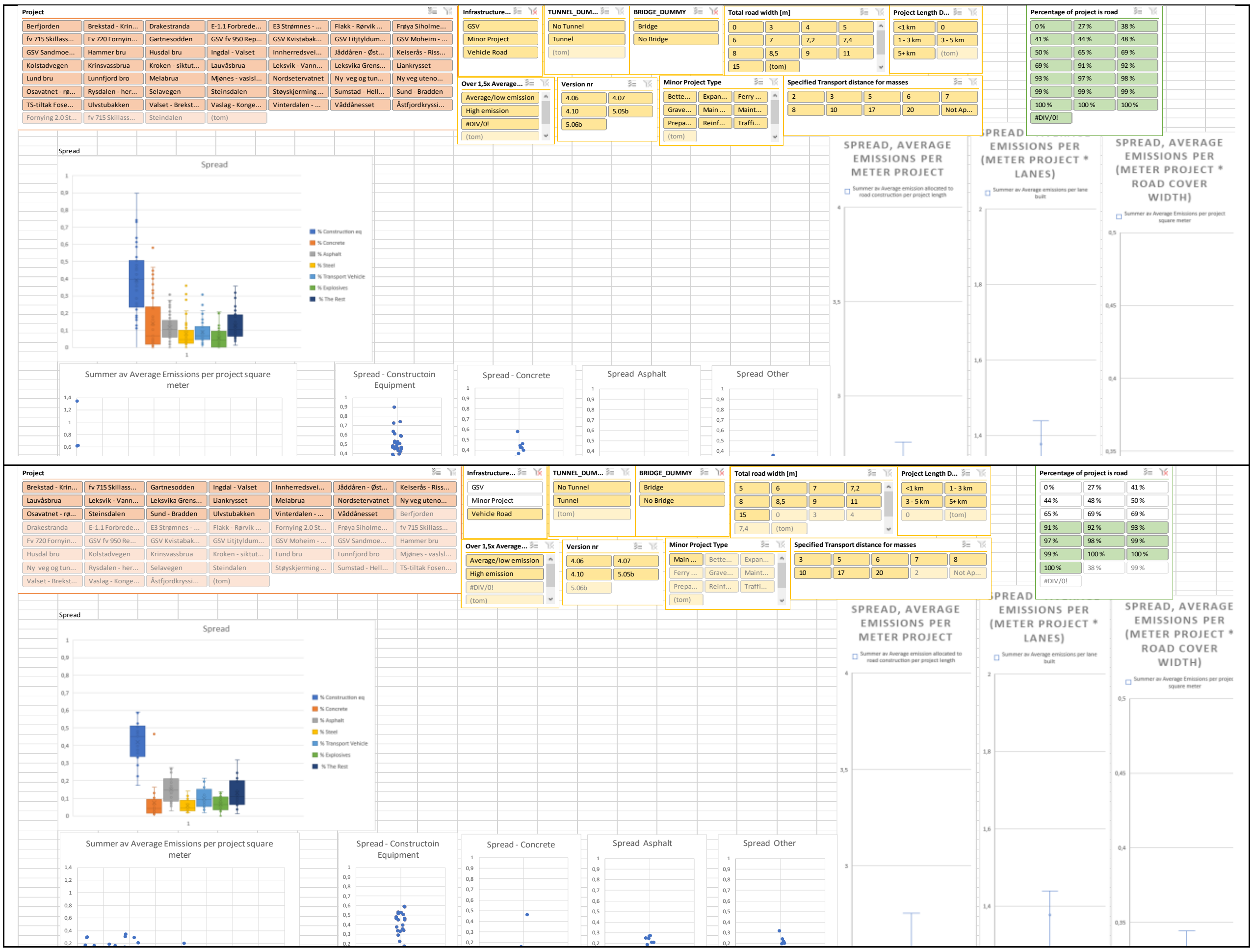


Figure 13: Example of the interactivity in the statistical analysis sheet, on top we have the statistics for the entire portfolio, on bottom only data for vehicle roads with <10% bridges and tunnels are selected. As we can see, when different values are selected, the graphs change accordingly. If further analysis is desired the example can be reproduced In the LCA databank.

5.2. Emission profile for the portfolio

Using the LCA databank the main contributors to emissions was identified for both the scope 1 and the scope 3 perspective for the entire portfolio. The databank has charts available where emissions are separated into the 28 main emission sources provided by VegLCA, by grouping together similar categories of data as described in method, we get the following results that can be seen in the figure 14:

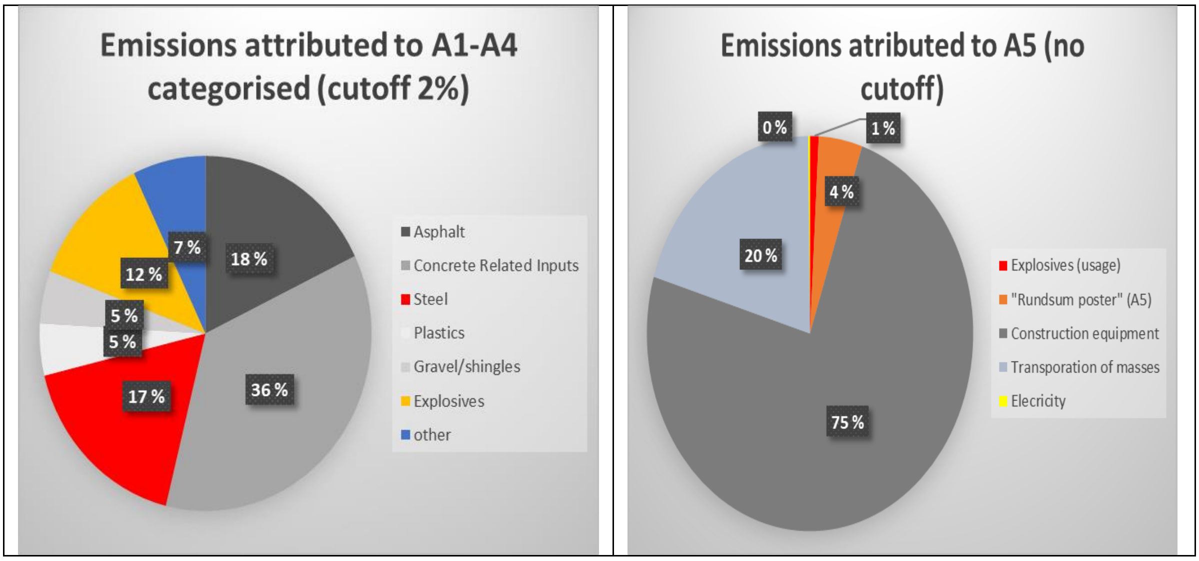


Figure 14: Emission profile for the entire portfolio, to the right we have the A1-A4 process that describes the emissions associated with the materials consumed in the projects, and in A5 we have the emissions associated to the construction phase of the projects.

The emission total for the A1-A4 process is 134 200 tonnes of CO_2eq., 55.5% of total.

- Concrete has 48 345 tonnes of CO_2eq., 36% of the A1-A4 process, and 20.0% of total.
- Asphalt has 23 932 tonnes of CO_2eq., 18% of the A1-A4 process, and 9.9% of total.
- Steel has 23 262 tonnes of CO_2eq., 17% of the A1-A4 process, and 9.6% of total.
- Explosives has 16 350 tonnes of CO_2eq., 12% of the A1-A4 process, and 6.76% of total.
- Gravel/shingles has 6 355 tonnes of CO_2eq., 5% of the A1-A4 process, and 2.67% of total.
- Plastics has 16 350 tonnes of CO_2eq., 5% of the A1-A4 process, and 2.63% of total.

The emission total for the A5 process is 107 608 tonnes of CO_2eq., 44.5% of total.

- Construction equipment. has 80 134 tonnes of CO_2eq., 75% of the A5 process, and 33.1% of total.
- Transportation of masses has 21 713 tonnes of CO_2eq., 20% of the A5 process, and 8.98% of total.
- "Rundsum poster" has 4 652 tonnes of CO_2eq., 4% of the A5 process, and 1.92% of total.
- Explosives (usage) has 916 tonnes of CO_2eq., 1% of the A5 process, and 0.38% of total.
- Electricity has 193 tonnes of CO_2eq., 0% of the A5 process, and 0.08% of total.

5.2.1. Emission profile for subsets within the portfolio

The study has also looked at the emission profile for several subsets within the portfolio, and the graphsheets for the different scenarios is available in appendix B and can be reproduced in the LCA databank. The following scenarios were looked at:

- All projects.
- Vehicle road projects – All.
- Vehicle road projects – Without tunnels, without bridges.
- Vehicle road projects – With tunnels, without bridges.
- Vehicle road projects – Without tunnels, with bridges.
- Vehicle road projects – With tunnels and with bridges.
- Vehicle road projects – Without tunnels, without bridges 3+km road built.
- Vehicle road projects – Without tunnels, without bridges <3km road built.
- GSV – Pedestrian and Cycling projects – All.
- Minor Projects – All.
- All projects – specified transportation distance <10km.
- All projects – specified transportation distance 10+km.

The study would like to highlight the following findings.

- The 31 vehicle road project is the source of 92% of the emissions in the analysed portfolio.
- The 2 vehicle road projects with tunnel, without bridge, have “Concrete” and “Construction equipment” as two significant contributors to the emission. However, sample size is low.
- The 12 vehicle road projects without tunnels or bridges, have “Asphalt” and “Construction equipment” as two significant contributors to the emission.
- The 6 vehicle road projects with tunnel, with bridge, make up half of the emissions in the portfolio while only providing a ¼ of the total project length built.
- For vehicle roads without bridges or tunnels, there seems to be little difference between projects built >3km at a time, compared to the projects built <3km at a time.

5.2.2. Major and Large emission contributors for the portfolio identified

For the overall portfolio the following are considered major contributors to the emissions of the assessed projects (15%>):

- 33.1% of the emissions come from construction equipment related emissions.
  - Here of 27.2% is attributed to fuel consumption. *
  - And 5.9% is attributed to other sources, such as maintenance, depreciation, etc.**
- 20.0% of the emissions come from concrete related emissions.
  - 1.25% is from concrete-elements.
  - 3.59% is from concrete-vaults.
  - 8.47% is from cast in place concrete.
  - 6.69% is from shotcrete.

Further, the following are considered large contributors to the emissions of the assessed projects (>5%):

- 9.9% of the emissions come from asphalt.
- 9.6% of the emissions come from steel products.

- 9.0% of the emissions come from fuel consumption and wear and tear on transport vehicles.
- 7.2% of the emission come from explosive production and usage.

** Derived from number found by research questions regarding fuel consumption, 65 789 tonnes of CO_2eq. comes from fuel consumption, which makes up 27.2% of the 241 838 CO_2eq. emissions from the overall portfolio.*

*** By subtraction, the remaining 5.9% of emissions comes from other construction equipment related sources.*

Together these 6 emission sources contribute to 89% of the total emissions in the portfolio. All other sources contribute 11% of the emissions.

Actions and policies made to address emissions from road infrastructure construction for a similar portfolio as the one assessed, that does address these contributors, will have an impactful effect on emission cuts. Such actions could consist of:

- Reducing demand for high emission contributors by optimizing plans and make do with less where possible.
- Seeking to substitute high emission contributors by substituting them with equally good materials, that have low carbon emissions.
- Encourage innovation in high emission contributors to cut emissions in manufacturing.

5.2.3. Averages for Road, Tunnel and Bridge related emissions

VegLCA presents emission data based on the process source codes inputted, and allocates emissions to a road, tunnel or bridge category, based on what process code was used. In figure 15, we see the averages for the entire project for the different infrastructure types.

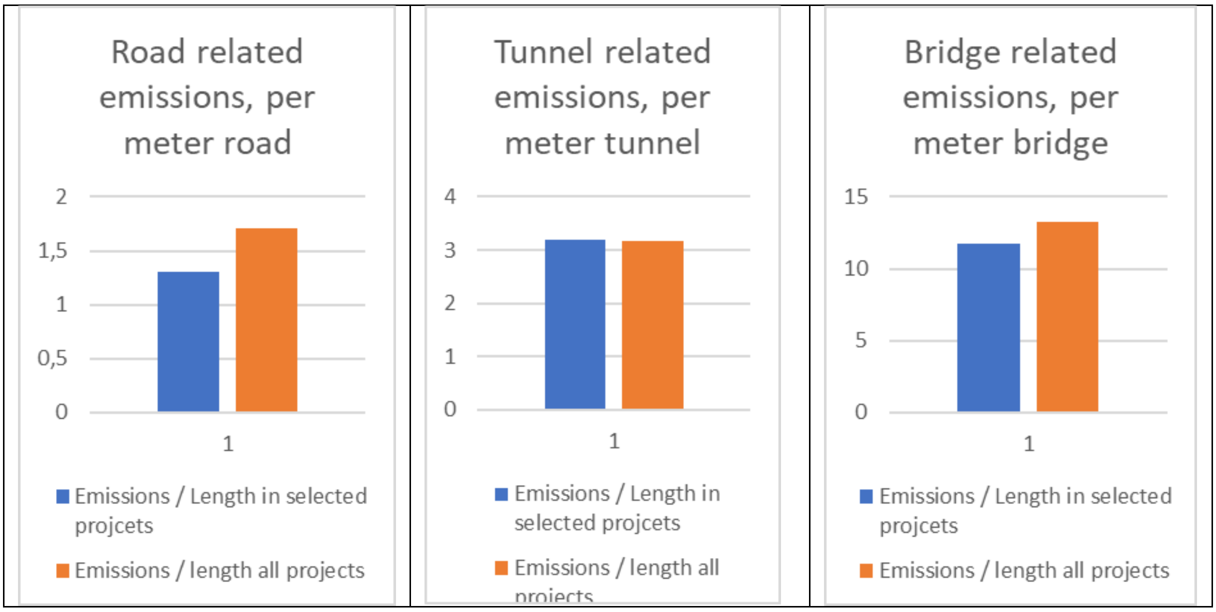


Figure 15: Left – Road related emissions per vehicle road – no tunnel no bridge. Middle tunnel related emissions, per tunnel meter, and bridge related emissions per meter bridge.

For the portfolio analysed in this study we had average road related emissions per meter road to be 1.31 tCO_2eq/m, with bridges having about 9 times that at 11.7 tCO_2eq/m, and tunnels at 3.20

tCO_2eq/m. This suggests that Bridges and Tunnels will heavily impact the emission profile of a road construction project.

5.3. Spread for the largest 6 categories of emissions

As described in 5.1.6, there is a sheet in the Excel databank dedicated to statistical analysis, all the graphs and charts from chapter 5.3. subchapters are available via the LCA databank, Statistical Analysis sheet.

5.3.1. Before removing outliers

After identifying the 6 largest contributors for the entire portfolio, I decided to look at the emission distributions allocated to these 6 categories for each individual assessed project. The goal is to identify the spread, to be able to say something about a typical project, and not just a whole portfolio. The spread will be identified in two steps, first for the spread for the entire portfolio, then outliers and other data will be analysed and considered removed, before the new spread without outliers is discovered.

The emission-data for each of the categories was divided by the total emissions and graphed for projects. The results are found in figure 16 and figure 17 and appendix C and can be reproduced in the LCA databank.

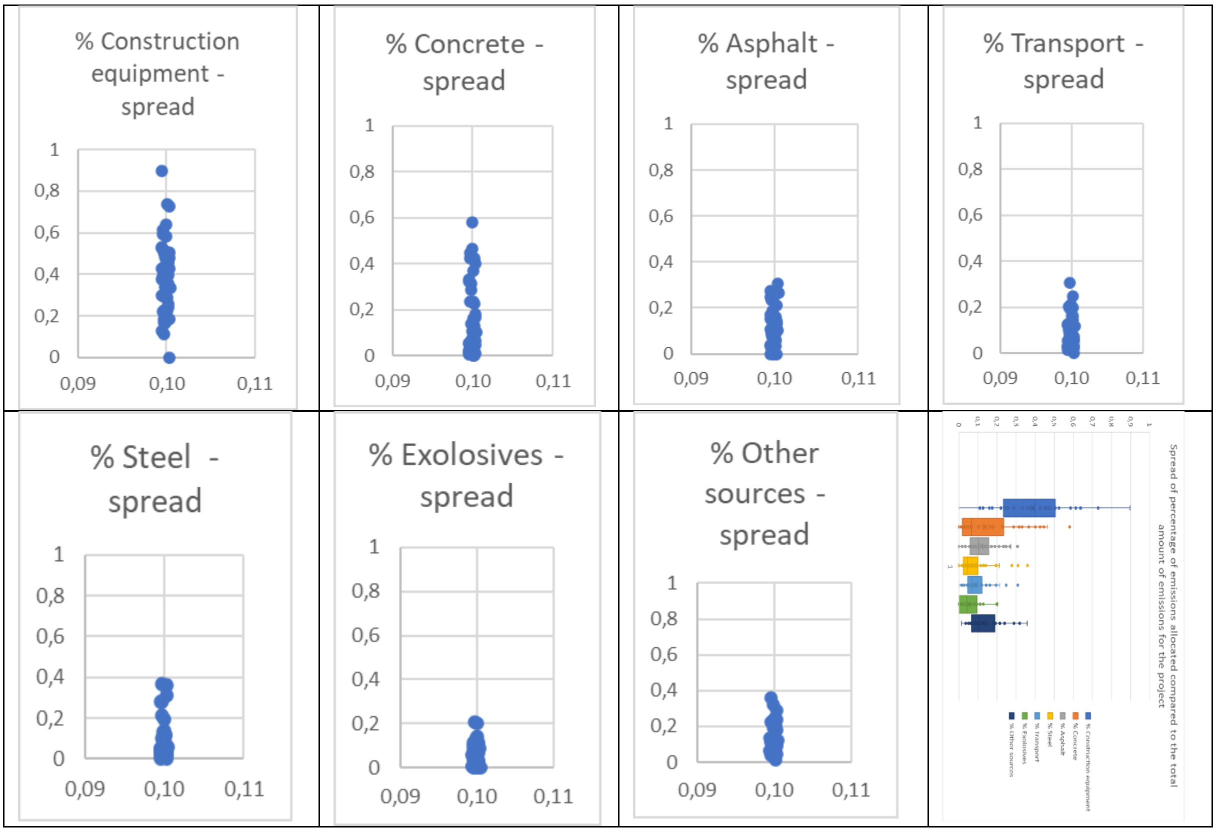


Figure 16: The spread found for the different emission profiles for each of the individual projects with regards to the 6 largest contributors of the portfolio. We can see tat construction equipment is the contributor that is most likely to contribute a majority of emissions in a typical project, but for some of the projects the contributions have been below 20%.

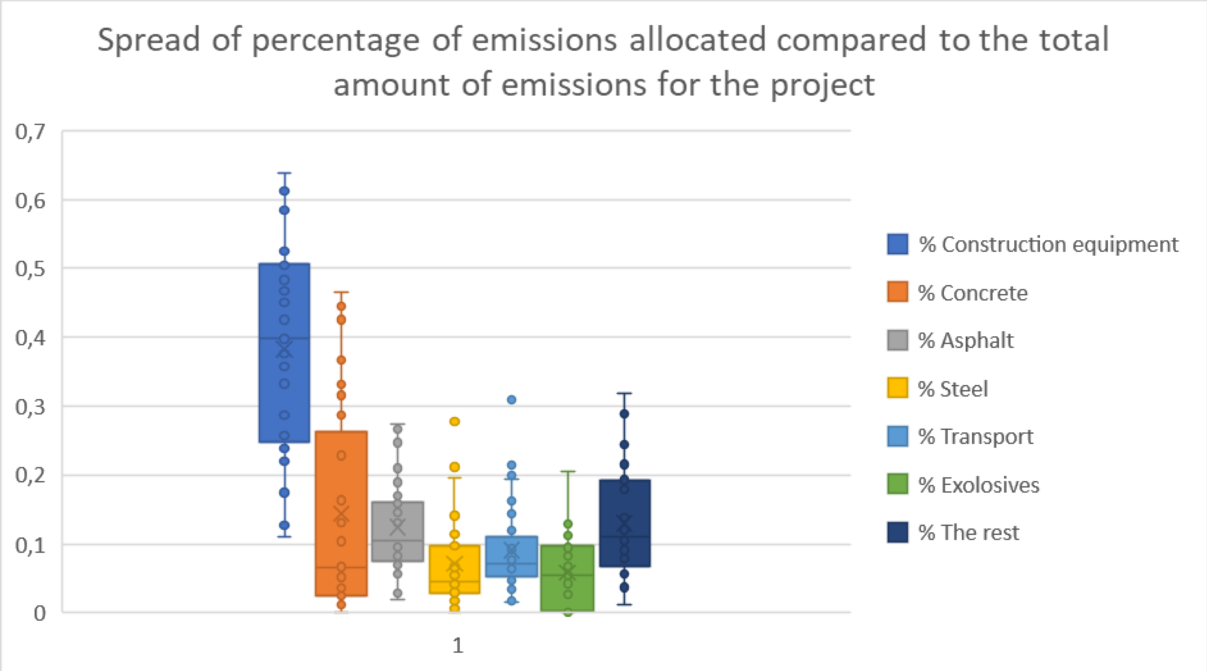


Figure 17: The spread for the distribution of percentages for the 6 largest emission contributors in the portfolio, when all projects are selected.

Results

A majority of the projects have a spread for the identified six big emission contributors so that they make up 80% or more of the total emissions of each project.

- Three projects had the major 6 emission categories contribute less than 75% of all emissions. They had 71%, 68% and 64%.
- For seven projects the major 6 emission categories contributed between 75% and 80% of all emissions
- For four projects the major 6 emission categories contributed between 80% and 85% of all emissions
- For twelve projects the major 6 emission categories contributed between 85% and 90% of all emissions
- For seventeen projects the major 6 emission categories contributed between 90% and 95% of all emissions
- For six projects the major 6 emission categories contributed between 95% and 100% of all emissions

5.3.2. Average emissions per meter project built

It was also looked at average emissions per meter road built and per meter project built and graphed them against meters of projects built, to see if there are some results that suggest that average emissions per meter road is higher when a low or high amount of roads are built at the same time. The results are found in figure 18.

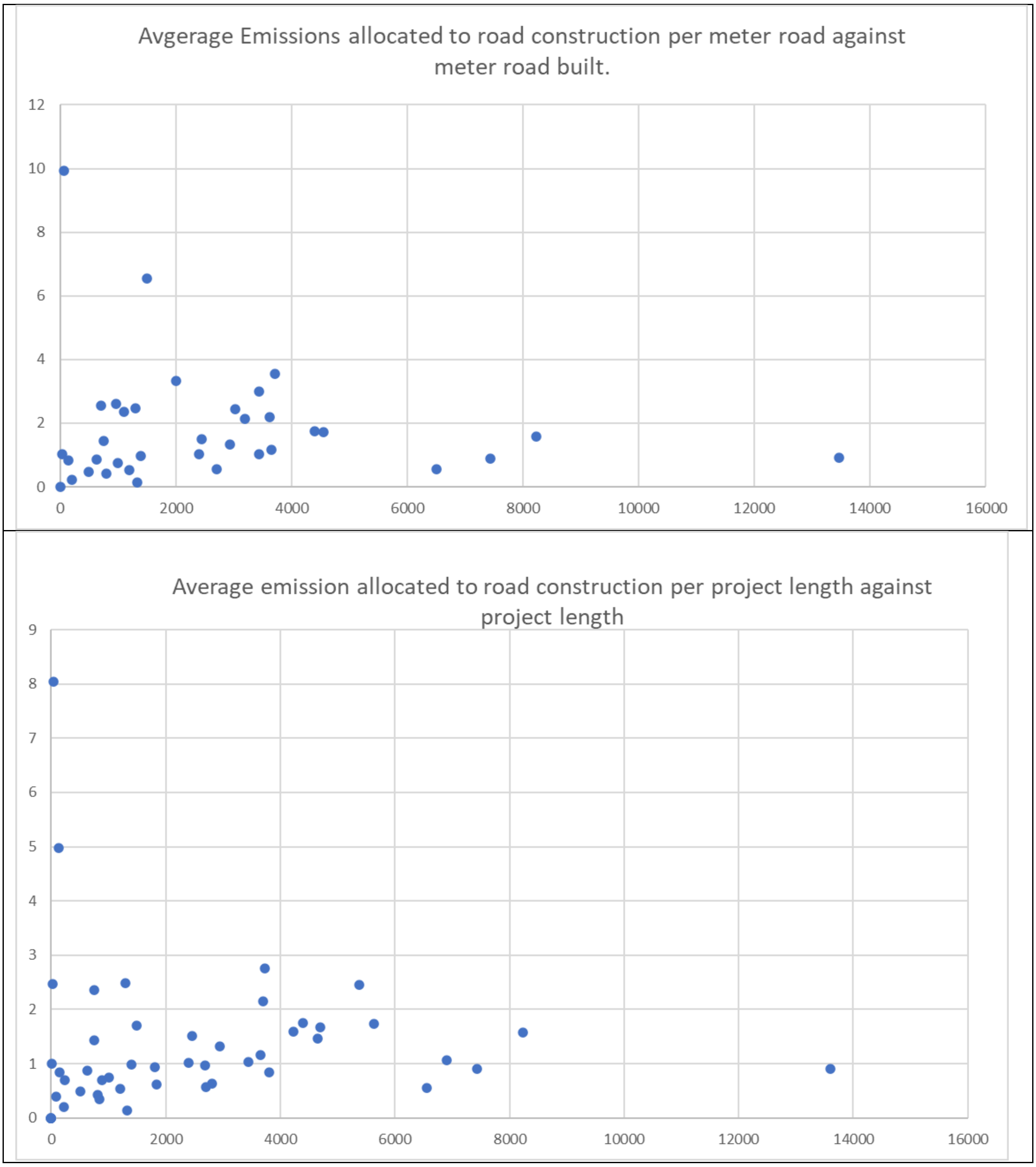


Figure 18: Graphs where average emissions per meter road / meter total project, is graphed against the length of the road/project. The idea was to see whether or not average emissions becomes lower if a longer stretch is built at the same time, but there seems there seems there is no such information to be gained within the dataset.

These graphs showed the need to investigate for outliers and decide wether or not to disregard the outliers and also decide whether or not other data from the dataset should be disregarded before doing a new round of graphing.

5.3.3. Identifying, reviewing, and setting aside outliers

From the average emissions per meter project or road built, there are two projects that have results way beyond the others. These are the projects "14 – Lund bru" and "8 – Krinsvassbrua." By investigating these two projects it is discovered that both projects are mainly bridge-projects where the bridge is less than 100 meters, but at least half of the entire project. Having less meters of road to allocate emissions to for averaging means that the projects probably are less than reliable to use to predict models from unless one wants to look specifically at how bridges impact road construction emissions. Therefore, short road projects should be excluded if they contain primary bridges and tunnels.

A parameter was made that compared the length of road in daylight, to the total project length, and for projects with less than 300 meters, where at least 35% of the project is either bridge or tunnel, it was defined out from further analysis.

Excluding the following 3 datasets, all of them bridges:

- 36 – "Husdal Bru"
- 14 – "Lund bru"
- 8 – "Krinsvassbrua"

Further it was decided that all projects that are considered "Minor Projects", with the exception of project "40 – kolstadvegen" should be excluded from the further analysis as the contents of the project, as they do not construct new road infrastructure and therefore has a much different emission profile than a typical road project.

Excluding the following additional 11 projects:

- 29 – "E1.1 – Forberedende tiltak"
- 34 – "Kroken-siktutbedring"
- 43 – "Selavegen"
- 48 – "Hammer bru"
- 05 – "Vaslag – Kongenvoll forsterkning"
- 49 – "Drakestranda"
- 27 – "Fv 720 Fornying 2.0 "
- 26 – "Lunnfjord bru"
- 21 – "Flakk – rørvik fergekai"
- 28 – "TS tiltak fosen"
- 22 – "Valset – Brekstad fergekai"

Leaving us with 35 datasets left to do further analysis. The 14 projects removed made up about 5% of the total project length in the portfolio, and 5% of the emissions allocated to road construction. So, 95% of emissions allocated to road construction, and project length remain in the dataset.

5.3.4. Results after removing outliers

After removing outliers, the spread and averages was analysed again. Results can be found in figures from figure 19 to figure 22 and appendix D, and it can be reproduced in the LCA databank.

After removing the outliers, the data seemed to be allocated more concentrated than before. It still seems to be the case that the identified 6 major contributors to emissions contribute to the majority of emissions.

- Two projects had the major 6 emission categories contribute less than 75% of all emissions. In those they contributed 71% and 68% of the total emissions.
- For six projects the major 6 emission categories contributed between 75% and 80% of all emissions.
- For four projects the major 6 emission categories contributed between 80% and 85% of all emissions.
- For seven projects the major 6 emission categories contributed between 85% and 90% of all emissions.
- For ten projects the major 6 emission categories contributed between 90% and 95% of all emissions.
- For six projects the major 6 emission categories contributed between 95% and 100% of all emissions.

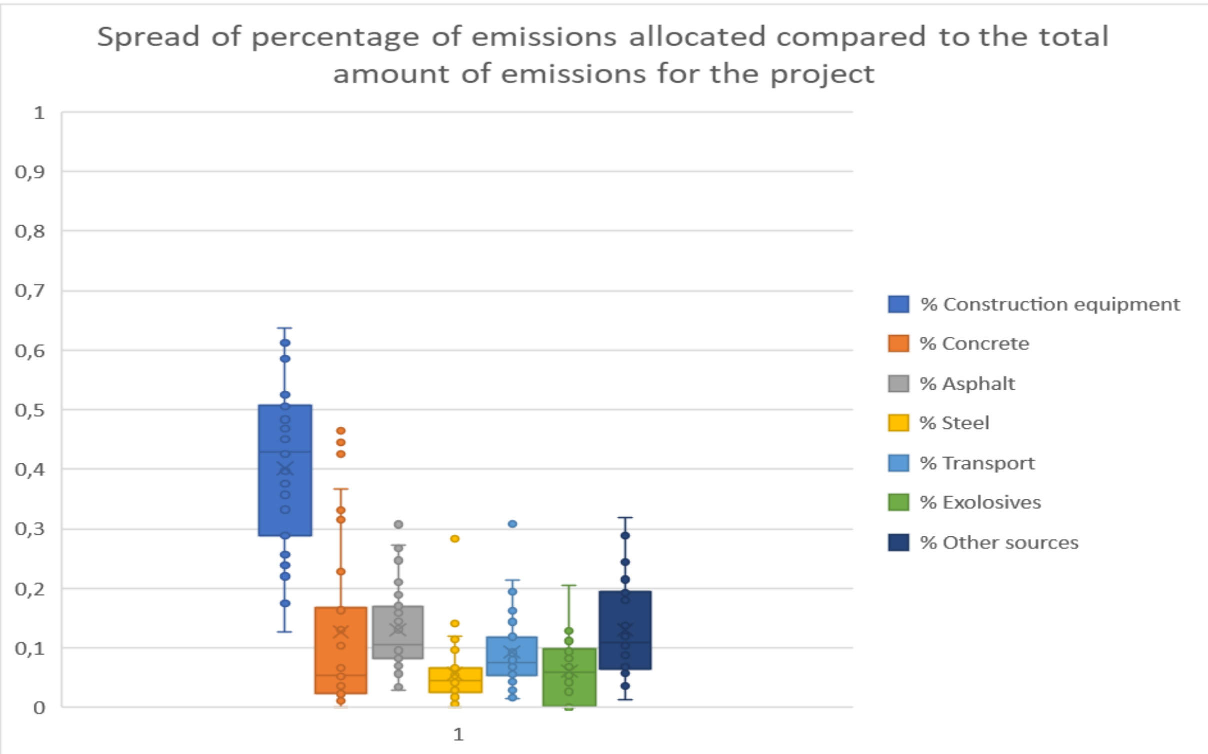


Figure 19: Spread for the largest 6 emission contributors for the individual projects within the portfolio after removing the outliers, we see that after removing the very small bridges and the other outlier-projects that concrete as a contributor is a bit lower than it was when outliers were included.

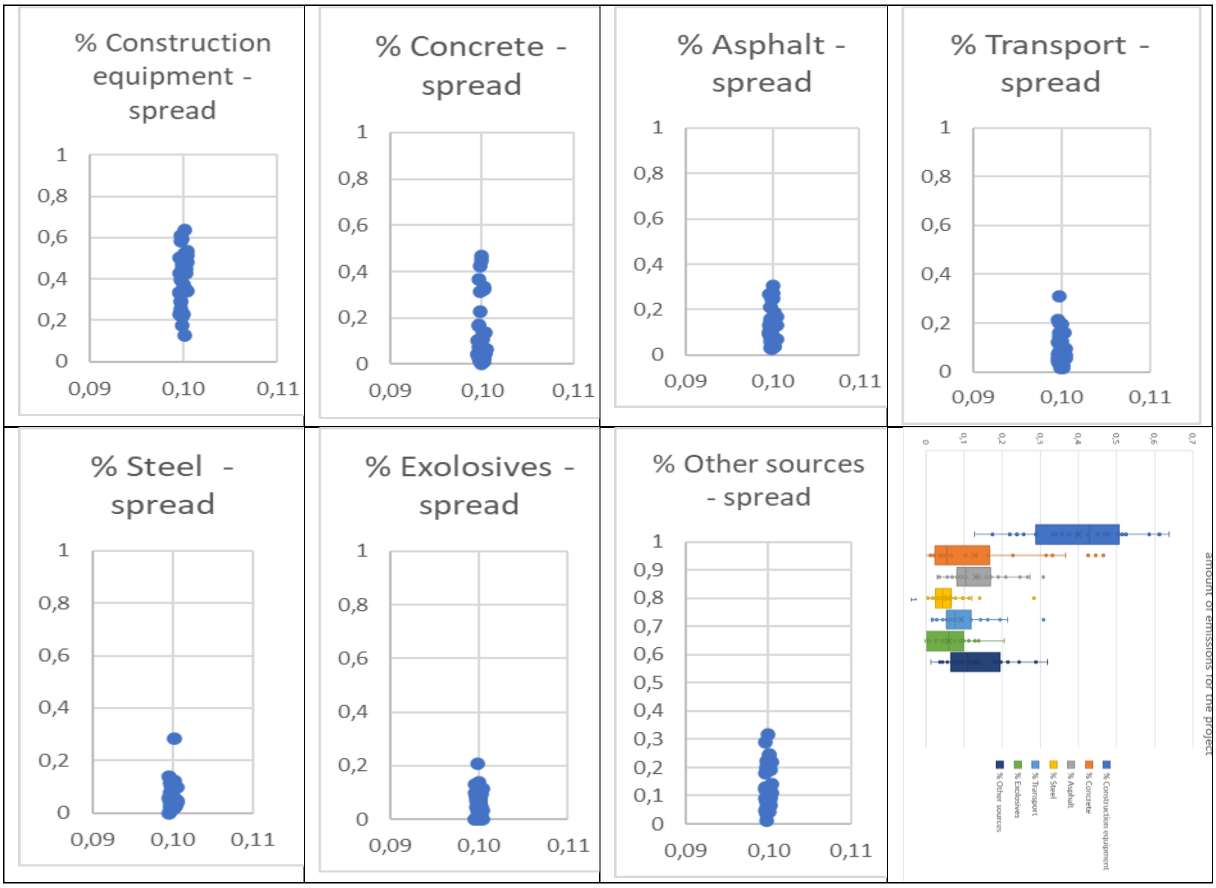


Figure 20: The spread of the 6 major and large emission contributors for the portfolio after removing the outliers.

After removing the outliers, the spread is more concentrated for all the categories. However, there appears to still be subsets within the dataset that affect the spread. For example, in figure 20, emissions attributed to concrete seem to have one group around 0.4, and the other group around 0.1.

Average emissions per project length, comparing project length with lanes and road cover width

In the graphs in figure 21, the projects have been compared with average emissions per project length built, per project length built multiplied with the number of lanes, and per project length multiplied with road cover width, against project length. The reasoning behind these different comparisons is that for most projects left (22) two lanes were built, but for 11 only one lane was built, and for 2 projects 3 lanes were built, and that might affect the average emissions per meter project. The same thinking was done with road cover width as road cover build varies from 3 meters to 15 meters, where the projects built typically are around 8 meters wide. As the average emissions of the projects were to be re-balanced for number of lanes and road cover width, the Y axis was also rebalanced to reflect a 2:1 ratio on typical lanes, and 8:1 ratio on typical road cover width.

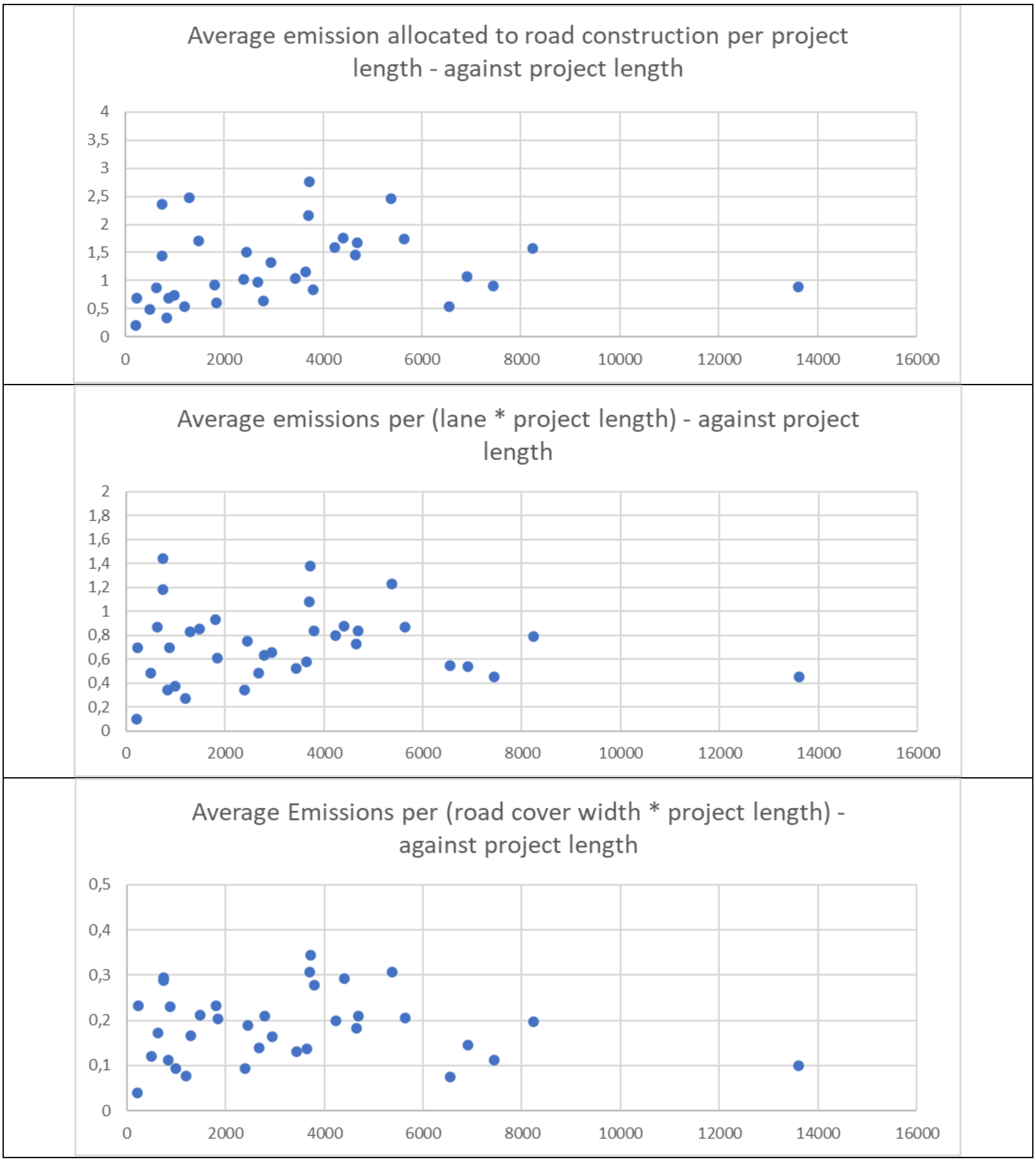


Figure 21: Plotted average emissions per project length, for the project length, project length multiplied by lanes and project length.

In figure 21 we have plotted average emissions per project length, for the project length, project length multiplied by lanes and project length and road cover width to see if there are some benefits to be building longer stretches of roads at the same time, the same that was investigated in figure 18. After the removal of outliers, it can seem more likely that longer projects have lower average emissions per project. However, the datasets have few projects over 6 km so more data is needed before conclusion is possible. This will have to be investigated further.

Spread for average emissions per project length, with regards to lanes and road cover width

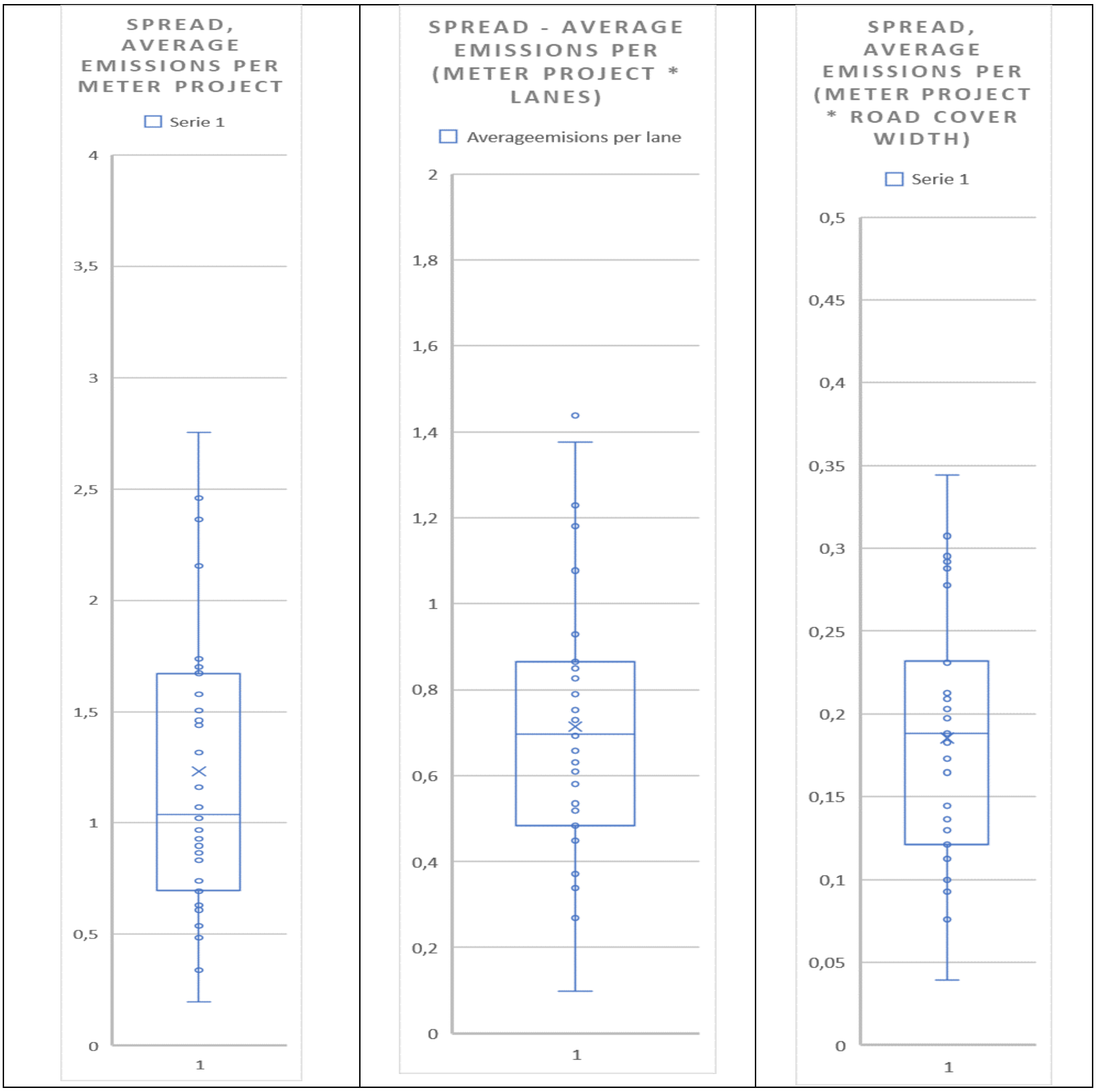


*Figure 22: Spread for the average emissions per meter project, per meter project * lane, and per meter project with regards to road cover width.*

Looking at the spread for the average emissions per meter project, per meter road project * lanes, and per meter road project * road cover width, the same rebalancing of the y axis as was done in figure 21. In figure 22 we see that the spread is more concentrated when taking into account road width or the number of lanes. Outliers were checked, but no pattern seemed to be dominant in either case. For both the cases of lanes and road cover width – 6 out of the 7 best and worst cases were the same projects. While one of the bottom 7 projects (from lanes / road cover) come out as better than some of the top 7 projects (from lanes / road cover), when looking at project length. 5 out of the 7 high emission outliers are the same in all 3 perspectives. Two of the 7 low emission outliers are the same in all 3 perspectives. The spreads suggest that for road construction, most projects should fall within:

- [0.69 – 1.67] – tonnes CO_2eq. per meter project built.
- [0.48 – 0.87] – tonnes CO_2eq. per (meter project * number of lanes) built.
- [0.121 – 0.232] – tonnes CO_2eq. per (meter project * road cover width) built.

5.4. Spread for different infrastructure parts

5.4.1. Vehicle road – No tunnel, No bridge

There are 11 vehicle road projects with no bridges and no tunnels. They make up 27% of the total project length, and 18% of the total emissions. The spread for the selection can be seen in figure 23, and table 2:

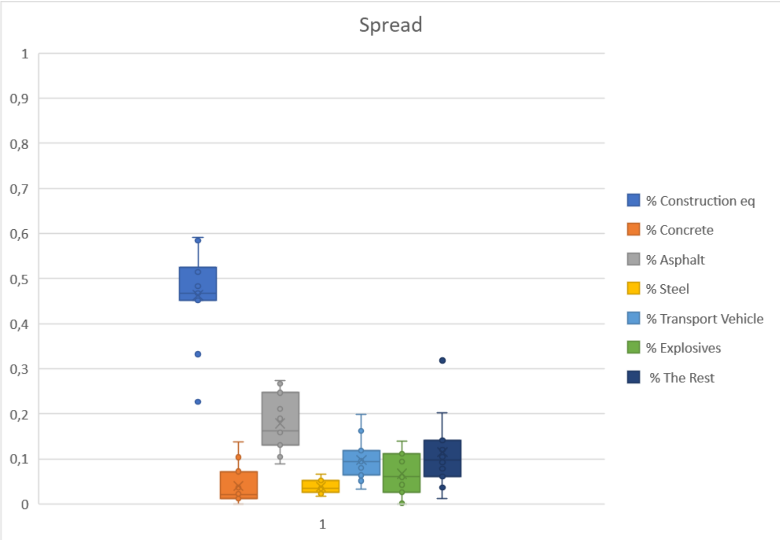


Figure 23: Spread for the 11 vehicle road projects with No tunnel, No bridge.

Table 2: Values for the spread for large and major emission contributors in figure 23:

Contributor	Low end CI	High end CI	Median	Average
Construction eq.	45.2%	52.5%	46.8%	46.3%
Concrete	1.18%	7.23%	2.10%	4.05%
Asphalt	13.1%	24.7%	16.1%	17.9%
Steel	2.52%	5.28%	3.49%	3.81%
Transport vehicle	6.36%	11.9%	9.49%	9.74%
Explosives	2.65%	11.2%	6.02%	6.67%
The rest.	6.16%	14.1%	9.73%	11.5%

Project-Average Road construction emissions per meter project values:

- [0.87 – 1.58] – tonnes CO_2eq. per meter project built.
  - Average 1.26, median 1.04.
- [0.35 – 0.86] – tonnes CO_2eq. per (meter project * number of lanes) built.
  - Average 0.62, median 0.64.
- [0.0929 – 0.197] - tonnes CO_2eq. per (meter project * road cover width) built.
  - Average 0.164, median 0.165.

The major takeaway from looking at vehicle projects without tunnels and bridges, is that emissions from the construction equipment and transportation vehicles make up over half of the total emissions, while asphalt also typically makes a >15% emission contribution. However, it is also worth noting that the mean for Concrete, Steel, Explosives and "the rest" indicate that about 20% of emissions will from such projects will not be accounted for if one only looks at machinery and asphalt, while the average amounts to 26%.

5.4.2. GSV – Pedestrian and Cycling roads

There are 7 projects that are only pedestrian and cycling roads. they make up 10% of the total project length and account for 4% of the total emissions. The spread can be seen in figure 24, and table 3.

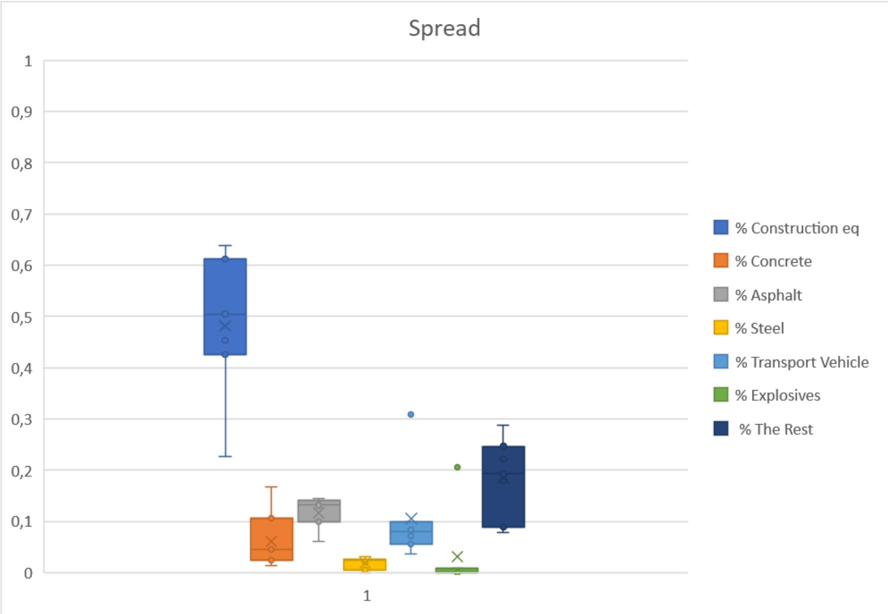


Figure 24: Spread for the 7 projects that are only pedestrian and cycling roads.

Table 3: Values for the spread for large and major emission contributors in figure 24:

Contributor	Low end CI	High end CI	Median	Average
Construction eq.	42.5%	61.2%	50.5%	48.2%
Concrete	2.43%	10.6%	4.59%	6.14%
Asphalt	9.97%	14.1%	13.2%	11.6%
Steel	0.57%	2.59%	2.04%	1.87%
Transport vehicle	5.57%	9.95%	8.05%	10.5%
Explosives	0.16%	0.82%	0.82%	3.10%
The rest.	8.83%	24.7%	19.3%	18.5%

Project - Average road construction emissions per meter project values:

- [0.61 – 0.83] – tonnes CO_2eq. per meter project built.
  - Average 0.68, median 0.69.
- [0.41 – 0.80] – tonnes CO_2eq. per (meter project * number of lanes) built.
  - Average 0.59, median 0.66.
- [0.203 – 0.232] - tonnes CO_2eq. per (meter project * road cover width) built.
  - Average 0.214, median 0.231.

For these projects the emission profile is quite similar to the one of vehicle roads without tunnels and bridges. At first glance they seem more efficient for emissions per meter road, but when looking at lanes and road cover they come out the same lane wise, but worse per square meter. The projects also seem to typically have a higher contribution from "the rest" than the other categories. There are indicators that pops out when investigating single projects, but nothing that seem like a typical trend for all the projects. Trenching, use of natural rocks, moving arable land, are some of the contributors that are proportionally much larger for pedestrian and cycling roads.

5.4.3. Bridges

Looking at the bridges of the portfolio, we have 17 vehicle road projects with bridges. We see from figure 25, and figure 26, that the emission profile for a project change drastically when the bridge is a major part of the project length, compared to a small part. We know from chapter 5.2.3, that bridges have almost 9 times the emission per meter project than road does. This indicates that bridges have concrete and steel as major emission contributors. Details for figure 25 and 26, can be found in table 4 and 5.

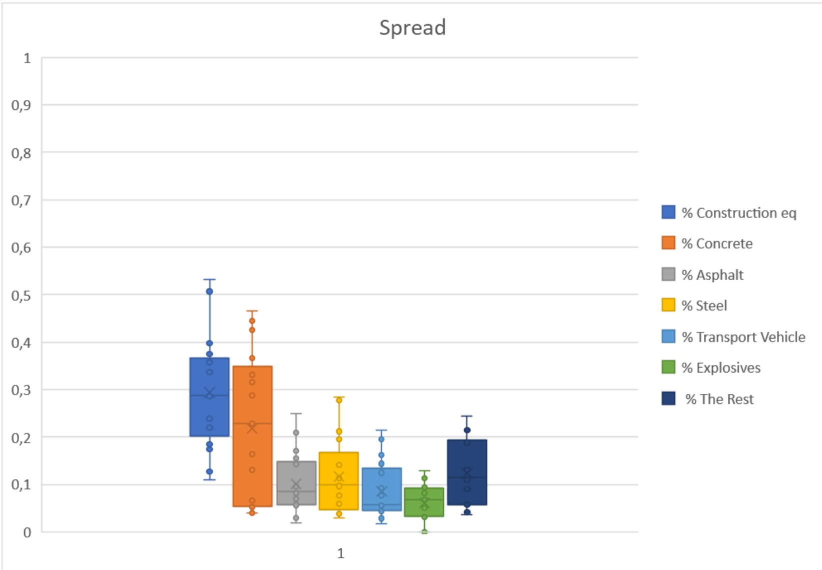


Figure 25: Emission profile for the vehicle road projects that contain bridges within the dataset.

Table 4: Values for the spread for large and major emission contributors in Figure 25:

Contributor	Low end CI	High end CI	Median	Average
Construction eq.	20.3%	36.6%	28.8%	29.4%
Concrete	5.34%	34.9%	22.8%	21.8%
Asphalt	5.80%	14.9%	8.52%	10.1%
Steel	4.72%	16.8%	9.88%	11.7%
Transport vehicle	4.56%	13.4%	5.67%	8.57%
Explosives	3.25%	9.28%	6.77%	6.10%
The rest.	5.80%	19.3%	11.4%	12.4%

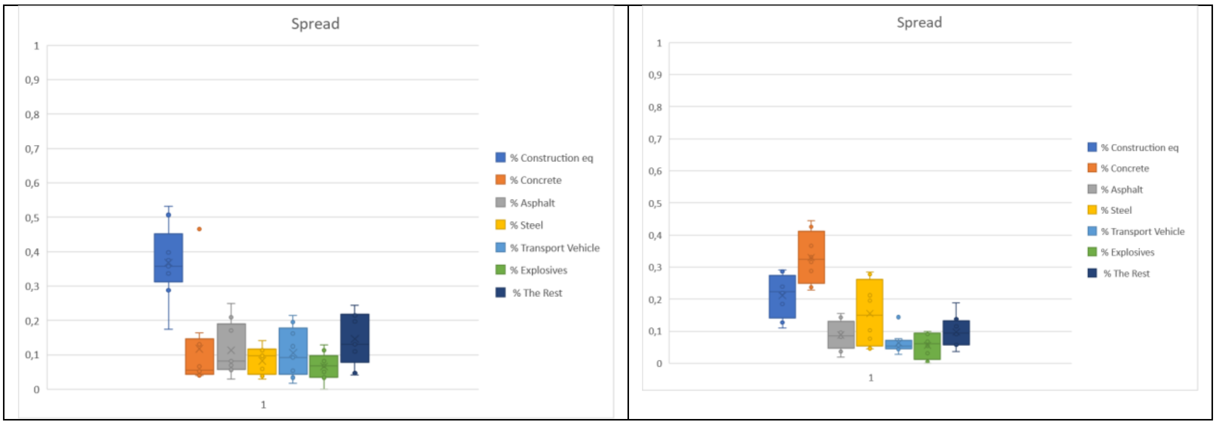


Figure 26: For the Bridges, the spread for contributors varies a lot between the 9 bridges that were less than 10% of the entire project (to the left) and the 8 bridges that were more than 30% of the entire project (on the right). No bridges in the Portfolio were between 10% and 30% of project length.

Table 5: Values for the spread for large and major emission contributors for bridge projects with <70% road, in the right of figure 26:

Contributor	Low end CI	High end CI	Median	Average
Construction eq.	14.2%	27.5%	22.3%	21.1%
Concrete	25.0%	41.1%	32.4%	33.0%
Asphalt	4.75%	13.1%	8.58%	8.77%
Steel	5.34%	26.1%	14.9%	15.5%
Transport vehicle	4.48%	7.14%	5.47%	6.33%
Explosives	1.13%	9.37%	6.11%	5.54%
The rest.	5.75%	13.2%	9.48%	9.80%

5.4.4. Tunnels

Looking at tunnels we see that the spread for the tunnels is quite similar to the spread for bridges where non-road infrastructure is a major part of the project. There are only 8 projects in our portfolio with tunnels in them, so there is too little information to go on to do comparisons as we did with the bridges in figure 26. Concrete stands out as a major contributor together with construction equipment for projects with tunnels. The spread for tunnels can be seen in figure 27 and table 6.

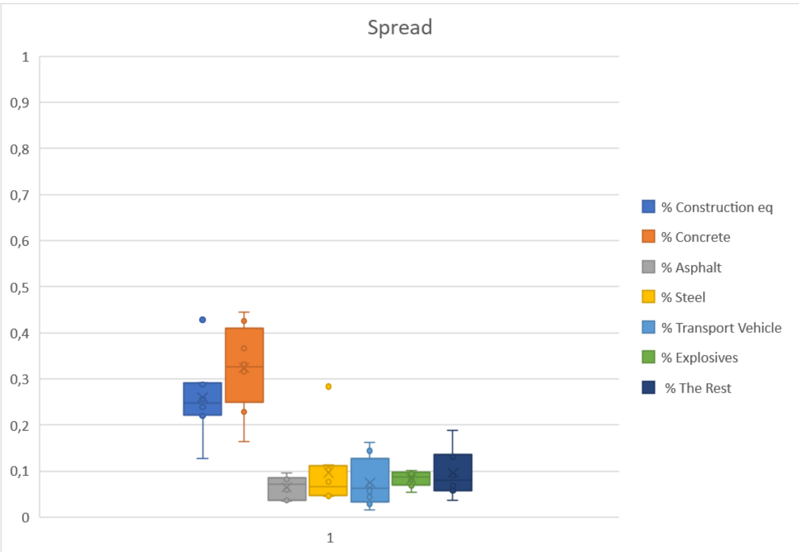


Figure 27: Emission profile for the vehicle road projects that contain tunnels within the dataset.

Table 6: Values for the spread for large and major emission contributors in figure 27:

Contributor	Low end CI	High end CI	Median	Average
Construction eq.	22.2%	29.0%	24.8%	26.0%
Concrete	25.0%	41.1%	32.7%	32.5%
Asphalt	3.65%	8.61%	7.06%	6.47%
Steel	4.75%	11.1%	6.55%	9.68%
Transport vehicle	3.25%	12.7%	6.32%	7.46%
Explosives	6.70%	9.81%	8.67%	8.33%
The rest.	5.76%	13.6%	7.95%	9.62%

5.4.5. High Emission versus average and low emission projects (per project meter)

The average for the entire portfolio was 1.96 tonnes per meter project length. The parameter "Over x1.5 Average emissions per Project meter." (Column AH in the Input Datatable) was made to sort projects into two categories, based on if they had more than x1.5 the average, or less than x1.5 the average. After excluding the minor projects, we look at the spread for the high emission projects, and the average low emission project to see if there is some interesting data there.

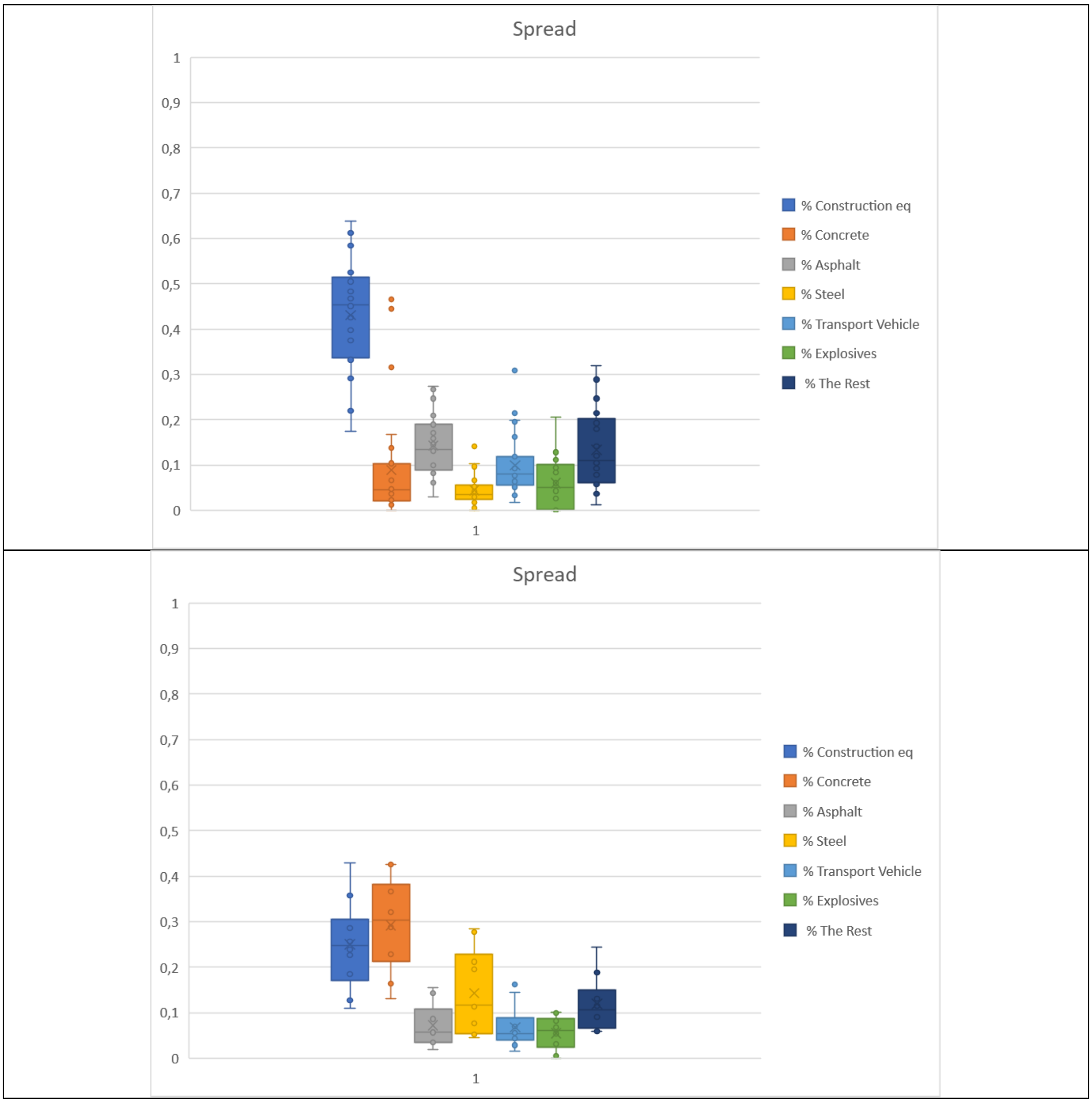


Figure 28: Comparing the 27 Average/low emission projects (on top) with the 9 "high emission" projects (on bottom), we see that the projects that have above average emissions per meter project length typically have more emissions from concrete and steel, compared to average/low emission projects.

Figure 28 shows us that, the low/average emission projects have construction equipment and asphalt as the main emission contributors, but the high-emission projects have much larger portions of emission from concrete and steel. When looking at the data and sorting them from highest to lowest average emission per meters, short projects only consisting of bridges, and all the tunnel projects top the list, which can explain why the concrete and steel contribution are so high compared to the average/low emission projects of the portfolio.

5.4.6. Averages for projects based on project length, <1km, 1-3km, >3km

As the spreads in figure 21 indicated that longer projects might have more efficient emissions per meter project than shorter projects, they were grouped in 4 groups dependent on project length. The four groups were <1 km, 1-3 km, >3 km. For bridges and tunnels not to affect the results, only road-projects without bridges and tunnels were investigated for this effect relative to one another. The dataset also separates entries for >3 km into 3-5 km, and > 5km, but due to the low sample size (3 & 2), these categories they were grouped together.

<1 km (5 projects): - Project - Average road construction emissions per meter project values:

- [0.516 – 1.152] – tonnes CO_2eq. per meter project built.
  - Average 0.806, median 0.696.
- [0.254 – 1.01] – tonnes CO_2eq. per (meter project * number of lanes) built.
  - Average 0.672, median 0.695.
- [0.143 – 0.260] - tonnes CO_2eq. per (meter project * road cover width) built.
  - Average 0.207, median 0.231

1-3 km (7 projects): Project - Average road construction emissions per meter project values:

- [0.609 – 1.51] – tonnes CO_2eq. per meter project built.
  - Average 1.07, median 0.741.
- [0.286 – 0.722] – tonnes CO_2eq. per (meter project * number of lanes) built.
  - Average 0.475, median 0.490.
- [0.0926 – 0.203] - tonnes CO_2eq. per (meter project * road cover width) built.
  - Average 0.145, median 0.165.

>3 km (5 projects) Project - Average road construction emissions per meter project values:

- [0.886 – 1.67] – tonnes CO_2eq. per meter project built.
  - Average 1.22, median 1.04.
- [0.338 – 0.844] – tonnes CO_2eq. per (meter project * number of lanes) built.
  - Average 0.558, median 0.654.
- [0.121 – 0.285] - tonnes CO_2eq. per (meter project * road cover width) built.
  - Average 0.202, median 0.197.

As the average and the median emissions per meter project seem to increase when similar projects are isolated this way, there is nothing to support the idea that there is correlation with longer projects and more efficient emissions, however, the sample sizes for each of the selections are very low so more data is needed should such data be used, to make sure that outliers are not impacting the results.

5.5. Investigating emission and potential emission cuts

5.5.1. Construction Equipment

Through interpreting the Environmental Impact Assessment, we gathered that 33.1% of the emissions for the entire portfolio come from construction equipment related emissions. Where 27.2% is attributed to fuel consumption and 5.9% is attributed to other sources, such as maintenance, depreciation, etc.

By investigating the Inventory Analysis, we are able to gather that for the entire portfolio 24 732 720 litres of diesel is estimated to be consumed by construction equipment in the 49 infrastructure projects. Using the conversion ratio (Eq. 3.4) we get that the amount of work done by the construction equipment is:

Equation 5.1: Work done by ICE - Construction equipment in the portfolio:

$$24\,732\,720\, l * 4\frac{kWh}{l} = 98\,930\,880\, kWh \approx 98.9\, GWh$$

And using the conversion ratio (Eq. 3.5) for translating a litre of diesel into electricity that had to be produced to power battery driven electrical engines to do the same work we get:

Equation 5.2: Electricity production needed to cover the work done:

$$24\,732\,720\, l * 5.07\frac{kWh}{l} = 125\,394\,890.4\, kWh\ \approx 125.4\, GWh$$

To find the emissions attributed to this work done we take the emission ratio we decided to use during research 2.66kgCO_2/litre and multiply that with the amount of diesel consumed by construction equipment.

Equation 5.3: Emissions from burning diesel in construction equipment:

$$24\,732\,720\, l * 2.66\frac{kgCO_2eq}{l} = 65\,789\,035\, kgCO_2eq \approx 65\,800\, tonnCO_2eq.$$

As addressed chapter 3.7. The study sees 4 different scenarios of how to calculate emissions as necessary to address. In addition, some of these scenarios have different subsets, so in all the study will look at the following 6 scenarios:

- **S_1N – 12 gCO_2eq./kWh** – The emissions attributed to the Norwegian electricity-consumption mixture.
- **S_2E – 307 gCO_2eq./kWh** – Emissions attributed to production of electricity in Europe.
- **S_3P – 950 gCO_2eq./kWh** – Emissions attributed to producing electricity with petroleum.
- **S_3N – 411 gCO_2eq./kWh** – Emissions attributed to producing electricity with natural gas.
- **S_4_2030 – 261 gCO_2eq./kWh** – Emissions from European electricity mix in 2030.
- **S_4_2050 – 19.2 gCO_2eq./kWh** – Emissions from European electricity mix in 2050.

Further the study investigated the possible emission-cuts for different degrees of electrification. Transitioning the entre machinepark of Norwegian entrepreneurs will take some time, so we will be looking at how much emissions would have been cut in the portfolio had respectively 5%, 10%, 25%, 50%, 70% and 100% of the Work done, been done with EE rather than ICE.

Table 7: Emissions saved for different percentages of the workload of the projects in the portfolio for construction equipment done with electricity instead of diesel:

		S_1N	S_2E	S_3P	S_3N	S_4_2030	S_4_2050
Workload done by electricity	EL gCO2eq/kwH	12	307	950	411	261	19,2
0 %	0% el	0	0	0	0	0	0
	100% diesel	65789	65789	65789	65789	65789	65789
	Sum	**65789**	**65789**	**65789**	**65789**	**65789**	**65789**
5 %	5% el	75	1925	5956	2577	1636	120
	95% diesel	62500	62500	62500	62500	62500	62500
	Sum	62575	64424	68456	65076	64136	62620
	Saved emission	**3214**	**1365**	**-2667**	**713**	**1653**	**3169**
10 %	10% el	150	3850	11913	5154	3273	241
	90% diesel	59210	59210	59210	59210	59210	59210
	Sum	59361	63060	71123	64364	62483	59451
	Saved emission	**6428**	**2729**	**-5334**	**1425**	**3306**	**6338**
25 %	25% el	376	9624	29781	12884	8182	602
	75% diesel	49342	49342	49342	49342	49342	49342
	Sum	49718	58966	79123	62226	57524	49944
	Saved emission	**16071**	**6823**	**-13334**	**3563**	**8265**	**15845**
50 %	50% el	752	19248	59563	25769	16364	1204
	50% diesel	32895	32895	32895	32895	32895	32895
	Sum	33647	52143	92457	58663	49259	34098
	Saved emission	**32142**	**13646**	**-26668**	**7126**	**16530**	**31691**
70 %	70% el	1053	26947	83388	36076	22910	1685
	30% diesel	18750	18750	18750	18750	18750	18750
	Sum	19803	45697	102137	54826	41660	20435
	Saved emission	**45986**	**20092**	**-36348**	**10963**	**24129**	**45354**
100 %	100% el	1505	38496	119125	51537	32728	2408
	0% diesel	0	0	0	0	0	0
	Sum	1505	38496	119125	51537	32728	2408
	Saved emission	**64284**	**27293**	**-53336**	**14252**	**33061**	**63381**

Table 8: Percentage of emissions saved for different percentages of the workload of the projects in the portfolio for construction equipment done with electricity instead of diesel:

		S_1N	S_2E	S_3P	S_3N	S_4_2030	S_4_2050
Workload done by electricity	EL gCO2eq/kwH	12	307	950	411	261	19,2
0 %	0% el	0	0	0	0	0	0
	100% diesel	65789	65789	65789	65789	65789	65789
	Sum	**65789**	**65789**	**65789**	**65789**	**65789**	**65789**
5 %	5% el	75	1925	5956	2577	1636	120
	95% diesel	62500	62500	62500	62500	62500	62500
	Sum	62575	64424	68456	65076	64136	62620
	Saved emission	**1,3 %**	**0,6 %**	**-1,1 %**	**0,3 %**	**0,7 %**	**1,3 %**
10 %	10% el	150	3850	11913	5154	3273	241
	90% diesel	59210	59210	59210	59210	59210	59210
	Sum	59361	63060	71123	64364	62483	59451
	Saved emission	**2,7 %**	**1,1 %**	**-2,2 %**	**0,6 %**	**1,4 %**	**2,6 %**
25 %	25% el	376	9624	29781	12884	8182	602
	75% diesel	49342	49342	49342	49342	49342	49342
	Sum	49718	58966	79123	62226	57524	49944
	Saved emission	**6,7 %**	**2,8 %**	**-5,5 %**	**1,5 %**	**3,4 %**	**6,6 %**
50 %	50% el	752	19248	59563	25769	16364	1204
	50% diesel	32895	32895	32895	32895	32895	32895
	Sum	33647	52143	92457	58663	49259	34098
	Saved emission	**13,3 %**	**5,6 %**	**-11,0 %**	**3,0 %**	**6,8 %**	**13,1 %**
70 %	70% el	1053	26947	83388	36076	22910	1685
	30% diesel	18750	18750	18750	18750	18750	18750
	Sum	19803	45697	102137	54826	41660	20435
	Saved emission	**19,0 %**	**8,3 %**	**-15,0 %**	**4,5 %**	**10,0 %**	**18,8 %**
100 %	100% el	1505	38496	119125	51537	32728	2408
	0% diesel	0	0	0	0	0	0
	Sum	1505	38496	119125	51537	32728	2408
	Saved emission	**26,6 %**	**11,3 %**	**-22,1 %**	**5,9 %**	**13,7 %**	**26,2 %**

As we see from the results in table 7 & 8, a substantiable amount of emissions would have been cut in the portfolio if the goal of 70% non-fossil non-road construction equipment is solved with electrical engines. Dependant on how the electricity is produced between 4.5% to 19% emissions could be saved over such a portfolio in the future. However, we also see that there are cases, like in scenario S_3P where electricity production is done with a generator running on petroleum, and that is an overall worse solution with regards to Carbon-impact.

Fuel consumption is also a big source of direct emissions from the construction sites 98.8% in our portfolio with the usages of explosives also contributing a little according to the LCA-databank. Using the same method as earlier, but investigating emissions with regards to direct emissions we get the following Table 9:

Table 9: Saved direct emissions if workload was electricity based. Note that electricity has no direct emissions (Scope 1) attributed to them unless the electricity is produced on site:

		S_1N	S_2E	S_3P	S_3N	S_4_2030	S_4_2050
Workload done by electricity	EL gCO2eq/kwH	12	307	950	411	261	19,2
0 %	0% el	0	0	0	0	0	0
	100% diesel	65789	65789	65789	65789	65789	65789
	Sum	**65789**	**65789**	**65789**	**65789**	**65789**	**65789**
5 %	5% el	*75*	*1925*	*5956*	*2577*	*1636*	*120*
	95% diesel	62500	62500	62500	62500	62500	62500
	Sum direct	62500	62500	62500	62500	62500	62500
	Saved emission	**4,0 %**	**4,0 %**	**4,0 %**	**4,0 %**	**4,0 %**	**4,0 %**
10 %	10% el	*150*	*3850*	*11913*	*5154*	*3273*	*241*
	90% diesel	59210	59210	59210	59210	59210	59210
	Sum direct	59210	59210	59210	59210	59210	59210
	Saved emission	**8,1 %**	**8,1 %**	**8,1 %**	**8,1 %**	**8,1 %**	**8,1 %**
25 %	25% el	*376*	*9624*	*29781*	*12884*	*8182*	*602*
	75% diesel	49342	49342	49342	49342	49342	49342
	Sum direct	49342	49342	49342	49342	49342	49342
	Saved emission	**20,2 %**	**20,2 %**	**20,2 %**	**20,2 %**	**20,2 %**	**20,2 %**
50 %	50% el	*752*	*19248*	*59563*	*25769*	*16364*	*1204*
	50% diesel	32895	32895	32895	32895	32895	32895
	Sum direct	32895	32895	32895	32895	32895	32895
	Saved emission	**40,3 %**	**40,3 %**	**40,3 %**	**40,3 %**	**40,3 %**	**40,3 %**
70 %	70% el	*1053*	*26947*	*83388*	*36076*	*22910*	*1685*
	30% diesel	18750	18750	18750	18750	18750	18750
	Sum direct	18750	18750	18750	18750	18750	18750
	Saved emission	**57,7 %**	**57,7 %**	**57,7 %**	**57,7 %**	**57,7 %**	**57,7 %**
100 %	100% el	*1505*	*38496*	*119125*	*51537*	*32728*	*2408*
	0% diesel	0	0	0	0	0	0
	Sum direct	0	0	0	0	0	0
	Saved emission	**80,7 %**	**80,7 %**	**80,7 %**	**80,7 %**	**80,7 %**	**80,7 %**

And we can see that transitioning from ICE to EE for construction equipment has a considerable effect on the direct emissions of a construction site. Achieving Klimakur 2030's goal of 70% of workload done with electrical engines (or other non-fossil means) would reduce direct emissions by 57.7% no matter how Scope 2 emissions are allocated.

Besides emission regarding fuel usage there are additional emissions attributed to construction equipment regarding wear and maintenance that will be addressed later in the study together with wear and maintenance of transportation vehicles.

5.5.2. Transportation Vehicles

Through interpreting the Environmental Impact Assessment, we gathered that 8.98% of the emissions for the entire portfolio come from transportation vehicles related emissions. Where 27.2% is attributed to fuel consumption and 5.9% is attributed to other sources, such as maintenance, depreciation, etc.

Using the same method as with the construction equipment, by investigating the Inventory Analysis, we can gather that for the entire portfolio 5 553 556 litres of diesel is estimated to be consumed by construction equipment in the 49 infrastructure projects. Using the conversion ratio (Eq. 3.4) we get that the amount of work done by the construction equipment is:

Equation 5.4: Work done by ICE - Construction equipment in the portfolio:

$$5\,553\,556\,l * 4\frac{kWh}{l} = 22\,214\,224\,kWh \approx 22.2\,GWh.$$

And using the conversion ratio (Eq. 3.5) for translating a litre of diesel into electricity that had to be produced to power battery driven electrical engines to do the same work we get:

Equation 5.5: Electricity production needed to cover the work done:

$$5\,553\,556\,l * 5.07\frac{kWh}{l} = 28\,156\,528.92\,kWh \approx 28.2\,GWh$$

To find the emissions attributed to this work done we take the emission ratio we decided to use during research 2.66kgCO_2/litre and multiply that with the amount of diesel consumed by construction equipment.

Equation 5.6: Emissions from burning diesel in construction equipment:

$$5\,553\,556\,l * 2.66\frac{kgCO_2eq}{l} = 14\,772\,458.96\,kgCO_2eq \approx 14\,800\,tonnCO_2eq.$$

As with construction equipment we are going to be looking at the 6 scenarios described in chapter 3.4.

- **S_1N – 12 gCO_2eq./kWh** – The emissions attributed to the Norwegian electricity-consumption mixture.
- **S_2E – 307 gCO_2eq./kWh** – Emissions attributed to production of electricity in Europe.
- **S_3P – 950 gCO_2eq./kWh** – Emissions attributed to producing electricity with petroleum.
- **S_3N** – **411 gCO_2eq./kWh** – Emissions attributed to producing electricity with natural gas.
- **S_4_2030** – **261 gCO_2eq./kWh** – Emissions from European electricity mix in 2030.
- **S_4_2050** – **19.2 gCO_2eq./kWh** – Emissions from European electricity mix in 2050.

Further the study investigated the possible emission-cuts for different degrees of electrification. Transitioning the entre machinepark of Norwegian Transportation Vehicle will take some time, so we will be looking at how much emissions would have been cut in the portfolio had respectively 5%, 10%, 25%, 50%, 70% and 100% of the Work done, been done with EE rather than ICE.

Table 10: Emissions that would have been saved in the portfolio, given that the transportation workload is done with electrical engines instead of diesel engines:

		S_1N	S_2E	S_3P	S_3N	S_4_2030	S_4_2050
Workload done by electricity	EL gCO2eq/kwH	12	307	950	411	261	19,2
0 %	0% el	0	0	0	0	0	0
	100% diesel	14772	14772	14772	14772	14772	14772
	Sum	**14772**	**14772**	**14772**	**14772**	**14772**	**14772**
5 %	5% el	17	432	1337	579	367	27
	95% diesel	14033	14033	14033	14033	14033	14033
	Sum	14050	14466	15371	14612	14401	14060
	Saved emission	**722**	**306**	**-599**	**160**	**371**	**712**
10 %	10% el	34	864	2675	1157	735	54
	90% diesel	13295	13295	13295	13295	13295	13295
	Sum	13329	14159	15970	14452	14030	13349
	Saved emission	**1443**	**613**	**-1198**	**320**	**742**	**1423**
25 %	25% el	84	2161	6687	2893	1837	135
	75% diesel	11079	11079	11079	11079	11079	11079
	Sum	11163	13240	17766	13972	12916	11214
	Saved emission	**3609**	**1532**	**-2994**	**800**	**1856**	**3558**
50 %	50% el	169	4322	13374	5786	3674	270
	50% diesel	7386	7386	7386	7386	7386	7386
	Sum	7555	11708	20760	13172	11060	7656
	Saved emission	**7217**	**3064**	**-5988**	**1600**	**3712**	**7116**
70 %	70% el	237	6051	18724	8101	5144	378
	30% diesel	4210	4210	4210	4210	4210	4210
	Sum	4447	10261	22934	12311	9354	4588
	Saved emission	**10325**	**4511**	**-8162**	**2461**	**5418**	**10184**
100 %	100% el	338	8644	26749	11572	7349	541
	0% diesel	0	0	0	0	0	0
	Sum	338	8644	26749	11572	7349	541
	Saved emission	**14434**	**6128**	**-11977**	**3200**	**7423**	**14231**

Table 11: Percentage of emissions that would have been saved in the portfolio, given that the transportation workload is done with electrical engines instead of diesel engines:

		S_1N	S_2E	S_3P	S_3N	S_4_2030	S_4_2050
Workload done by electricity	EL gCO2eq/kwH	12	307	950	411	261	19,2
0 %	0% el	0	0	0	0	0	0
	100% diesel	14772	14772	14772	14772	14772	14772
	Sum	**14772**	**14772**	**14772**	**14772**	**14772**	**14772**
5 %	5% el	17	432	1337	579	367	27
	95% diesel	14033	14033	14033	14033	14033	14033
	Sum	14050	14466	15371	14612	14401	14060
	Saved emission	**0,3 %**	**0,1 %**	**-0,2 %**	**0,1 %**	**0,2 %**	**0,3 %**
10 %	10% el	34	864	2675	1157	735	54
	90% diesel	13295	13295	13295	13295	13295	13295
	Sum	13329	14159	15970	14452	14030	13349
	Saved emission	**0,6 %**	**0,3 %**	**-0,5 %**	**0,1 %**	**0,3 %**	**0,6 %**
25 %	25% el	84	2161	6687	2893	1837	135
	75% diesel	11079	11079	11079	11079	11079	11079
	Sum	11163	13240	17766	13972	12916	11214
	Saved emission	**1,5 %**	**0,6 %**	**-1,2 %**	**0,3 %**	**0,8 %**	**1,5 %**
50 %	50% el	169	4322	13374	5786	3674	270
	50% diesel	7386	7386	7386	7386	7386	7386
	Sum	7555	11708	20760	13172	11060	7656
	Saved emission	**3,0 %**	**1,3 %**	**-2,5 %**	**0,7 %**	**1,5 %**	**2,9 %**
70 %	70% el	237	6051	18724	8101	5144	378
	30% diesel	4210	4210	4210	4210	4210	4210
	Sum	4447	10261	22934	12311	9354	4588
	Saved emission	**4,3 %**	**1,9 %**	**-3,4 %**	**1,0 %**	**2,2 %**	**4,2 %**
100 %	100% el	338	8644	26749	11572	7349	541
	0% diesel	0	0	0	0	0	0
	Sum	338	8644	26749	11572	7349	541
	Saved emission	**6,0 %**	**2,5 %**	**-5,0 %**	**1,3 %**	**3,1 %**	**5,9 %**

As we see from the results in table 10 and 11, a notable amount of emissions would have been cut in the portfolio if the goal of 50% non-fossil transportation vehicles is solved with electrical engines. Dependant on how the electricity is produced between 0.7% to 3% emissions could be saved over such a portfolio in the future. Not quite as much as for construction equipment, but as transportation was registered only as a large contributor, while construction equipment is a major contributor, it is cuts for transportation vehicles are expected to have less of an impact on the Carbon intensity.

We see also here that there in scenario S_3P where electricity production is done with a generator running on petroleum that it is an overall worse solution with regards to emissions.

Fuel consumption for transportation vehicles is also a source of direct emissions from construction sites. The following data in table 12 is the same emission cuts, but with regards to the amount of total direct emissions.

Table 12: Direct emissions from transportation vehicles, given different amounts of workload being done with electricity, again as electricity has no scope 1 emissions attributed to them the source is irrelevant.

		S_1N	S_2E	S_3P	S_3N	S_4_2030	S_4_2050
Workload done by electricity	EL gCO2eq/kwH	12	307	950	411	261	19,2
0 %	0% el	0	0	0	0	0	0
	100% diesel	14772	14772	14772	14772	14772	14772
	Sum	**14772**	**14772**	**14772**	**14772**	**14772**	**14772**
5 %	5% el	*17*	*432*	*1337*	*579*	*367*	*27*
	95% diesel	14033	14033	14033	14033	14033	14033
	Sum	14033	14033	14033	14033	14033	14033
	Saved emission	**0,9 %**	**0,9 %**	**0,9 %**	**0,9 %**	**0,9 %**	**0,9 %**
10 %	10% el	*34*	*864*	*2675*	*1157*	*735*	*54*
	90% diesel	13295	13295	13295	13295	13295	13295
	Sum	13295	13295	13295	13295	13295	13295
	Saved emission	**1,8 %**	**1,8 %**	**1,8 %**	**1,8 %**	**1,8 %**	**1,8 %**
25 %	25% el	*84*	*2161*	*6687*	*2893*	*1837*	*135*
	75% diesel	11079	11079	11079	11079	11079	11079
	Sum	11079	11079	11079	11079	11079	11079
	Saved emission	**4,5 %**	**4,5 %**	**4,5 %**	**4,5 %**	**4,5 %**	**4,5 %**
50 %	50% el	*169*	*4322*	*13374*	*5786*	*3674*	*270*
	50% diesel	7386	7386	7386	7386	7386	7386
	Sum	7386	7386	7386	7386	7386	7386
	Saved emission	**9,1 %**	**9,1 %**	**9,1 %**	**9,1 %**	**9,1 %**	**9,1 %**
70 %	70% el	*237*	*6051*	*18724*	*8101*	*5144*	*378*
	30% diesel	4210	4210	4210	4210	4210	4210
	Sum	4210	4210	4210	4210	4210	4210
	Saved emission	**13,0 %**	**13,0 %**	**13,0 %**	**13,0 %**	**13,0 %**	**13,0 %**
100 %	100% el	*338*	*8644*	*26749*	*11572*	*7349*	*541*
	0% diesel	0	0	0	0	0	0
	Sum	0	0	0	0	0	0
	Saved emission	**18,1 %**	**18,1 %**	**18,1 %**	**18,1 %**	**18,1 %**	**18,1 %**

Transitioning from ICE to EE for transportation vehicles has a substantiable effect on the direct emissions of a construction site. Achieving Klimakur 2030's goal of 50% of workload done with electrical engines (or other non-fossil means) would reduce direct emissions by 9.1% no matter how Scope 2 emissions are allocated.

Besides emission regarding fuel usage there are additional emissions attributed to transportation vehicles regarding wear and maintenance that will be addressed later in the study together with wear and maintenance of construction equipment.

5.5.3. Investigating concrete

As concrete related inputs make up 20.0% of the emissions of the portfolio, further investigating was done. After sorting the dataset from high to low emissions in the 3 different categories allocated to concrete emissions it was discovered that 11 different projects made up the list of the top 7 emission contributors for each category. 6 projects are amongst the top 7 for at least two categories, and three projects are top 7 in all three categories.

Further investigating the 6 projects that were top 7 in concrete emissions in at least two categories it was discovered:

- The projects were, catalogue number: 4, 31, 30, 9, 18 & 24.
- The projects all had tunnels, with at least 1-kilometre tunnels in total per project.
- They totalled for 79.1% of the concrete emissions.
  - They made up 29.2% of all emissions allocated to concrete-elements.
  - They made up 93.5% of all emissions allocated to concrete-vaults.
  - They made up 70.7% of all emissions allocated to cast in place concrete.
  - They made up 91.4% of all emissions allocated to shotcrete.
- The projects caused 46.5% of all emissions in the portfolio.
  - Out of these, concrete contributed 34.0%, with construction equipment second for 20.8%, steel for 12.8%, transport 6.81%, explosives 7.32%, asphalt 6.76%, for a total of 89.49% - while other sources contributed 10.51%.

Further investigating the two remaining projects with tunnels, 19 & 20. They had the following characteristics:

- They totalled for 7.54% of the concrete emissions – (bringing the total for all projects with tunnels up to 86.6% of all concrete emissions).
  - They made up 5.20% of concrete elements emissions, bringing total up to 34.4%.
  - They made up 6.54% of concrete-vault emissions, bringing total up to 100%.
  - They made up 8.58% of cast in place concrete emissions, bringing total up to 79.3%.
  - They made up 7.18% of shotcrete emissions, bringing total up to 98.6%.
- The projects made up 7.33% of all emissions in the portfolio. (Bringing the total for project with tunnels up to 53.8%).
  - Out of these, concrete contributed 20.6%, with construction equipment 32.6%, steel for 9.74%, transport 12.3%, explosives 7.66%, asphalt 5.35%, for a total of 88.3% - while other sources contributed 11.7%.

This suggests that if seeking to cut emissions from concrete, a lot can be achieved by looking at how concrete is utilized in projects where tunnels are being built. When looking at the spread for concrete as a percentage of total emissions, all the projects where concrete made up more than 20% of emissions, were either, short bridges, ferry quays or tunnel projects.

Investigating the kinds of concrete used in the tunnel projects we get the following list:

Table 13: Qualitative Inventory Analysis for what kind of concrete is used in the tunnel projects:

	Cast in place [m3]		Concrete Elements [tonnes]	Concrete Vault [m2]	Shotcrete [m3]	
	B35 CEM-I	B45 CEM-I	B45 CEM-I	CEM-I	B35 -CEM I	B35-CEM-I - With Plastics fibres
E-3 Str	884	2948	1442	36000	130	5105
Berfjord	1132	1186	69	31000	105	4225
Ryssdalen	380	3228	242	25750	162	4280
Åstfjord	2745	17837	650	0	370	9020
Snilldal (ny veg og tun)	1360	3396	422	29500	300	4800
Mjønes Vass	735	3179	220	53000	0	12864
Sumstad	155	872	184	10500	40	1640
Krokstadøra (ny veg)	200	2778	343	1700	70	1500

All projects investigated and shown in table 13 have CEM-I, classified concrete. As studies have shown that it is possible to produce concrete, with reduced emissions compared to the CEM-I types, (Limbachiya, Bostanci and Kew, 2014) we are investigating how such a choice would have impacted the dataset. VegLCA gives CEM II/A (low-carbon concrete class A) and CEM II/B (low-carbon concrete class B) concretes as options to choose from when selecting what kinds of concretes are used in the project. Using the values VegLCA considers as standard values for the CEM II/A and CEM II/B counterparts in Norway we get the following result as shown in table 14.

Table 14: Investigating what the emissions would have been for these quantities of concrete given different production methods:

	Cast in place [m3]		Concrete Elements [tonnes]	Concrete Vault [m2]	Shotcrete [m3]	
	B35 CEM-I	B45 CEM-I	B45 CEM-I	CEM-I	B35 - CEM I	B35-CEM-I - With Plastics fibres
Sum of all 8 tunnel projects	7591	35424	3572	187450	1177	43434
CEM I Emissions	330	360	200	43,7	332	342
CEM II/A Emissions	280	290	173	37,2	258	268
CEM II/B Emissions	210	220	146	37,2	258	268
Emissions, tonnes with CEM I	2505,03	12752,64	714,40	8191,57	390,76	14854,43
Emissions, tonnes with CEM II/A Counterparts	2125,48	10272,96	617,96	6973,14	303,67	11640,31
Emissions, tonnes with CEM II/B Counterparts	1594,11	7793,28	521,51	6973,14	303,67	11640,31

Sum of concrete emissions in the 8 tunnel projects for cast in place concrete, concrete elements, concrete vaults, and shotcrete:

- 39 409 tonnes CO_2eq. with CEM-I emission numbers.
- 31 934 tonnes CO_2eq. with CEM-II/A emission numbers, 19% lower than CEM I.
- 28 826 tonnes CO_2eq. with CEM-II/B emission numbers, 27% lower than CEM I.

This suggests that if CEM II/A concrete had been used instead of the CEM I concrete, 7 475 tonnes of CO_2eq. emissions could have been saved. And if CEM II/B concrete had been used instead of CEM I concrete, 10 583 tonnes of emissions could have been saved.

The effect of choosing CEM II/B over CEM II/A seems to come from using it in cast in place concrete, and concrete elements.

For a goal of cutting emissions from infrastructure projects containing tunnels, demanding CEM II/A or CEM II/B for concrete vaults and shotcrete products, and CEM II/B for concrete elements and cast in place concrete would cut emissions related to the concrete used by 27%, compared to if CEM I concrete products are used, for a portfolio similar to the one assessed.

If these projects had used CEM II/A and CEM II/B concrete as suggested here, the total emissions from the 8 projects would have been cut from 130 275 by 10 583 to 119 692, achieving a CO_2eq. emission cut of 10.2% in these projects.

The same emission cut for these 8 projects would have contributed to a 4.38% emission cut for the entire portfolio.

Looking at the spread for the projects, to look for which of the different concrete types contribute the most to concrete emissions, I realise that “Åstfjordkryssinga” and “Ny veg utenom krogstadøra” are outliers that have more emissions attributed to bridge-construction than tunnel-construction in their assessments. This causes their emissions to heavily come from Cast in place concrete, while the other projects have their concrete emissions mainly from concrete vaults and shotcrete, as seen in figure 33, removing “Åstfjordkryssinga” and “Ny veg utenom krogstadøra” heavily impacts the spread.

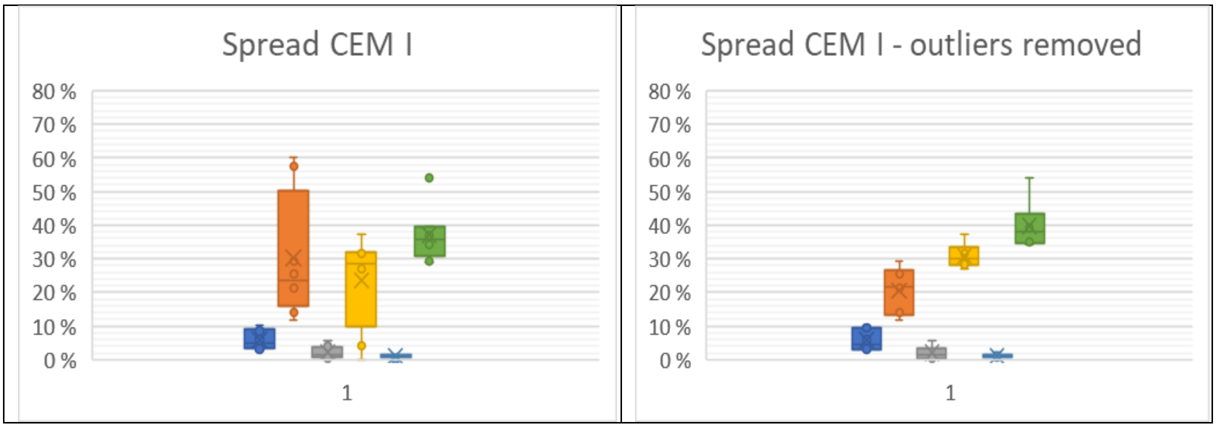


Figure 29: Comparing the spread of tunnel projects before and after removing the two tunnel-outliers. On the left we have all the tunnels, and on the right the same projects after the outliers are removed. The spread is more collected after removing the outliers.

With this new insight, the suggestions for usage of CEM II/A and CEM II/B concrete products, could be expanded to also include concrete bridges, especially considering CEM II/B for cast in place concrete.

5.5.4. Investigating asphalt

The study from SINTEF claims that asphalt produced on a lower temperature, asphalt produced with fossil free components, or asphalt with high degree of recycled asphalt is products entrepreneurs can provide today, but there are little demands for them by the road owners (SINTEF, 2021). These are also the suggestions Zero have for cutting emissions in the asphalt component of the roads (Zero, 2020).

333 801 tonnes of asphalt have been consumed in the 49 projects of the portfolio, for 23 932 tonnes of CO_2eq. emissions, for an average of 71.7 kg CO_2eq./tonnes asphalt. The 20 projects with the most asphalt consumed it was found that 58% of the asphalt consumed was Asphalt-gravel, and 35% of the asphalt was in the category “asphalt-gravel-concrete and asphalt concrete” the other 4 categories of asphalt shared the remaining 7% of the total tonnage.

As the technological advancement within the field of asphalt moves rapidly, the best suggestion for emission cuts within the asphalt sector might be a different approach than by setting a demand for specifics kinds of asphalt, and rather offer bonus incentives for better emission-standards can be an approach.

Trøndelag fylkeskommune has since 2018 been using CO_2eq. as one of the selection mechanics for asphalt-contracts (contracts for refreshing the asphalt), offering entrepreneurs bidding for the contracts a bonus in the competition if they have the least carbon impact in their solution, by giving competitors an artificial increase in their bid price, based on how much more CO_2eq. they will use than the one with the lowest carbon impact.

Competing on carbon impact for asphalt in a construction contract is less advisable, as asphalt usually according to the spread research, only contribute between [8.2%,17%] of the total emissions in a project, with 10.5% being the mean for the projects when outliers was removed. However, working together with the entrepreneur to find good emission cuts within asphalt should be possible as the entrepreneurs claim that they have better products available, but meet little demand for them (SINTEF 2021). A study where CO_2eq. emissions was weighted as much as costs in asphalt contracts, showed that given the opportunity to earn more money, entrepreneurs found ways to optimize production for less emissions during laying of asphalt (Anthonissen et al, 2015). Optimizing delivery, and energy efficiency as some of the measures (Anthonissen et al, 2015). Trøndelag fylkeskommune also already has some experience with asphalt where bitumen is replaced with a plant based alternative (Bygg.no, 2021). Together with the entrepreneur Veidekke the bio-asphalt was tried at county road 700, and the results after testing were good enough that the asphalt further is employed at a national-road E14 (Aarhus, 2021). The article claims that the innovation goes fast enough that emission cuts within asphalt should be possible for up to 80% within a few years (Aarhus, 2021). Australian research supports the claim that bio-based binders in asphalt should be able to lower the carbon impact of asphalt, in the study 25% of the bitumen was replaced with lignin and it was found that it reduced the Global Warming potential by 5.72% for the asphalt (Tokede et al, 2020), extrapolating that it could be possible with up to 20% emission cuts. A study in Netherlands found that bio-based asphalts could have reduced carbon impacts between 25-70% dependant on which layer and what method for manufacturing was used. (Moretti et al, 2022). Several studies are investigating properties of different adhesives for asphalt to be able to warm mix it rather than hot mix it (Caputo et al, 2022; Hu et al, 2022; Liang et al, 2022; Wang et al, 2021; Sukhija, Wagh and Saboo, 2021) suggesting great improvements in the energy saving in future asphalt laying. A different recent study shows promise by using waste from building demolition as the aggregate for subbase in road pavement (Tefa et al, 2022). All the recent developments within the field, show that it should be possible to replace bitumen with bio-based bindings, use recycled materials for some of the asphalt, combined with more knowledge about how to produce asphalt as warm mix, rather than hot mix show that the field is in rapid development, and thus any static advice on what to do within the field will probably be outdated by the time such advice is enacted, the best advice would therefore be to work together with asphalt-entrepreneurs to push the boundaries of what is possible within asphalt, keep them on their toes to take advantage of the rapid new innovations within the field.

Suggestions for Asphalt

Demand EPDs and use them in future LCAs for projects. Work with entrepreneurs to keep them on their toes to take advantage of the rapid new innovations within the field and implement new solutions to cut emissions within asphalt. The bonus and malus incentives for emissions could be a good way to achieve emission cuts within an emission contributor where the developments are rapid, as you can demand a threshold to beat, rather than a specific solution. When actions taken in asphalt-contracts can be documented to efficiently reduce emissions, enact policies to demand such actions also to be taken in construction of new road projects, and not only during refreshing of the asphalt.

5.5.5. Investigating Steel

Steel is a major contributor to the projects that has a large portion of the project being a bridge or a tunnel, according to the dataset, shown in figure 26 & 27. The steel industry is improving steel production regarding emissions by reducing the amount of energy required to make steel by 60% since 1960 (Worldsteel Association, 2017), employing Carbon Capture and Storage (CCS) Technology cutting emissions by 50%-60% (Santos et al, 2013) and recycling steel scrap (Chisalita et al, 2019). CCS is costly, and for steel-manufacturers to willingly be producing steel more expensive, then purchaser needs to be willing to pay a higher price for steel produced with less emissions. Public offices should make sure that steel consumed by their road constructions is low-emission steel. Therefore, EPDs of steel used within the project should be gathered and used in future analytics of LCA.

A different way to reduce emissions from steel is in projects containing bridges and tunnels, to in early planning look for alternative routes that demand less emission-intensive infrastructure like tunnels and bridges or for such infrastructure to be built by less carbon-intensive materials. For the portfolio analysed in this study we had average road related emissions per meter road to be 1.31 tCO_2eq./m, with bridges having 9 times that at 11.7 tCO_2eq./m, and tunnels at 3.20 tCO_2eq./m.

Suggestions for steel

Again, demand EPD, and demand low-emission alternatives for projects where steel is a large or major contributor to emissions, such as bridges and tunnels. If possible, reduce the amount of steel needed by looking for alternative routes, or alternative materials to steel for construction.

5.5.6. Investigating Explosives

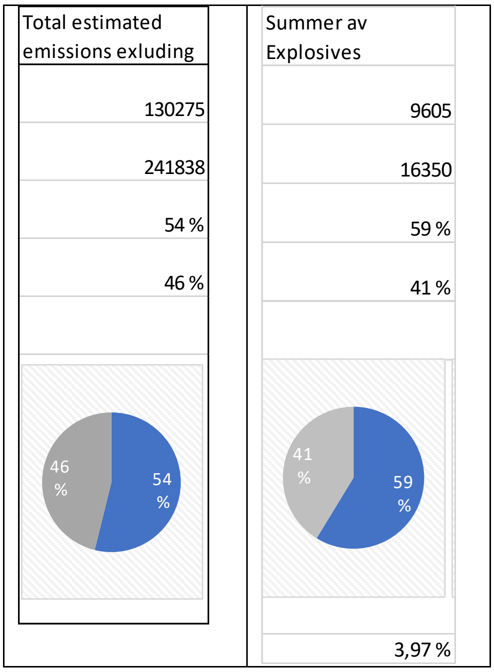


Figure 30: The amount of total emissions, and explosive related emissions for tunnel-projects. Comparing them they do not seem to be much larger than expected

Investigating the emissions attributed to explosives for the portfolio there seems to be little stand-out trends and insights to highlight. As tunnelling in Norway primary is driven by explosives, I would have expected a majority of the emissions attributed to explosives to be allocated to tunnels. When looking at the data for tunnels we see however, that while yes 59% of the emissions attributed to explosives are allocated to the 8 projects in the portfolio with tunnels, that is not un-expected as the projects overall had 54% of the total emissions in the portfolio. Looking at the spread for explosives for all projects in figure 16, it is apparent that none of the projects had enormous emissions from explosives.

For the projects with tunnels emission from explosives varied between 5% to 10% of the total emissions in the projects – which suggest that to gain benefits from doing actions to cut emissions through explosives the same action will have to be taken for all road construction, and not just allocated to tunnelling to be effective.

Alternatives to using explosives might be few, studies regarding tunnelling show that rock class has a lot to say for the environmental impact of tunnelling (Huang et al, 2020), and the hard rock mass of Norwegian Mountains are less suited to alternative excavation methods than explosive usages (Rodríguez and Pérez, 2021).

Again, the best course of action for reducing emissions would be to get EPDs from entrepreneurs that are building tunnels, other ideas would include to use more time to plan and prepare each salvo to increase the efficiency of rock excavated per explosive (Zero, 2020).

5.5.7. Investigating wear, tear, and maintenance

Wear, tear, and maintenance of Construction equipment and Transportation vehicles accounted for most of the emissions allocated to construction equipment and Transportation vehicles that did not come from fuel consumption.

Out of the entire portfolio 42% was allocated to construction equipment and transportation vehicles, and that was further separated to 33% of that being fuel consumption and 9% being wear tear and maintenance. Construction equipment and transportation vehicles have a heavy up-front emission output during production and has an expected amount of workdays during its expected lifetime which infrastructure projects consume. To reduce emissions allocated to wear tear and maintenance, it would be beneficial to have an efficient usage of such material and not have unnecessary high capacity.

Efficient planning reduces the amount of unused capacity demanded and mitigating risk of material damages through safety protocols would reduce material loss to accidents. Minimalizing the need for transportation vehicle workhours by optimising mass balance and using excess masses in the projects (Zero, 2020). Finding and planning uses for excess masses after projects, so they do not end up as waste.

6. Discussion

6.1. What the results tells us

6.1.1. Benefit of a large sample size with harmonized data

The other studies I have seen on LCAs on road infrastructure, either have a very small sample size of projects, or they have a large sample size with harmonization difficulties (Hoxha et al, 2021). Studies based on a small sample size could get coloured by single projects, while studies with harmonization difficulties can have trouble giving apples-to-apples comparisons. Now the study of the overall portfolio of this study was skewed by a few very emission-intensive projects, but because of the large sample size we were able to identify it. The spread for emission profiles within single projects was also visibly skewed when comparing the average and the mean values within the spread, as seen in figure 31.

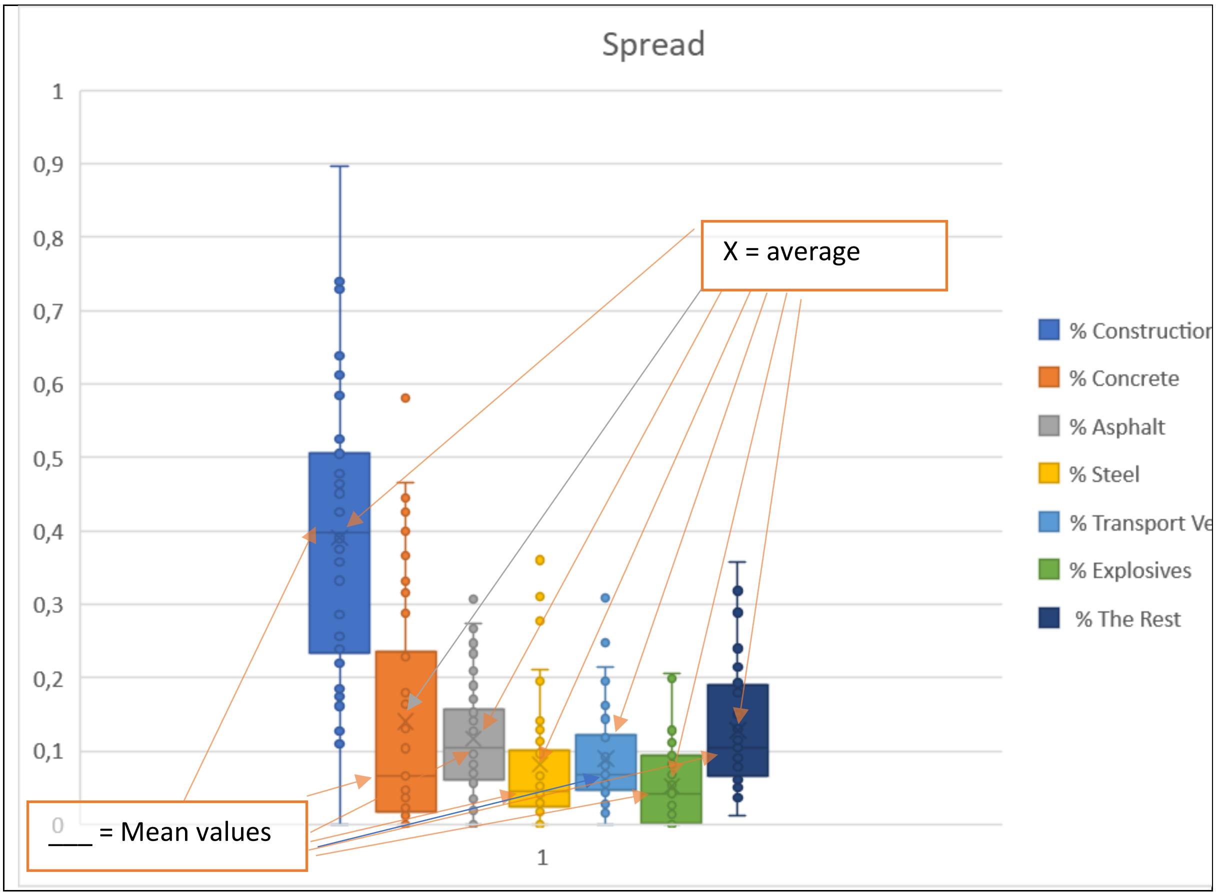


Figure 31: The spread for all projects of the portfolio. for some of the emission contributors the average and the mean values are off by almost 10 percentage points, this indicates that data will be skewed based on some factors.

For concrete the average values and the mean and average values for the percentage of emission contributed by concrete within each project, is off by almost 10 percentage points. This indicates that there are specific characteristics within these projects that largely contribute to concrete emissions, the same is also seen for steel projects. What is interesting is how the mean value for the spread is different from the emission portfolio overall.

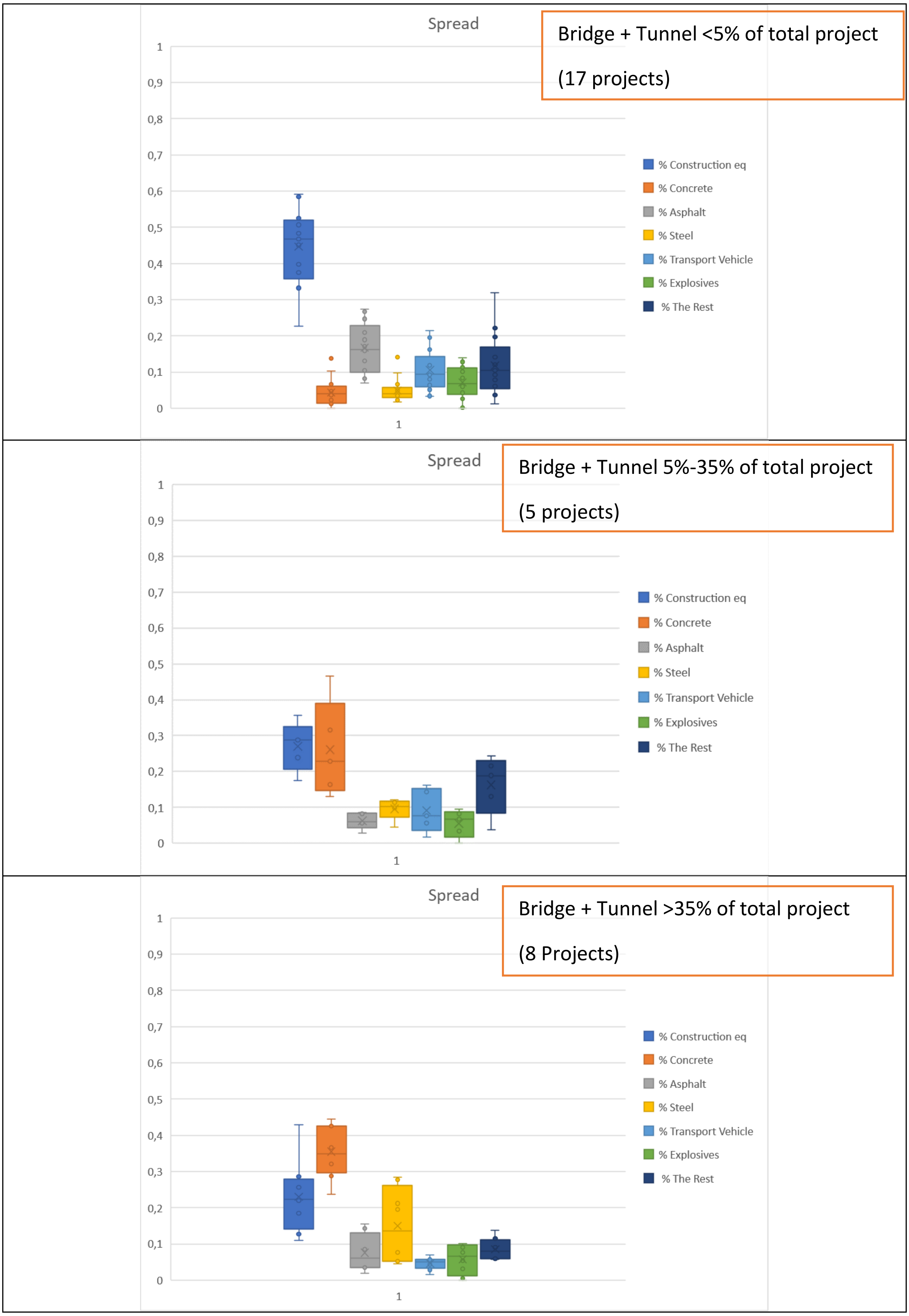


Figure 32: Spread for the individual projects when separating the projects into selections based on how much of the total project length that is either bridge or tunnel.

Through investigating it was found that this discrepancy is largely attributed to the fact that the project portfolio is made up of projects with different characteristics, specifically some of them have tunnels, some bridges, some neither, some both, and some of the projects are not directly road construction. If we separate the data into 3 categories, one for projects that are vehicle roads with 95% or more non-bridge non-tunnels, one category for projects with 66%-95% vehicle roads and the rest tunnels and bridges, and the rest where <66% is vehicle roads as shown in figure 32, we see that when a higher percentage of the project that is non-road the emission-profile changes drastically, bearing in mind that when splitting up the dataset the selections of data have smaller sample-sizes.

I would say that a major benefit of this study, compared to other studies I have seen is that we have a much larger sample size to harvest data from, making us able to look for and identify such differences between types of projects. In addition to being a large data sample, the assessments are all made by the same assessor with the same LCA tool in the same country within a relatively short time span. This drastically lessens the burden of harmonization between the different assessments in the portfolio, admittingly they are done in different versions of the VegLCA tool, which will be the source of some error, but this could be very much fixable by harmonizing the data between versions, which is suggested for future research.

6.1.2. Take away from the spread

- We have identified 4 large and 2 major emission-contributors from the portfolio.
- We have identified that what contributors are large and what are major contributors change dependant on how much of the project is vehicle road, bridge and tunnels.
    - For road projects where bridges and tunnels are less than 5% of the project:
        - Construction equipment and asphalt are typically major contributors (>15%).
        - Explosives and transportation are typically large contributors (15%>5%).
        - Concrete & steel are typically small contributors. (<5%).
    - For road projects where bridges and tunnels are 5%-35% of the project:
        - Construction equipment and concrete are typically major contributors.
        - Explosive, steel, asphalt & transportation are large contributors.
    - While for road projects where bridges and tunnels are >35% of the project:
        - Construction equipment, concrete & steel are now major contributors.
        - Asphalt, transportation, and explosives are large contributors.
- We have identified that the 6 emission contributors identified as large and major usually make up at least 80% of project emissions, typically make up 85%-90% of emissions, and for our portfolio always made up at least 64% of the emissions.

6.2. Takeaway from the results to the research questions

6.2.1. Electrifying non-road machinery and heavy transportation

The portfolio of LCAs we analysed had a 33% of the emissions attributed to direct consumption of fossil fuels at construction sites, or by transportation vehicles and it was by far the most important single contributor to emissions. Transitioning away from burning fossil fuels, over to using a different energy bearer that can do the same work is a necessary step to cutting emissions. It is however, important to be aware of how different energy-bearer might have an effect on the climate instead of what effect burning diesel had.

Whether engines in the future are running on electricity (Andwari et al, 2017), Hydrogen (Bakar et al, 2022) or Ammonia (Cardoso et al, 2021) is not the important factor it is how the energy bearer is produced. In our analysis we looked specifically at transitioning towards electrical engines, and it was shown that how the electricity was made has an important impact on the scope 2 emissions from the construction equipment and transportation vehicles. If the electricity is produced with clean and renewable energy then electricity is a much better alternative than consuming diesel, but if the transition towards Electrical engines is a direct cause for a generator running on fossil fuels, that might even be worse with regards to emissions, in addition to it costing more. This is very important to be aware of, because if policies are enacted to transition from Internal Combustion Engines to Electrical Engines, but there is not infrastructure in place to connect the equipment to the electrical grid, then that policy might do the opposite of what it was intended to achieve. The same will be true for ammonia, hydrogen, or other possible energy-bearers if they are chosen instead, if they are not produced with clean and renewable energy then it is just a few added steps for the same emissions resulting in a worse emission-to-work ratio.

6.2.2. Effect of achieving the goals of Klimakur 2030, transitioning towards EEs instead of ICEs

If the goals of Klimakur 2030 had already been achieved in Trøndelag, where respectively 70% of the workload done by heavy construction equipment and 50% of the workload done by transportation vehicles is done with electrical power rather than fossil fuels, the portfolio of projects we analysed would have had 66.8% less direct emissions (Scope 1) than they were found to have, and 22% less total emissions (Scope 3). This should mean, that if Trøndelag Fylkeskommune can enact policies so that the local entrepreneurs fulfil those criteria by 2030, emissions from a similar portfolio of projects in 2030-2040 would be expected to have 66.8% less scope 1 emissions, than the portfolio for 2010-2022 had.

However, from a scope 2/3 perspective the cuts are only efficient as long as the electricity consumed is produced with clean and renewable energy. Policies about electrification cannot be done in a vacuum and should also be accompanied by policies to expand production of clean renewable energy, as it was showed that Norway has an energy surplus, but not enough to replace all fossil-fuel usage as of now (Statistisk Sentralbyrå, 2022b).

6.2.3. How should we attribute emissions from electricity

As discussed in chapter 3.7, there are several different ways to interpret the emissions attributed to electricity. In addition to the different Scenarios to consider for what should be the correct way to calculate emissions, there is also the different kinds of Scopes of emissions to consider too. For example, while the Norwegian electricity mixture was considered to be 12 $gCO_2eq./kWh$ in a Scope 2 analysis (Norges Vassdrag- og Energi- direktorat, 2022c), it was considered to be 28 $gCO_2eq./kWh$ in a Scope 3 analysis (Scarlat et al, 2022).

A reason for why I have spent a lot of time on the emissions for electricity in this thesis, is that I think it is not a straightforward answer to how to always do the calculations. With regards to direct emissions (Scope 1) electricity is always better than petrol. That is, of course unless the electricity is generated on site with a generator, the scope 1 emissions from the construction equipment is better, but the scope 1 emissions from the construction site becomes worse! This could look better on paper if the generator is moved off-site, but the same emissions are now there. Therefore, I think that when looking at construction sites at least scope 2 emissions must be attributed to the machinery, when comparing wat kind of power source to consider for the future.

There are also the Scope 3 emissions to consider, with harvesting and transporting oil, production of powerplants, and manufacturing of hydrogen should that be the chosen energy bearer. These need to be considered in systems where similar emissions are attributed to other materials, as for example when making emission profiles, but should they be accounted for when choosing between solutions for the future? There is the opportunity cost of energy consumed cannot be consumed elsewhere as for other materials. There is also a sunk cost in materials consumed to construct such infrastructure, but that does not necessarily translate into new emissions in the future to replace it.

I think that while it is important to be aware of the implications of the different scenarios and scope of electricity when comparing LCAs with one another, one must not lose sight of the large problem one is trying to solve – the reduction of carbon impact on a long-term basis. If disagreements around how to attribute emissions to electricity cause confusion that leads the transition away from fossil fuels to halt, then the debate probably does more harm than good. The benefits we have seen in this study regarding to what emissions will be based on electricity made from clean renewable sources rather than diesel are so large that they dwarf the differences between a scope 2 and a scope 3 analysis for clean renewable energy, when comparing scope 2 emissions between diesel to clean renewable electricity, and scope 3 emissions between diesel and clean renewable electricity.

6.2.4. Biofuels – Good or bad

Producing biofuels have some of the same problems as the other energy-bearers, in that they demand resources to produce the energy-bearer and if they are not clean and renewable energy, then they either are not clean, looking at the Swedish study where production criteria were optimal (Basile et al, 2022) they found the emission through production not be around 0.4 $gCO_2eq./MJ_{MeOH}$. If we translate that into per kWh by dividing 0.4 by 0.2778 (as explained for Eq. 3.3), we get 1.44 $gCO_2eq./kWh$, which is less than the 12 $gCO_2eq./kWh$ for the Norwegian electricity mixture (Norges Vassdrag- og Energi-direktorat, 2022c).

Biofuels can be produced very emission efficiently (Basile et al, 2022), however biofuels have the drawback of still producing some emissions when burned. In addition, what biomaterial is used to produce the biofuel is important to pay attention to, if a crop such as rapeseed is cultivated for the sole purpose of producing biofuel, then there are emissions attributed to cultivation to take into account (Basile et al, 2022). Land usage itself is also a factor when land is converted to producing biofuels (Maia and Bozelli, 2022), and if land usage conversion to biofuels lead to deforestation elsewhere there are additional negative impacts, there are also the ethical concerns about using limited resources as farmable land and freshwater for biofuels rather than food (Sikarwar et al, 2017). Biofuels can be produced by other means though, biofuels produced by utilizing bio-waste and by-products from food production (Areeshi, 2022; Gupte et al, 2022) is a great way to produce biofuels at the same time as one deals with waste-management of a different process, combined with forestry these biomass sources could be a source of 50-150 Exajoules of energy annually in 2050 (Popp et al, 2014).

While biofuels are proven to be cleaner than fossil fuels (Humpenöder et al, 2013), they still release emissions, and are interrupting the fast carbon cycle. Looking at the slow carbon cycle, biofuels are much better than fossil fuels as they are not introducing new carbon into the fast carbon cycle by disrupting the slow carbon cycle, however they are still hindering the absorption of carbon for the fast carbon cycle and ideally should be avoided at long term but could still be a good option compared to fossil fuels short term.

A Malasyan study did an LCA for comparing land usage for Large Scale Solar farming, and land usage for Palm-oil biofuels, concluded that large scale solar farming was overall a better choice than palm-oil biofuels, and that while solar panels use some scarce minerals farmed biofuel uses scarce agricultural resources like freshwater (Phuan et al, 2022). Especially interesting was it that the land usage needed to make palm-oil biofuel for Malaysia to reach their emission-cut goals was 171 higher than the land usage needed for solar panels to produce enough clean electricity to do the same job (Phuan et al, 2022).

With the perspective that farmed biofuels, and solar panels basically are two different ways of harvesting solar-energy, where farmed biofuels are much less area-effective than solar panels, it makes little sense for me to encourage the use of farmed biofuels, when it in theory would have been much more efficient of using biofuel-farmland for solar panels. Using farmland for solar panels is also a silly idea, as they do not need arable land which is a scarce resource. However, biofuels based on extracting energy from bio-waste is not demanding scarce resources in the same way, instead they are reducing waste from different sectors, and would seem like a better solution than farmed biofuels.

6.3. Comparing our data, with data from other studies

While the scopes of different studies might be different, there can still be something to learn from comparing our assessments with the other we have researched. Compared to the Chinese study in Xi'an (Li et al, 2020) the Chinese road had 84.49 CO_2eq./m^2, while looking at the average emissions per m^2 in the figures for spread (figure 22) we see that our dataset has a somewhat higher emission profile from road construction per m^2, than them, with both the average and the mean hovering around 190 kgCO_2eq./m^2. While our dataset contains projects typically 8 meters wide with 2 lanes and built-in rural environments, the Chinese road was 60 m wide 6 lanes + 2 non-motor lanes and built in an urban environment (Li et al, 2020). If we compare emissions per lane built, we see that Trøndelag roads come out around 700 kgCO_2eq./meter*lane (figure 22), while adjusting the Chinese study for lanes we find them to have 633 kgCO_2eq./meter*lane if we consider the non-vehicle lanes as lanes, illustrating that it is hard to compare emissions road for road when they are vastly different metrics, and why apples-to-apples comparisons are important. The study of the Chinese highway found concrete and steel to be the largest material contributors to emission (Lou et al, 2021). In our study we found that Concrete was the largest contributor, but steel was narrowly beaten by asphalt as a main contributor for the portfolio when it comes to emissions attributed to consumption of material. When looking at the spread it was discovered that for Trøndelags portfolio of projects emissions attributed to steel and concrete was heavily impacted of whether projects had tunnels or bridges as a part of them, while the emission contribution factor of asphalt was much more stable. When investigating the steel and concrete emissions for Trøndelags portfolio it was found that the vehicle road projects without tunnels and without bridges had about 6% emission contribution from concrete and steel all together. This suggested that the Chinese highway-project might include a bridge or a tunnel, that might influence what materials came out with the highest emission impact and investigating the study again It indeed included a 240 m bridge.

6.4. Uncertainty

6.4.1. Impact of the different versions of VegLCA on the results

The total update between versions 4.06 and 5.06b might be a source of an error that is hard to estimate a fix for without re-doing all the older assessments in a newer version. It is my opinion that it would be too much work to manually re-do every single assessment ever done each time some minor adjustments have been implemented. It should be possible to make a simple program or macro in excel to take in assessments made in older versions of VegLCA and make the adjustments needed to upgrade them to never versions without the need for manual labour each time a newer version is out. This is left for a future study, and it is that the differences in the different versions of VegLCA is most probably a source of some minor errors relative between datasets inputted into the databank.

6.4.2. Some assessments are made long after the project is complete

Some of the assessed projects were built early in the 2010s, while the LCAs were made in the period 2020-2022. As the industry standard has changed somewhat during the 10 years, we can expect the assessment to have a somewhat lower precision on estimating the emission of the built projects. However, when looking at the portfolio as if it was built today with regards to finding emission-cuts for the future, this should not have a impact on the efficiency of the suggestions.

6.5. Following up the changes for draft-contracts

Statens Vegvesen supply contract-drafts for road construction which amongst other suggest low-carbon concrete, demanding EPDs for asphalt, construction concrete and steel-armament actively using VegLCA for emission-planning amongst other things (Statens Vegvesen, 2022b; Statens Vegvesen ,2022c). Paying attention to the evolution of the climate section of these contracts and enforcing these suggestions is a really good idea for implementing good emission cuts, as whenever good industry practices evolve, they can easily be distributed to all road construction offices through changes in these contracts. Looking at the example for the concrete, we found while investigating concrete that had the demands from the draft-contracts that class B35 and B45 concrete used for construction to not surpass respectively 280 & 290 kgCO_2eq./m^3 (Statens Vegevesen, 2022c) been enacted since 2010 for the entire portfolio of projects the emissions allocated to concrete would have been 19% lower, given the quantity of concrete had remained the same. Had EPDs for asphalt, concrete and steel armament been provided in the LCAs then the information provided in the portfolio would have been a much more precise estimate of the actual emissions associated with the projects.

6.6. Lack of EPDs in the assessments of the portfolio

While this study has managed to find emission results for a portfolio put together of infrastructure projects representative for the activities of Trøndelag Fylkeskommune, there is little documented evidence in the assessment for project specific material choices in the form of EPDs. Which means – every time VegLCA calculates the emissions for asphalt, concrete, steel, or other contributors in the assessments, instead of using specific and precise documented EPDs for the emissions in the project, the tool instead used the generalized emissions attributed to standards for Norwegian road construction. This means that the results this study got, while giving an indication to what such a portfolio would have produced in emissions for a typical Norwegian road construction project, it does not give precise results for the Trøndelag fylkeskommune portfolio in specific unless the Norwegian standard for road construction was used at all projects.

A remedy for this could be to demand EPDs, preferably for all contributors, but at least for the main six emission contributors found by this study. By collecting EPDs for the 6 largest contributors a similar portfolio would have accounted for about 89% of the Scope 1,2 & 3 emissions, based on the data from this study.

While EPDs are most suitable to material contributors such as: steel, concrete, asphalt, and explosives, for non-road machinery and transportation it might be more challenging, so a different option could be to demand a specific quality with regards to emissions of construction equipment and transportation vehicles.

This leads us to the suggestion for policy makers: Work towards systematically working with emissions for the large contributing factors, by demanding EPDs for asphalt, steel, concrete and explosives. Use these EPDs in the continued work with assessing emissions from projects to gain precise knowledge about the emissions from your activities.

6.7. Building road infrastructure, from an emission point of view, was it worth it

Every now and again, the thought strikes me; would it be better to not build more infrastructure and just let it decay controlled? To explore this, data from the portfolio is used to look at differences in emissions now and in an imagined scenario where the infrastructure in the portfolio was not improved.

It has been shown that the portfolio of projects has built 87.7 km roads, 13.7 km tunnels, 2.65 km bridges and released about 240 000 tonnes of CO_2eq.

There are so many factors to take into account for such a question and while the study will not expand on all of them and only choose a few of them to expand upon, to see whether the investment/saved ratio is in the ballparks of 1:10, 1:1 or 10:1. I think it is an important question to address – as building less infrastructure always is an option.

The big idea is that we should limit the emissions the world produce annually that contribute to global warming. Should there be a case for reducing emissions by simply reducing the amount of activity done in the infrastructure sector or would that have a negative impact on the environment in total?

The study will now compare the emission attributed to the road investments, and the traffic that uses it over the lifetime. There will be some assumptions made.

Based on the metadata provided for year mean traffic on the roads, the vehicle kilometres traversed along the vehicle roads assessed are 172 742.240 daily. The European Environment Agency estimated in 2019 that the average emissions from a new car is 120.4 gCO_2eq. per vehicle kilometre (European Environment Agency, 2021b). Assuming it can be used as a representative emission for the fossil fuelled part of the vehicle park active in the period 2010-2060, it gives us:

Equation 6.1: Emissions saved because of shorter travel distance for the daily traffic of Laksevegen:

$$120.4\ g\frac{CO_2eq.}{veh * km} * 172\ 742\ veh * km * day = 20\ 798\ 136\ \frac{gCO_2eq.}{day}$$

Equation 6.2: Expanding upon eq. 6.1 to give annual emissions save:

$$20\ 798\ 136\ \frac{gCO_2eq.}{day} * 365\ \frac{day}{year} = 7\ 591\ 319\ 932\ \frac{gCO_2eq.}{year} = 7\ 591\ tonnes\frac{CO_2eq.}{year}$$

Expanding to give us the emissions caused by traffic over the expected lifetime of 50-60 years is tricky as more and more of the vehicle park will convert to electric, or other clean energy sources. But if we assume that half of the vehicle-kilometres travelled over the lifetime will be done with fossil fuelled cars (some of the roads in the sample have already existed for ten-twelve years) we can get closer to a number to compare with the investment cost.

Equation 6.3: Emissions saved for personal vehicles over project lifetime:

$$7\ 591\ tonnes\frac{CO_2eq.}{year} * 0.5 * 60\ \frac{years}{lifetime} = 227\ 740\ tonnes\frac{CO_2eq.}{lifetime}$$

The study has yet to address that there are also heavier vehicles traveling along these roads. The study will for the sake of simplicity estimate that 10% of the traffic today is heavy transportation and assume that the emissions related to personal traffic in cars over the period is 90% of the 227 740.

Equation 6.4: Eq. 6.3 calibrated for the heavy traffic modulo:

$$227\ 740 * 0.9 = 204\ 966\ tonnes\ \frac{CO_2eq.}{lifetime}$$

Data from the European Automobile Manufacturers Association suggests that new heavy-duty vehicles are releasing around 80-50 (g/tkm)CO_2eq. getting more effective with higher tonnage (European Automobile Manufacturers Association, 2020). Let us assume that the heavy transport will maximise their transport capabilities and do 60 tonnes each, we get that the emissions per vehicle kilometre for the heavy transportation trucks are:

Equation 6.5: Emissions from heavy traffic:

$$50\frac{gCO_2eq.}{tkm} * 60\ tonnes = 3\ 000\ \frac{gCO_2eq.}{km}$$

Assuming 10% of the 172,742 vehicle kilometres travelled annually come from fully loaded heavy duty trucks, doing the same operation from before we get that the heavy-duty traffic produces:

Equation 6.6: Expanding eq. 6.5 for emissions for heavy traffic over project lifetime:

$$3\ 000\frac{gCO_2eq.}{veh * km} * 172\ 742\ veh * 0.10 * km * day * 365\frac{day}{year} * 0.5 * 60 = 567\ 457\ tonnes\ CO_2eq.$$

Further there is traffic growth to take into account, while there is a national goal that there should be no growth in personal vehicle transportation, research Trøndelag fylkeskommune has done suggests that in 2050 the amount of tonnage that is transported on the Trøndelag road-network has doubled compared to 2012 levels. (Trøndelag Fylkeskommune, 2018b). So increasing 567 457 with 50% should give some estimate here for a total 851 000 tonnes.

For an accumulated 1 055 966 $\text{tonnes CO}_2\text{eq}$. over the lifetime for both cars and heavy-duty vehicles.

Now to be “worth it” the investment of 240 000 tonnes of CO_2eq. + 1 055 966 tonnes of CO_2eq. caused by traffic, must be lower than what the emission case would have been for the same roads without the newly upgraded roads.

The road projects have improved two aspects the study finds worth highlighting regarding emissions saving.

1. They have upgraded road infrastructure so that heavy-duty trucks can have increased workloads compared to what was possible before, and less problems traveling the roads during winter leading them to transport with less fuel consumption.
2. They have shortened traveling distance, for example, according to the project manager of “Laksevegen” the 25km of new roads built there (the 10 projects in the database marked ”Laksevegen”), shortened the travel distance for traffic there by 12.5km (Internal documents).

For the study to quantify these further assumptions must be made.

1. Accelerating and decelerating is a factor in fuel consumption and eliminating unnecessary speed-changes through maintaining speed limits and widening roads, so no slowing down is needed when meeting other traffic, will have some effect on fuel consumption. A study of busses in China suggested that by breaking and accelerating more efficiently, the busses could save 5%-7% of fuel consumed. If we also factor in the efficiency gained by needing fewer trucks since trucks can carry more tonnage and are more efficient per tonnage when heavier loaded (Xu et al, 2016). It would be fair to assume that emissions from heavy trucks would have been 10% higher and 7% higher for personal vehicles without the new roads, amounting to:

Equation 6.7: Ballpark emission-savings from less acceleration:

$$0.10 * 851\,000 + 0.07*205\,000 = 99\,450 \text{ tonnes higher.}$$

2. Looking at the projects in “Laksevegen”, we see that the projects have cut the travel distance with 12.5 kilometres. Based on the data in the databank for the related projects, the year traffic there is average 1950 over the stretch, with 23% of this as heavy traffic. Here the new road saved 12.5 * 1950 * 0.77 * 365 = 6 850 593 vehicle kilometres for passenger cars annually, and 12,5 *1950*0,23*365 = 2 046 281 vehicle kilometres for heavy-duty trucks annually. Using the same rates as previously, this shortening of travel distance would save:

Equation 6.8: Emissions saved for personal cars in laskevegen:

$$6\,850\,593 * 120 * 60 * 0.5 = 24\,662\ tonnes\ CO_2\text{eq.}$$

Equation 6.9: Emissions saved for heavy transportation attributed to shortening of travel distance:

$$2\,046\,281 * 3000 * 60 * 0.5 * 1.5 = 276\,247\ tonnes\ CO_2eq.$$

It would save 276 247 tonnes CO_2eq. for heavy-duty transportation accumulating 300 909 tonnes CO_2eq. saved over the road’s lifetime.

Now these two factors accumulate to about 400 000 tonnes CO_2eq. that would have been added to the system extra if it had not been for the 240 000 tonnes CO_2eq. investment done by the portfolio.

This thought experiment concludes that there is no evidence that building new road infrastructure necessarily is a net-loss with regards to emissions over the lifetime of the system if you also include the effect it has on traffic. By example, the distance shortened by the partial project “Laksevegen” which makes up 10 of the projects in the portfolio, made the entire portfolio emission- ”profitable” by itself.

– This can be considered an interesting find and future research on the subject is suggested. It concludes that road infrastructure could come out emission-positive over a lifetime, given that it provides shortening of travel distances for large transport vehicles, even for lower amounts of traffic if the share of heavy transportation is high enough.

Now there is a lot not taken into the account here, emissions attributed to maintenance both for road, and traffic, traffic safety just to name a few, a study of initial construction and maintenance suggest that 2/3 of the emissions should come from the initial construction phase (Julien, Dauvergene, Cerezo, 2014). Other research however has highlighted the harmonization problems when comparing LCA studies from this decade (Jafari et al, 2016); Hoxha et al, 2021). At this first glace however, these ballpark-numbers indicate that the differences between emission inputs and outputs are not in the area of a magnitude 10< over the lifetime. There is also something to be considered that emissions cuts need to be implemented by 2030 and 2050, which could implicate how cuts in emissions at different times are valued.

7. Conclusion

For this thesis, an Excel-database that take in data from the Inventory Analysis, and Environmental Impact Assessments from LCAs made in the LCA tool VegLCA has been built. This databank lets an assessor get insight in trends and differences within the datasets.

A major benefit for this study is that the quantity of data available from the same road-network assessed within the same scope and made with the same tool makes it possible to do apple-to-apple comparisons between them, and thus gain insight into relative differences between road projects. The scope for this study has been a Cradle-to-gate perspective. Highlights from these insights include:

We identified that for the portfolio of 49 projects 55.5% of emissions were allocated to material consumption, and 44.5% of emissions to the building process (chapter 5.2). For the portfolio we identified two major contributors to emissions: Construction equipment, and concrete is responsible for respectively 33% and 20% of the total emissions in the portfolio, (for phases A1-A5). We further identified four more large emission contributors, asphalt (9.9%), steel (9.6%), explosives 6.8%), and transportation vehicles (9.0%). The contributions for the different materials vary dependant on what kind of infrastructure type the project has as a part.

For vehicle roads without tunnels and bridges, construction equipment typically accounts for 45%-53% of the emissions, with asphalt contributing between 13%-25%, and transportation vehicles contribute around 6.4%-12% of the emissions. On average those three contributors make up 74% of all emissions in such projects (table 2).

Similar results were found for pedestrian/cycling roads, construction equipment made up 43%-61% of emissions, asphalt 10%-14% and transport 6%-8%. On average these three contributors made up 70% of emissions (table 3).

For projects with bridges, the emission profile is very dependent on how much of the project is non-road infrastructure as seen in the comparison in chapter 5.4.3 (figure 26), and figure 32. On average bridge-related emissions per meter bridge is 9 times higher than road related emission per meter road for our portfolio (figure 15). For projects with bridges, that had less than 70% pure road infrastructure, concrete made up 25%-41% of emissions, construction equipment 14%-28%, and steel did 5%-26% for our portfolio (table 5). On average these three contributors made up 70% of emissions from such projects.

Projects with tunnels have a similar emission-profile to that of bridges, but while concrete and construction equipment are the standout major contributors with respectively 25-41% and 22%-29% emissions, there is no clear cut third largest contributor, but asphalt, steel, transportation vehicles and explosives all contribute in the area 3.25%-12.7% each (table 6). On average the two largest contributors contribute 59% of emissions, while the next four contributors contribute 32% of the total.

After analysing the spread for the projects after removing the outliers we found that for most projects 80% - 95% of emission come from the 6 identified major and large contributors. Suggesting that general attention towards these 6 materials for all future projects is needed, to reduce future emissions.

Projects with bridges and tunnels are heavily overrepresented in the group of projects that have high carbon-emission compared to the length of infrastructure projects, with significantly higher contributions from concrete and steel, compared to vehicle road projects without bridges or tunnels.

Therefore, special attention to the usage of steel and concrete need to be taken building bridges and tunnels, in addition to the general attention each of the other four identified contributors.

Further we investigated potential emission cuts. We identified that if the future workload used in projects are done by a machine park that is 70% electrical construction equipment and 50% transportation vehicles, as per the national goal of Klimakur 2030 (Miljødirektoratet, 2020), and that electricity is produced by clean renewable sources, the portfolio would have caused 22% less emissions overall. This is a clear indicator that working towards transitioning from a fossil powered machine park towards an emission-free one should be a priority.

We further looked at the other major contributor; concrete and looked at what impact it would have if the concrete had been specified as low-emission concrete with the 8 projects with the most concrete related emissions as an example. Had the portfolio of projects been built with the concrete that is now considered industry standard by the draft-contracts (Statens Vegvesen, 2022c), concrete emissions would have been 27% lower, and the entire portfolio would have had 4.38% less emissions for using low carbon concrete for the 8 tunnel projects.

For asphalt, explosives, and steel there are opportunities to cut emissions by demanding low-emission alternatives, use more time in planning to avoid oversizing and by using recycled materials. But what is important for these components (also including concrete) is to demand Environmental Product Declarations (EPDs), and actively use them comparatively in planning to estimate emissions and use them in revision after finished construction to conclude what the actual emissions are. EPDs helps the project achieve a more precise estimate of what emissions it caused. Without EPDs the industry standard will be what is assumed used in projects, and one might overpay for quality low-emission components without being able to document the effect.

All in all, we have shown that making a databank of LCAs made with the same LCA tool is a great way to analyse the data and gain insight into the properties of the data. We have gained insights in what 6 emission contributors make up the majority of the emissions from a portfolio of road infrastructure projects typical to a public office such as Trøndelag Fylkeskommune.

8. Suggestions for policymakers

8.1. Follow up the goals of Klimakur2030 when it comes to electrifying machinery

Klimakur 2030 lists a goal, that in 2030 70% of new non-road construction equipment, and 50% of heavy-duty transportation vehicles are non-fossil, for example electric.

A project where 70% of the workload of construction equipment is done with electric, or other non-fossil energy-source cuts scope 1 (direct) emissions by 57.7% and overall scope 1-3 emissions by 19.0%.

A project where 50% of the workload of transportation vehicles is done with electric, or other non-fossil energy-source cuts scope 1 (direct) emissions by 9.1% and overall scope 1-3 emissions by 3.0%.

Achieving both goals of Klimakur 2030 will cut scope 1 emissions by 66.8%, and Scope 1-3 emissions by 22.0%. There is shown that there is enough clean electricity surplus in Norway to support such a transition.

Enacting policies that gradually help the entrepreneurs transition from diesel engines to electric engines is a good way to cut emissions for such a portfolio.

8.2. Demand low-emission alternatives for concrete used in tunnels and bridges

To cut emissions from infrastructure projects containing tunnels or concrete bridges, demanding CEM II/ A or CEM II/B for concrete vaults and shotcrete products, and CEM II/B for concrete elements and cast in place concrete would cut emissions, compared to using CEM I counterparts. It is included in SVVs available draft-contracts (Statens Vegvesen, 2022c) and should be enforced. Had the portfolio had low-emission concrete, then emissions from concrete would have been 27% lower, and the portfolio would have cut an overall 4.4% of emissions.

8.3. Establish systematic work with VegLCA, or other LCA tools for road construction projects through the entire road construction process

Using a LCA tool during planning will help planners identify possible emission cuts, and early see the effect of demanding different kinds of low-emission counterpart to industry standard-materials. Using such tools before and after projects and comparing them to a project where no emission-cut actions were taken, will give documentation to how much emission cuts was achieved by the actions taken for the project.

8.4. Demand more EPDs

The lack of EPDs for the assessed projects makes the precision in assessed LCA data to be low. When using a LCA tool such as VegLCA, if no specific EPDs for projects are provided the tool has to assume emissions by using standard data.

Work towards systematically working with emissions for the large contributing factors, by demanding EPDs for the large material contributors to emissions: Asphalt, steel, concrete and explosives. Use these EPDs in the continued work with assessing emissions from projects to gain precise knowledge about the emissions from your activities. Making it easier to cut emissions.

8.5. Follow up the draft-contracts

Statens Vegvesen supply contract-drafts for road construction. If all road construction offices in Norway are paying attention to the evolution of the climate section of these contracts, then the developers of these contracts can easily distribute cutting edge climate-policy to the entire industry.

8.6. Biofuels

Advanced biofuels produced by food waste can be a decent solution long term. Farmed biofuels are inefficient use of arable land and should not be used as a permanent solution. Farmed biofuels are better than fossil-fuels as they do not disrupt the slow carbon cycle but is far inferior to clean electricity.

9. Suggestions for future research

- Further research – by gathering more data from similar projects to be able to do analysis of an even greater dataset of road construction projects to see if there is possible to give confidence-intervals for emissions based on how much roads, tunnels, bridges etc one wants to build.
- Further research about whether upgrading road infrastructure will contribute to more or less emissions over the project's lifetime, when compared to a zero-alternative that also includes maintenance.
    - It would be particularly interesting to do further research on saved emissions from traffic based on upgrading existing infrastructure.
    - It would also be interesting to see what consequences underspending on road maintenance has.
- Investigating what costs and cost-to-efficiency policies implemented based on the suggestions here could have.
- We know that there are some errors attributed to individual projects being assessed within different versions of VegLCA, making a program that can harmonize assessments done in older versions of VegLCA to new versions will increase the precision for old assessments.
- Further research on how choices in the construction phase impact the emissions during the lifetime usage phase. What are good actions to minimise emissions over lifetime?
- Improvements within VegLCA to further break down the different contributors within tunnels, roads and bridges would contribute to more precise knowledge about emissions from such infrastructure.

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A. Appendix A – The Excel Databank

Appendix A contains a through explanation of what goes on in the different sheets of the Climate LCA Databank.

Input Datatable.

The input datatable is where information from each project assessment is put into the databank.

It is important to format the data-area as a table. This is done in the "set inn" ("Insert") tab, with the "tabell" ("table") function. Then the following information is gathered from each project.

Catalogue number for ordering

The fist category is Catalogue number for ordering and is a column which is given a number according to in which order the assessments were put into the databank. It is there to provide a default "order" for the dataset, and to be able to easily re-organize the datasheet back to the default order should that be necessary. Second column is where information about which version of the VegLCA tool has been used for the assessment. As there are some minor adjustments between each version that impacts the output of each assessment the version number is needed to be able to say more about how precise the data might be.

Geographical and historical metadata

The second category is for carrying the metadata about building year, opening year, what road, which county, what kind of project it is and so on. These categories are necessary to be able to distinguish between them later in the process. The columns are:

Table 15: Columns for geographical data in the databank:

Column name	Description
Year, construction start	When the construction started, needed to calculate cost relative to inflation. Could also be interesting regarding to compare historical data on emissions.
Construction start source	For reference regarding construction start. – Some of the LCA's used in the study were found to have inaccuracies so it was decided to include sources for proving why there is discrepancies between the database, and the LCA's it is based on.
Year, road finished	When the construction finished, necessary to know for comparing deuteriation, and the need for future upgrades, and how long construction took.
Year, road finished source	For reference regarding construction completion.
County	Metadata for which county the project was built in, used for organizing the pivot dataset, and to distinguish between counties should the database be expanded to include datasets from different counties.
Regional Project	Metadata for which larger regional project the project is a part of, where applicable. For projects not included in a larger project they are categorized as "other standalone projects"
Project	Name of the project, usually describing the infrastructure and where it was built.
Road Number	Which county road the project is a part of.
Project Type	What kind of project it is, regarding to whether it is an investment in new road infrastructure, asphalting, general maintenance contracts etc, should the project be expanded to include those kind of contracts

Infrastructure type	Notes what kind of infrastructure that was built. We are here distinguishing between vehicle roads, GSV – Roads for pedestrians and cyclists, and "minor projects"
Minor Project type	Denotes whether it is a main project or what kind of minor project it is, as some of the assessed projects are un-typical road projects, but it could be interesting to be able to sort them out.
Project Specific data	Whether or not the project had specifications that diverges from the standard or if it only used the experience-based data that VegLCA had. This column was useful for putting in information to make dummy-value of since.
Electricity mix	What kind of electricity-mix that was used to calculate the emissions, for reference, all projects in the portfolio are calculated with the same electricity mix, but is nice for future reference.

Data and metadata for road length and width

These columns store information about the projects assessed that are related to length of different infrastructure parts in the projects. During the literature study it was discovered that there was lacking information about road width and lane width in a vast amount of the available studies that are done on this subject. As this information is interesting for researchers, the study has gathered them and included them in the databank. Some of the assessments had already provided such information and other had to be double checked in, eventual information found is inserted into the databank.

Table 16: Columns regarding road specifications in the databank:

Column name	**Description**
Lanes	The number of lanes built by the project. – some projects are adding lanes to existing roads and therefore might seem like they are building a smaller road than they are.
Lane width	How wide each lane is, in meters.
Shoulder width	How wide each shoulder is, in meters.
Sidewalk width	How wide each sidewalk is, in meters, if applicable. For the pedestrian/cyclist projects the width of the project is displayed here as the sidewalk-width.
Road Cover width	How wide the part of the road that is asphalted is.
Total road width	How wide the entire road is.
Meter road in daylight	How many meters long the constructed road is, that neither defined as a tunnel or as a bridge.
Tunnel (meters built)	How many meters in the project that is defined as a tunnel.
Bridge (meters built)	How many meters in the project that is defined as a bridge.
GSV (meters built)	How many meters of road for pedestrians and cyclist are built.
Road-width data source	Link to the Norwegian road administrations database for where the road width data was found
Road-width data year	What year the road width data was gathered from, for comparison, should the referenced road data be obsolete when looked up in the future.
Total project length	This column takes in the length of road, tunnels bridges and GSV and calculates the total length of the projects. The function input is: "=[@[Bridge (meters built)]]+[@[Tunnel (meters built)]]+[@[Meters Road in daylight]]+[@[GSV Meters Road]]" in Norwegian and English Excel.

Dummy Values

These are columns including dummy-values for separating projects on different qualities they have. Making such dummy values in the way the study has done, makes it easy to navigate the dataset in the future when we incorporate the slicer functions.

Table 17: explaining the dummy-values columns in the databank:

Column name	**Description**
BRIDGE_DUMMY	Dummy value that checks if the project has defined a part of it as a bridge or not, returning the values Bridge, or No Bridge so it can be used for comparison later. The function input is: “=HVIS([@[sq meters bridge]]=0;"No Bridge";"Bridge")” in Norwegian excel and “=If([@[sq meters bridge]]=0;"No Bridge";"Bridge")” in English excel
TUNNEL_DUMMY	Dummy value that checks if the project has defined a part of it as a tunnel or not, returning the values Tunnel, or No tunnel so it can be used for comparison later. The function input is: “=HVIS([@[sq meters tunnel]]=0;"No Tunnel";"Tunnel")” in Norwegian excel and “=if([@[sq meters tunnel]]=0;"No Tunnel";"Tunnel")” in English excel
Specified Transport distance for masses	In 17 of the assessed projects specific measures were taken to ensure the minimal transportation needs for each project, in this column it is denoted what specific value for travel distance is set in the project.
Project Length DUMMY	Dummy Value that takes the information in “total project length” and sorts the projects into 5 categories based on how long they are. The function input is: “=HVIS([@[Total Length of Project]]=0;"0";HVIS([@[Total Length of Project]]<1000;"<1 km";HVIS([@[Total Length of Project]]<3000;"1 - 3 km";HVIS([@[Total Length of Project]]<5000;"3 - 5 km";"5+ km"))))” in Norwegian excel and =IF([@[Total Length of Project]]=0;"0";IF([@[Total Length of Project]]<1000;"<1 km";IF([@[Total Length of Project]]<3000;"1 - 3 km";IF([@[Total Length of Project]]<5000;"3 - 5 km";"5+ km")))) in English Excel.
Average emissions per project meter	Takes in the total estimated emissions for the project and divides by the total length of the projects to give an indication of how much emissions there has been per finished project meters. For use in the next dummy value Function input is: “=[@[Total Estimated emissions (excluded area usage)]]/[@[Total Length of Project]]” in both Norwegian and English version of excel.
Over 1,5x Average emissions per Project meter	Takes in the information in the “average emissions per project meter” column and compares it to the total average emissions per project meter calculated in the project brain in cell E25, and gives information on whether or not the project has over or under 1,5 times the emissions per meter project or not. To be used to look at the characteristics of the projects that are high-emission. Function input:

	“=HVIS([@[Average emissions per project meter]]>'Document Brain'!$E$25*1,5;"High emission";"Average/low emission")” in Norwegian Excel, and “=IF([@[Average emissions per project meter]]>'Document Brain'!$E$25*1,5;"High emission";"Average/low emission")” in English Excel.

Metadata for traffic

These columns contain metadata for speed-limits and traffic, as they can be used for reference when creating similar purpose roads in the future.

Table 18: Columns containing traffic related data for the databank:

Column Name	**Description**
Speed limit	Speed limit of the constructed road. Some projects have variable speed-limits throughout the stretch.
Yearly day-average traffic	The amount of yearly average traffic, for comparison purposes
Heavy Traffic%	The amount of the traffic regarded as heavy vehicles
Traffic data year	The year the traffic data was gathered from according to the source.
Traffic Data source	The source of the traffic data.

Total quantity of masses

The 21 columns that make up the “total quantity of masses” section of the input datatable, is the first of the sections that inputs some of the output values from the VegLCA tool regarding the Inventory Analysis. The data put into the LCA databank from the assessments are the sums of the amounts for the entire project, for each project. Each column in the input datatable has information found in each of the rows in the “total amounts” in the VegLCA tool.

+ **Aggregert materialliste**

Budsjett, mengder

Materialkategori		Veg i dagen M+U	Veg i dagen D&V år	Tunnel M+U	Tunnel D&V år	Bru M+U	Bru D&V år	Sum M+U	Sum D&V år
Asfalt	tonn	500	-	-	-	-	-	500	-
Betongelementer	tonn	0	-	-	-	-	-	0	-
Betonghvelv	m2	-	-	-	-	-	-	-	-
Grus/pukk	tonn	1 680	-	-	-	-	-	1 680	-
Kalksementstabilisering	tonn	-	-	-	-	-	-	-	-
Plasstøpt betong	m3	-	-	-	-	-	-	-	-
Plast	tonn	2	-	-	-	-	-	2	-
Plastmembran/Geosynteter	m2	-	-	-	-	-	-	-	-
Sement	tonn	-	-	-	-	-	-	-	-
Sprengstoff	tonn	20	-	-	-	-	-	20	-
Sprøytebetong	m3	-	-	-	-	-	-	-	-
Strøsalt	tonn	-	-	-	-	-	-	-	-
Stål, armering og bolter kamstål	tonn	-	-	-	-	-	-	-	-
Stål, spennarmering	tonn	-	-	-	-	-	-	-	-
Stål, konstruksjonsstål	tonn	-	-	-	-	-	-	-	-
Stål, peler	tonn	-	-	-	-	-	-	-	-
Stål, spunt	tonn	-	-	-	-	-	-	-	-
Trevirke	m3	-	-	-	-	-	-	-	-
Dieselforbruk i anleggsmaskiner	liter	19 765	-	-	-	-	-	19 765	-
Dieselforbruk til massetransport (beregnet for tur/retur)	liter	23 890	-	-	-	-	-	23 890	-
Elektrisitetsforbruk	kWh	-	-	-	-	-	-	-	-

+ **Alle materialtyper**

Budsjett, mengder

Veg i dagen | Tunnel | Bru | Sum

... Mellomfaseverktøy | Prosjektbeskrivelse | Veg i dagen | Tunneler | Bruer | Totale mengder | Resultater | Resultatsammendrag | Utslippsfak

Figure 33: The columns under total amount of masses come from left to the right, in the same order as they do in VegLCA from top to bottom: Asphalt [tonnes], Concrete elements [tonnes], Concrete Vaults [square meters], Gravel/Shingles [tonnes], Chalkcemenet-stabilsator [tonnes], Cast in place concrete [cubic meters], Plastics [tonnes], Plastics membrane/geosynthetics [square meters], Cement [tonnes], Explosives [tonnes], Injection Concrete [cubic meters], salt [tonnes], steel armament bolts etc [tonnes], Steel tensile reinforcement-armament [tonnes], Steel construction-steel [tonnes], Steel peeles [tonnes], Steel, spunt [tonnes], Woodstuffs [cubic meters], Diesel for construction equipment [litres], Diesel for transportation of masses (round trip) [litres], Electricity Consumption [kWh].

For the projects assessed with VegLCA version 5.05B and 5.06B, the diesel-usage in construction equipment and transport vehicles were split into more daughter-categories, than the two that was distinguished between in the 4.xx versions. Neither of the projects assessed with the newer versions of VegLCA had differentiated data between the new categories, therefore the study chose to treat the new rows were for this study treated as if they had not been split into more categories and grouped them as if they had been assessed in a 4.xx version.

Trevirke	m3	7	-	-	-	-	-	7	-
Diesel i anleggsmaskiner, biodiesel iht omsetningskrav (anleggsdiesel)	liter	480 346	-	-	-	-	-	480 346	-
Diesel i anleggsmaskiner, biodiesel iht omsetningskrav (veitransport)	liter	-	-	-	-	-	-	-	-
El-forbruk i anleggsmaskiner	kWh	-	-	-	-	-	-	-	-
Diesel massetransport (t/r), biodiesel iht omsetningskrav (anleggsdiesel)	liter	-	-	-	-	-	-	-	-
Diesel massetransport (t/r), biodiesel iht omsetningskrav (veitransport)	liter	69 926	-	-	-	-	-	69 926	-
El-bruk til massetransport (beregnet for tur/retur)	kWh	-	-	-	-	-	-	-	-

Figure 34: In the newer versions of VegLCA, the information regarding fuel consumption has been allocated more cells.

Total emission data

The columns under "total emission data", contain the information for each asssessed project on how much emissions are allocated to the A1-A4 processes and the A5 process. There is also a column for Total emissions which is the A1-A5 processes, and the data for how much emissions are attributed to the consumption of land area.

The data in these columns are found in the "resultatsammendrag" (resultsynapsis) sheet in the VegLCA tool. The numbers in the input-sheet are manually plotted based on the results of the assesments, while the data in the synapsis sheet of each individual assessment are based on their input-data. This might cause some rounding errors to manifest themselves as small discrepancies between "total emisions" and what is gathered by adding column A1-A4 and A5 together. This is a relatively small source of error and the study has chosen to accept it.

Emission data, but more detailed on what infrastructure element caused it

The columns under "Emission data, but more detailed on what infrastructure element caused it" contain the same information as the columns under "Total emission data" but here they are further allocated to the individual infrastructure types Road constructoin, Bridge Constructon and Tunell Construction. There is also a column for "Direct emissions (From construction equipment, transportation and explosive-usage.)" displaying the emissions allocated to the project that is directly released by burning fuel or explosives as a part of the construction job. NOTE: For versions prior to the 5.06 version, the explosives usage was incorectly not included in this number and therefore has to be included at a later point in the "Document Brain"-sheet.

The same emission data but split into categories for each material that contributed to the emissions

The columns under "The same emission data but split into categories for each material that contributed to the emissions" are as described by the header the same emission data as in the two previous headers, but here separated into which materials that contributed to the specific emission.

While it would have been possible to calculate some of the information in "total emission data" and "emission data, but more detailed on what infrastructure element caused it" based on other information provided here, manually entering all the numbers gives a safety net where it is possible to compare the numbers instead, rather than to calculate them based on other data.

Comments and Corrections

The last header contains comments and corrections, where comments are where any comments about a dataset deemed necessary was placed, and "Corrections for wrong direct emissions" is a column where datasets with a version prior to 5.06B has manually allocated the emissions from explosive usage to be used for correcting the error in the older versions of the tool.

Statistical data

The final batch of columns provide the dataset with statistical data, amongst other used for the graphs for the "Statistical Analysis" sheet.

Table 19: Descriptions of what is to find in the "Statistical Data" columns in the Input Data-table:

Column name	**Description**
Avg. Emissions allocated to Road construction – per meter road built.	Takes in the emissions allocated to road construction and divides it by the amount of meters road constructed to give an average. Formula is "=[@[Emissions attributed to the roadconstruction]]/[@[Meters Road in daylight]]" for both Norwegian and English.
Traffic Work done	Calculates how much traffic work is done each day on the project, by taking in average traffic over a year, and multiples it by the length of the project. Formula is "=[@[Yearly day-average traffic]]*[@[Total Length of Project]]" for both Norwegian and English.
Column to plot against for graphs	Column for values that can be used to plot the spread for the different materials but give the plots a little bit of space. To make the numbers I used the function "=TILFELDIGMELLOM(4950;5050)/10000" (equal to "=RANDBETWEEN(4950;5050)/10000" in English.), and after all the rows have gotten a number, I cut out the entire column and pasted it back to where it was, but only pasting the numbers, so that the numbers do not have to jump around all the time. It can also be done manually by just entering a number between 0.495 and 0.505, for new rows if needed.
% Construction eq of total	Takes the emissions attributed to construction equipment and divides it by total emissions for the project, to get the percentage of the emissions for the project attributed to construction equipment. The formula is "=[@[Construction equipment]]/[@[Total Estimated emissions (excluded area usage)]]" for both Norwegian and English
% Concrete emissions of total emissions	Takes the emissions attributed to concrete and divides it by total emissions for the project, to get the percentage of the emissions for the project attributed to concrete. The formula is "=([@[Concrete-elements]]+[@[Cast in place concrete2]]+[@Shotcrete]+[@[Concretevaults - emissions]])/[@[Total Estimated emissions (excluded area usage)]]" For both Norwegian and English
% Asphalt emissions of total emissions	Takes the emissions attributed to asphalt and divides it by total emissions for the project, to get the percentage of the emissions for the project attributed asphalt. The formula is "=[@Asphalt]/[@[Total Estimated emissions (excluded area usage)]]" For both Norwegian and English
% Steel emissions of total emissions	Takes the emissions attributed to steel and divides it by total emissions for the project, to get the percentage of the emissions for the project attributed to steel. The formula is "=([@[Steel, other]]+[@[Steel-Armament, bolts and ridgesteel]]+[@[Steel, construction elements]]+[@[Steel, peels]]+[@[Steel, tensile reinforcement]]+[@[Steel "spunt"]])/[@[Total Estimated emissions (excluded area usage)]]" For both Norwegian and English
% Transport Vehicle emissions of total emissions	Takes the emissions attributed to transport vehicles and divides it by total emissions for the project, to get the percentage of the emissions for the project attributed to transport vehicles. The formula is "=[@[Transporation of masses]]/[@[Total Estimated emissions (excluded area usage)]]" For both Norwegian and English
% Explosives emissions of total emissions	Takes the emissions attributed explosives and divides it by total emissions for the project, to get the percentage of the emissions for the project attributed to explosives. The formula is "=([@[Explosives

	(usage)]]+[@Explosives])/[@[Total Estimated emissions (excluded area usage)]]" For both Norwegian and English
% Other factor of total emissions	Takes 1 and subtracts the rest of the categories to get what emissions are not already accounted for. The formula is: "=1-([@[% Exolosives emission of total emissinos]]+[@[% Transport Vehicle emissions of total emisssion]]+[@[% Steel emissions of total emissinos]]+[@[% Asphalt emission of total emissions]]+[@[% Concrete emission of total]]+[@[% Construction eq of total]])" For both Norwegian and English
Average emission allocated to road construction per project length	Calculates the acerage emissions allocated to road construction, per project length. Formula is: "=[@[Emissions attributed to the roadconstruction]]/[@[Total Length of Project]]" in both Norwegian and English.
Square meters	Calculates how many square meters of project is built. Formula is"=[@[Total road width '[m']]]*[@[Total Length of Project]]" in both Norwegian and English
Average emissions per project square meters	Average emissions, but per square meter. Formula is: "=[@[Emissions attributed to the roadconstruction]]/[@[Square meters]])" in both Norwegian and English.
Average emissions per lane built	Average emissions, but per lane. Formula is: "=[@[Emissions attributed to the roadconstruction]]/([@[Total Length of Project]]*[@[Lane factor]])" in both Norwegian and English.
Lane factor	Column where the number of lanes were added manually. 1 lane per vehicle road lane + 1 lane per pedestrian/cycling lane.
Percentage of project is road	Gives a value in percentage of how much of the project is road. Formula is: "=([@[GSV Meters Road]]+[@[Meters Road in daylight]])/[@[Total Length of Project]]" in both Norwegian and English.

Pivotable spreadsheet

After the databank is filled with all the data we want to analyse, it is needed to create a brain that allows us to find the information we want. In this study it was done with a two-part "brain", consisting of two excel-sheets. One of the sheets is a pivot-table based on the data from the input-sheet and the other sheet is a formula-sheet that crunches numbers based on the data in the input-table and the pivot table. For a finite dataset it is possible to do the operations in a single datasheet, but to be able to expand the dataset with new assessments, or new datasources, it is better to have them separated, so they will not interfere with each other when they grow.

To create the pivot table, the data in the "Input Datatable" was selected and a pivot table was created by clicking "Sett inn" (Insert) and "Pivotabell" (Pivotable) where the pivotable was sent to a new sheet, which then was renamed "Pivotable".

Box number 1 in figure 35 is what is available for us when the pivotable is fresh, clicking the empty pivotable opens the side-panel for box 2, 3, 4, 5 and 6 to show up. In Box 1 we see the results of how the pivotable is organized in boxes 2, 3,4 5 and 6. For now we are only clicking Box 1 to open the side-panel for Boxes 2, 3, 4, 5 and 6.

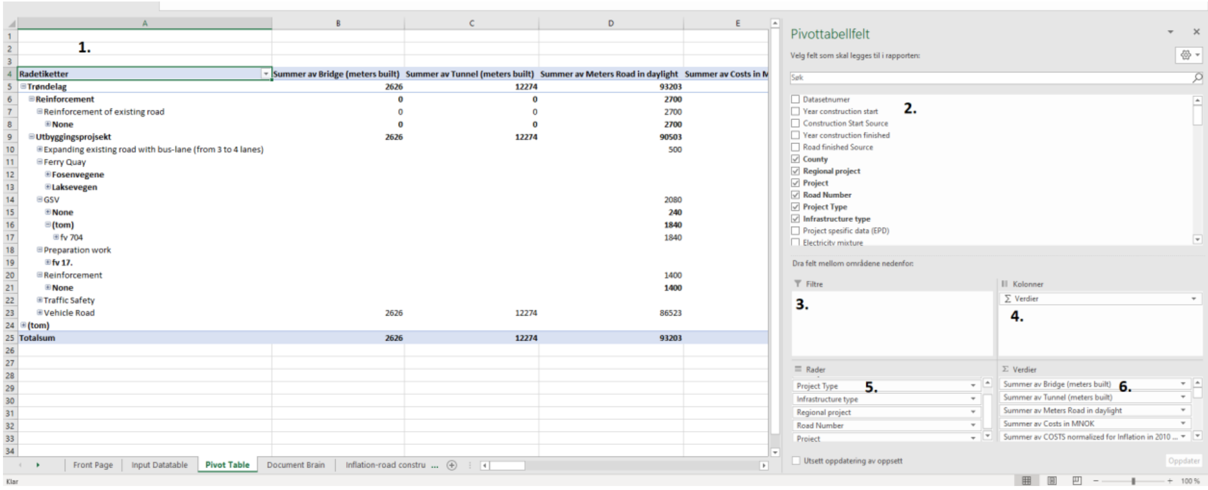

Figure 35: Illustration of the pivotable, the pivotable has 6 boxes which we are using to make the analysis brain. It is the numbering in this figure it is referred to in this sub-chapter.

Box number 2 in the figure 35 is where the selection of which columns from the input table that are going to make up the pivotable is done. By checking the checkboxes, it is signalized to the pivotable that the information is to be shown in the pivotable. When data is selected here, the pivotable guesses in which of the four boxes 3, 4, 5 and 6, the data is supposed to be based on what kind of data there is in the corresponding column. The information can be dragged around between the boxes should they fall into the wrong box. For this study the following checkboxes were checked*:

County, Regional project, Project, Road Number, Project Type, Infrastructure type. Meters road in daylight, Tunnel (meters built), Bridge (meters built), GSV Meters Road, Total Length of project, TUNNEL_DUMMY, Asphalt [tonnes], Concrete element [tonnes], concrete vaults [square meters], Gravel/Shingles [tonnes], Chalkcement-stabilisator [tonnes], Cast in place concrete [cubic meters], Plastics [tonnes], Plastic membrane/geosythetis [square meters], Cement [tonnes], Explosives [tonnes], Shotcrete [cubic meters] salt [tonnes], steel armament bolts etc [tonnes], Steel tensile reinforcement-armament, [tonnes], Steel construction-steel [tonnes], Steel peeles [tonnes], Steel spunt [tonnes], Woodstuffs [cubic meters], Diesel for construction equipment [litres], Diesel for transportation of masses (round trip) [litres], Electricity consumption [kWh], Estimated unaccounted emissions from land usage, (A1-A4)Emissions from materials, A5 Emissions from construction, RC(A1-A4), RC A5, TC (A1-A4), TC A5, BC (A1-A4), BC A5, Direct emissions (from construction equipment, transportation of masses and explosive-usage), Asphalt, Concrete-elements, concrete – emissions, Cast in place concrete2, Cement, Shotcrete, Steel other, Steel- Armament, bolts and ridgesteel, Steel construction elements, Steel peels, Steel tensile reinforcement, Steel "spunt", aluminium, EPS/XPS Plastics, Gravel, Shingles, Chalkcement-stabilisator, Lightweight clinker /Expanded silt, Foam glass granules, Explosives, Woodstuffs, Roundsum – Emissions, Other, Explosives (usage), Roundsum poster emissions, construction equipment, Transportation of masses, electricity, Correction for wrong direct emissions, Traffic Work done and Average emissions per lane built.

**There are some minor differences between the headers when listed here compared to the databank, as for example some of the headers contained commas to separate between what kind of steel category it was and this study has chosen to not include those listings without their commas to avoid confusion.*

Box number 3 in figure 35 is where we would have put the information used to sort between different kinds of projects if we wanted to use the built-in function of the pivotable, however in this study we are using a different function for this called “slicers,” which is found more intuitive and interactive by this study. This box is therefore skipped in this study.

Box number 4 in figure 35 is where it is described what the pivotable should do with the information provided in box 5 and 6. In this study we are leaving this as “∑ Verdier” (“∑ Values”), which indicates that we want the pivotable to summarize the values of the selected data.

Box number 5 in figure 35 is where we are telling the pivotable, how to group different information together by telling it what metainformation to group data by in descending order of rank. For the pivotable to always provide the sum of all selected parts in the same row, this study finds it easiest to choose a category where all the data has the same metadata as the top category, this way all selected data is always summarized in the same row, making data extraction easy. In this study the Metadata about what public office that provided the data was selected as the highest-ranking data for grouping. Had several different agencies provided data we could have added another column in the input data-table for example what country the data was for, or just a dummy-value called “sum of totals”.

In this study the following categories were chosen in the following top-down order:

County, Project Type, Infrastructure Type, Regional project, Road Number, Project.

Box number 6 in figure 35 is where we place all the different data, we want the pivotable to analyse. This is the data describing quantities of the data selected in box 2. Here it is important that “Summer av” (“sums of”) is selected as output data. (With one exception, we will be using the “antall” (amounts) of TUNNEL_DUMMY, to count the amount of selected projects).

The order of appearance for the datapoints in this box decides in what order the categories are placed in the pivotable. Where if the first one is placed in column B, the next on will be placed in column C and so on. It is not important that for reproduction that the categories are placed in the same order as done in this study. What is important is that if you want to reproduce the databank and have the categories in a different order than this study have placed them in, you will need to account for that during the “creating the brain” step for your databank, as the data in a column in this dataset will be assigned to a different column in your dataset, if they are in a different order.

In this study the following categories were chosen in this top-down order*:

Bridge (meters built), Tunnel (meters built), Meters Road in daylight, Traffic Work done, Average emissions per lane built, Estimated unaccounted emissions from land usage, Total Estimated emissions (excluded area usage), (A1-A4) emissions from materials, (A5) emissions from construction, Direct emissions (From construction equipment, transportation and explosive-usage), RC (A1-A4), RC A5, TC (A1-A4), TC A5, BC (A1-A4), BC A5, Asphalt, Concrete-elements, Concrete vaults – emissions, Cast in place concrete2, Cement, Shotcrete, Steel other, Steel- Armament bolts and ridgesteel, Steel construction elements, Steel peels, Steel tensile reinforcement, Steel “spunt”, Aluminium, EPS/XPS, Plastics, Gravel Shingles, Chalkcement-stabilisator, Lightweight clinker/Expanded silt, Foam glass granulates, Explosives, Woodstuffs, Roundsum – emissions, Other, Explosives (usage) Roundsum poster emissions, Construction equipment Transportation of masses, electricity, Total Length of Project, (!) Antall (amounts) of TUNNEL_DUMMY, GSV Meters Road, Asphalt [tonnes], Concrete elements [tonnes], Concrete vaults [square meters] Grave/Shingles [tonnes], Cast in place concrete [cubic meters], Plastics [tonnes], Plastics membrane/geosynthetics [square meters], Cement [tonnes], Explosives [tonnes], Shotcrete [cubic meters], Steel armament bolts etc [tonnes], Steel tensile reinforcement-armament [tonnes], Steel construction elements [tonnes], Steel peeles [tonnes], woodstuffs [cubic meters], Electricity Consumption [kWh], Diesel for transportation of masses (round trip) [litres], Diesel for construction equipment [litres], Corrections for wrong direct emissions, Steel spunt [tonnes], salt [tonnes, chalkcement-stabilisator [tonnes].

*Also here are there are *some minor differences between the headers when listed here compared to the databank, for example some of the headers contained commas to separate between what kind of steel category it was, and this study has chosen to not include those listings without their commas to avoid confusion.*

Slicers

The last important feature we are going to implement for this sheet is the slicers. A slicer is a tool for selecting information based on metadata or other features. It is here the dummy-values implemented earlier gets used. Right clicking a value from box 2 and clicking the "Legg til som slicer" ("add as slicer") creates a slicer.

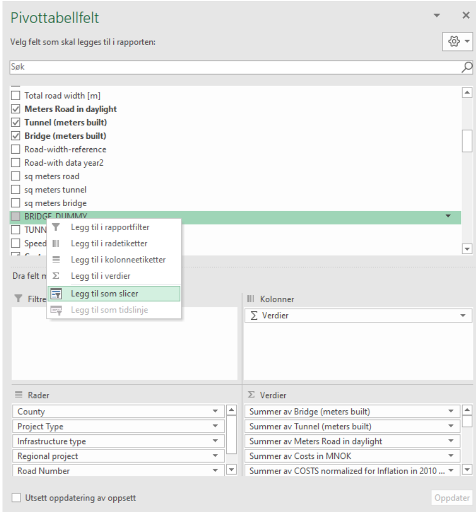

Figure 36: Visual example of how to create a slicer.

The box that pops up based on which category chosen for the slicer, has the same function as a drop-down menu for selecting what data to show in the pivotable, the main benefit of using a slicer instead of a drop-down menu, is that fewer clicks are needed to change the inputs, and that they give visual feedback to the user of what data they are viewing at any point.

Slicers can be understood as a form of "remote control" for the dataset we are looking at in the pivotable, and if copied over to other sheets in the same excel document they can still change the visuals of the table they are created from. A copied slicer is identical to the original slicer, and any selections done on either slicer is also selected on the other. This is used in this study to get a visually clean, and interactive front page, while leaving the clutter in a different part of the document.

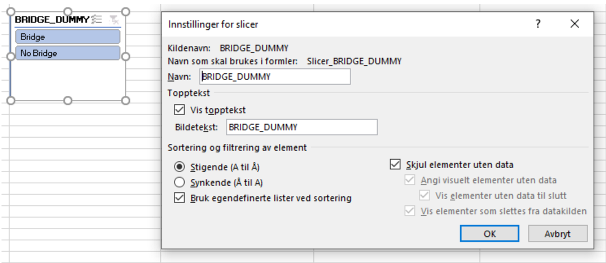

Figure 37: Visual example for how this study sets up the slicer.

In this study we are making slicers out of the following categories:

BRIDGE_DUMMY, TUNNEL_DUMMY, Project Length, Specified Transport distance, Total Road Width, Minor project type, Infrastructure Type, specified transport distance for masses, Project.

And this study made a copy of each of the slicers which was pasted into the "brain sheet" and the "front sheet" of the excel document.

Document Brain

The "Document Brain" is the spreadsheet that is designated to do the number crunching. It takes in information from the other sheets in the database and do calculations on them. For organizing the brain sheet, the study has prioritized making it easier to navigate and understand for the user rather than making it space-efficient. The different kinds of functions added to the brain will be made in groups of 10 rows, (or multiples of 10 if deemed necessary).

Slicers – Rows 1-10

From the earlier work the slicers that interact with the pivotable has been copied over here. Having them accessible in the document brain makes it easy to change selections viewed in the brain. For easier access to the slicers when we are expanding the spreadsheet with more formulas, we are going to freeze the first 10 rows of the sheet. To freeze the view in excel, mark the "n+1" rows as shown in figure 38 (this study wanted to freeze n=10 rows so 11 rows are marked) and click "visning" ("view"), "Frys ruter" ("Freeze panes") and select "Frys ruter" ("Freeze panes") from the dropdown menu.

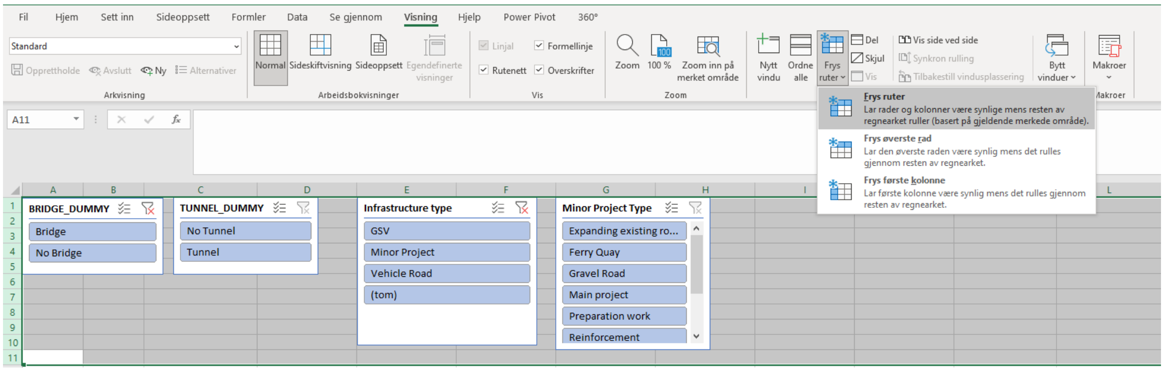

Figure 38: Where to find the function for freezing panes.

Percentage pies – Rows 11 to 20

The first functions created in the brain are the percentage pies. These have the task of giving visual feedback to the user about different aspects of the selected data. To create these this study used row 11 for the header, rows 12 to 16 was used for the table for input of data, row 17 used for describing the charts and row 18 was used for storing the finished pie charts. Rows 12-17 were given row height of 30, and row 18 a height of 140. All cells in these rows were given the "bryt tekst" ("break text") feature, so that enough of the information is visible.

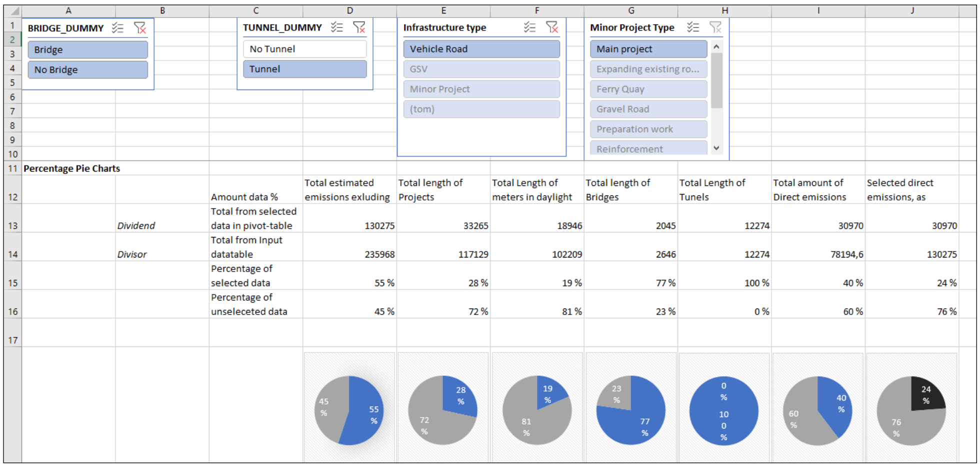

Figure 39: Example of the product for the first 7 percentage pie-charts, when the slicer for "Tunnel" is selected.

To create this function as seen in the figure 39, the header was put in row 11, descriptions of the rest of the table was put into column B and C as seen in figure 39. The input data from the other columns are as follows using column D as an example can be seen in table 20.

Table 20: Table explaining how pie charts are made in the databank:

Cell	Function	Description
D12	Total estimated emissions excluding area usage	Plain text describing what data is processed in this column
D13	='Pivot Table'!$H$9	Gathers the information stored in Cell H9 in the sheet named "pivotable" in this instance we are gathering sum of total estimated emissions (excluding area usage) for the projects that fit the criteria given by the selections of the slicers.
D14	=SUMMER(Tabell1[Total Estimated emissions (excluded area usage)]) (=Sum(Table1[Total Estimated emissions (excluded area usage)]	Gathers the sum of the data in the column "total estimated emissions (excluded area usage)" in the table put in the input table. This way whenever the table is expanded to include new assessments they will automatically be added to the formula.
D15	=D13/D14	Takes the data in D13 and divides it by the data in D14. This way we get how large amount of the emissions the selected projects have compared to all the assessed projects in a percentage.
D16	=1-D15	Takes one, and subtracts the value in cell D15, this will in this case give us the amounts of emissions attributed to the projects that are not selected in a percentage of the total.

The input data to make the rest of the cells in in the figure 39 is as follows:

Table 21: Table of contents for further pie charts made:

	E	F	G	H	I	j
Row 13	='Pivot Table'!$AT9	='Pivot Table'!$D$9	='Pivot Table'!$B$9	='Pivot Table'!$C$9	='Pivot Table'!$K$9	='Pivot Table'! $K$9
Row 14	=SUMMER(Tabell1[Total Length of Project]) in Norwegian or =SUM(Tabell1[Total Length of Project]) in English	=SUMMER(Tabell1[Meters Road in daylight]) in Norwegian or =SUM(Tabell1[Meters Road in daylight]) in English	=SUMMER(Tabell1[Bridge (meters built)]) in Norwegian or =SUM(Tabell1 [Bridge (meters built)]) in English	=SUMMER(Tabell1[Tunnel (meters built)]) in Norwegian or =SUM(Tabell1[Tunnel (meters built)]) in English	=SUMMER(Tabell1[Direct emissions (From construction equipment, transportation and explosive-usage.)]) in Norwegian or =SUM(Tabell1 [Direct emissions (From construction equipment, transportation and explosive-usage.)]) in English	='Pivot Table'! $H$9
Row 15	=E13/E14	=F13/F14	=G13/G14	=H13/H14	=I13/I14	=J13/J 14
Row 16	=1-E15	=1-F15	=1-G15	=1-H15	=1-I15	=1-J15

To make the pie charts, the study took and marked the information in C15, C16, and the cell in row number 12, 15 and 16 for the respective column the pie chart is going to visualize. Then clicked "sett inn" ("Insert") and the pie chart was selected from the list of diagrams. Then the pie-chart style was changed to a version that showed percentages, the pie-slice representing unselected data was given a grey colour, and the percentages changes to white. Choosing colours for the selected data the study went with blue for the data that represents data as an amount of the total analysed data, and other colours are chosen to illustrate that the data represents a different selection. The pie-chart in column J compares the selected projects direct emissions compared to the total emissions of the selected projects and are given a black colour to separate it from the other pie charts comparing for the total dataset.

These charts can be copied over to the other spreadsheets, the same way we did with the slicers. The study copied the pie charts over to the front page and placed them next to a description of what they illustrated for later usage.

This study made 37 such "percentage of total"-charts. These are mainly used to see what kinds of projects has contributed relatively more to different kinds of emission factors than others. For example, when selecting “Tunnels” in the TUNNEL_DUMMY Slicer, we get information related to the projects that had tunnels in them:

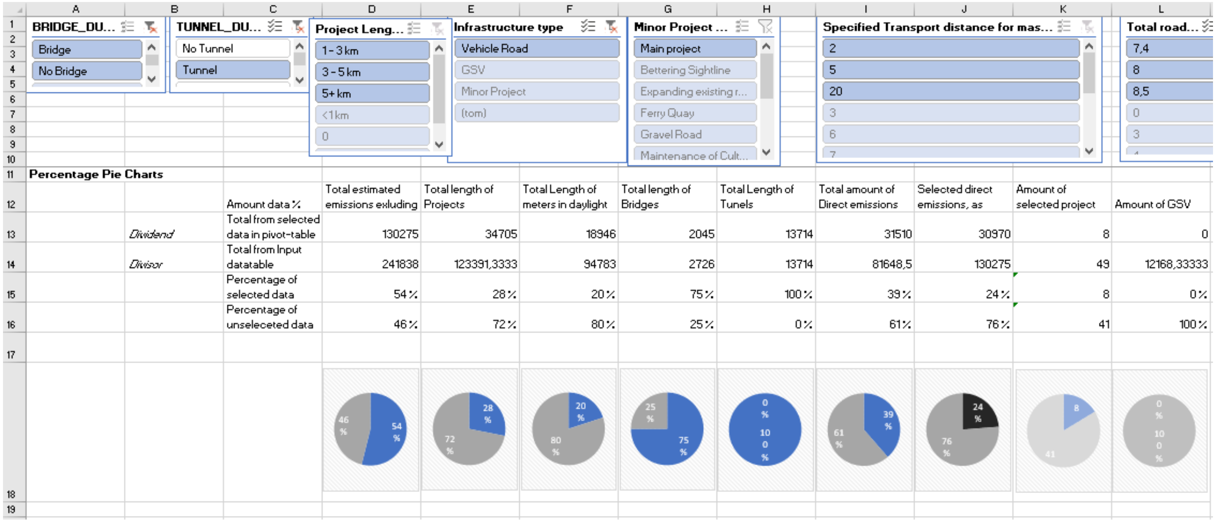

Figure 40: Screenshot of the finished pie-charts, in this selection we see all the tunnel project selected.

The first 9 pie-charts, as seen in figure 40, from column D to column L, shows information regarding the selected projects in relative comparison to the total.

Summer av Asphalt	Summer av Concrete-elements	Summer av Concretevaults -	Summer av Cast in place concrete2	Summer av Cement	Summer av Shotcrete	Summer av Steel, other	Summer av Steel-Armament, bolts
1213	167	0	7676	228	3354	170	3572
23932	3017	8684	20473	1231	16171	3767	10069
5 %	6 %	0 %	37 %	19 %	21 %	5 %	35 %
95 %	94 %	100 %	63 %	81 %	79 %	95 %	65 %
0,50 %	0,07 %	0,00 %	3,17 %	0,09 %	1,39 %	0,07 %	1,48 %

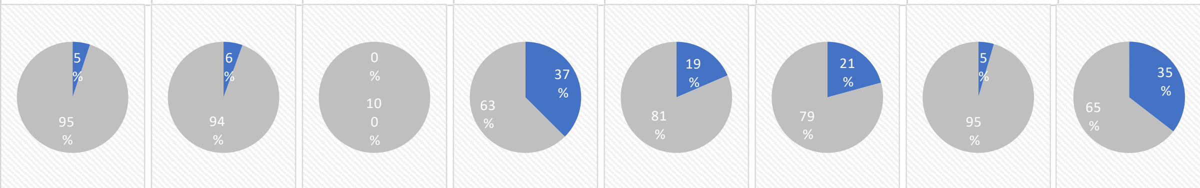

Figure 41: Close up of pie charts regarding emission categories, from the data we can see that the selected project(s) have a lot of cast-in-place concrete and steel armament bolts etc., but little other steel and no concrete vaults.

The following 28 charts between and including column N to column AO as we see an exempt from in figure 41 show information about how much of the total portfolio comes from the selected projects. The percentage number below each of these charts also show how much emissions they are as part of the total emissions. In figure 41 we can see that the emissions from “Summer av Cast in place concrete2” for the selected projects make up 37% of all emissions regarding cast in place concrete, for the portfolio, and 3.17% of all emissions of the portfolio. Comparing the pie charts with one another will give insight into what kind of emissions that are relatively dominant for the selection compared to the rest of the portfolio.

Average emissions per infrastructure quantity – Rows 21 to 30

In the rows between row 21 and row 30, the calculations for average emissions per meter infrastructure are done. In figure 42 there are bar-charts where dark blue and black are average-emission-data from the selected projects, and light blue and orange are average-emission data for the entire portfolio. The idea with these graphs is that one with a quick glance can gauge the efficiency for each group of projects in the portfolio, compared with the average.

For future iterations of the databank, it could be expanded to include selections from a secondary pivotable, so that it would be possible to compare between different selections within the dataset, but this will be left for future research.

Average emissions per infrastructure quantity												
		Average data		Emissions per meter project	Bridge related emissions, [total]; [selected]	Emissions per meter Bridge	Tunnel Related Emissions,[total];[selected]	Emissions per meter Tunell	Road Related Emissions, [total];[selected]	Emissions per meter road		Direct emissions per meter projcet
	Dividend	Total Emissions		241838	36229	36229	43628	43628	161784	161784		81648,5
	Divisor	Total projects length		123391,3333		2726		13714		94783		123391,3333
	Kvotient	Emissions / length all projects		1,959926953		13,29016875		3,18127461		1,706888366		0,661703685
	Dividend	Selected Emissions		33730	16525	16525	7415	7415	9790	9790		4289
	Divisor	Selected projects lenght		5633		730		3408		1495		5633
	Kvotient	Emissions / Length in selected projcets		5,98792828		22,6369863		2,175762911		6,548494983		0,761406

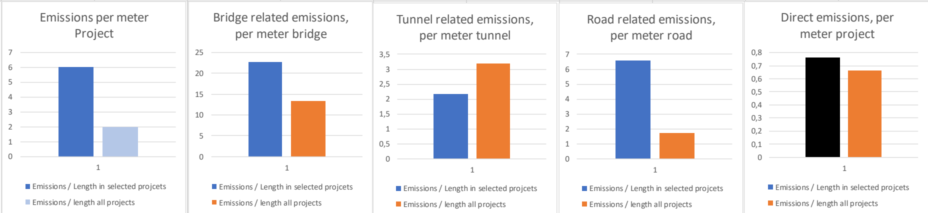

Figure 42: Overview of the average-emission graphs.

To make the graphs, we need the dividend and the divisor for both the selected group and for the entire portfolio. We take in the data for total emissions and total lengths for the specific infrastructure type and divide emission data with length data to get the average emissions per infrastructure length.

Emission data and length data are found either from the data already brought to the brain in rows 11-20, or by finding the corresponding data in the pivotable, or the input-data table. The average emissions from the selected projects and the total portfolio is then graphed with bar-charts for comparison. – Make sure that the bottom value for the y-axis is manually set to 0, this makes sure that the relative sizes between the two bars is always representable for the average emissions between the selection and the total portfolio.

Emission overview diagrams – Rows 31 to 40

The rows 31 to 40 are used for displaying the emission data for the selected projects with regards to the relative sizes of contribution from different contributors.

Rows 32 to row 34 take in emission data from the pivotable. Rows 35-36 group together some of the emissions categories, for example concrete and steel related emissions where the emissions come from similar materials. Row 37 is where the graphs are placed, and row 39 is the data in row 35-36, but in percentage out of the total emissions.

Column C to column M take in the data for what process the different emissions are allocated to and to which infrastructure type it was built. It distinguishes between Scope 3 emissions attributed to the materials used for road, bridge, and tunnel (A1-A4 Road construction, A1-A4 bridge construction, A1-A4 tunnel construction), and the emissions caused by the building process itself for road, bridge, and tunnel (A5 Road construction, A5 Bridge construction and A5 tunnel construction). The idea behind this graph, is to easily be able to gauge where to look for good places to cut emissions in future projects.

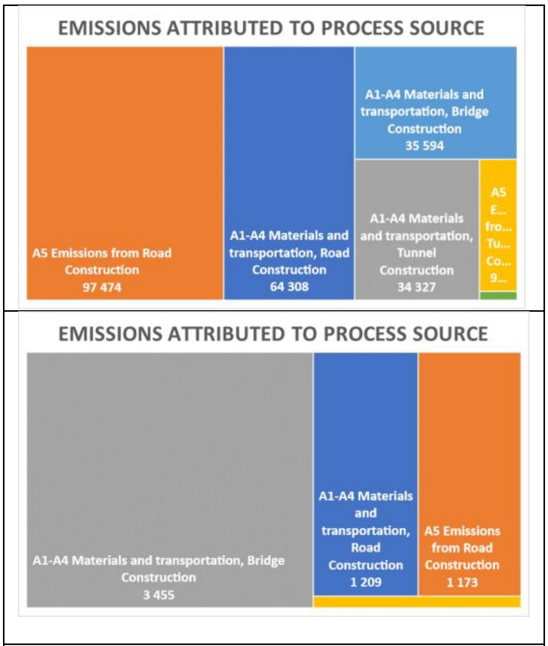

Figure 43: Example of results from the emissions attributed to process code - box graph on top – data for the entire portfolio, on bottom data from the two "Ferry quay" projects.

In Figure 43, the data for the entire portfolio and the data for the two ferry-quay projects can be seen. For the two ferry quays, about 4/5 of the emissions for the two projects are scope 3 emissions allocated to the materials used. This gives a great signal for the future that to cut emissions when building ferry-quays, you gain more by focusing on cutting emissions from materials consumed rather than transport and equipment usage. The amount of ferry quays in the dataset is very low however, therefore it is hard to say whether the data for ferry quays is representable or not, but both ferry quays have similar emission-profiles when looking at their data isolated.

In columns N to AO, the emission data are taken in from the pivotable and allocated to the 28 different emission categories presented in the result-synapsis of the LCAs. These data are used to make the "emission attributed to materials" box, and the emission data from row 36 where they are grouped together is used to make the charts "A1-A4 categorized (2% cutoff)" and "Emission attributed to A5 (no cutoff)" that shows the relative emission contribution from different contributors within the A1-A4 process and within the A5 process.

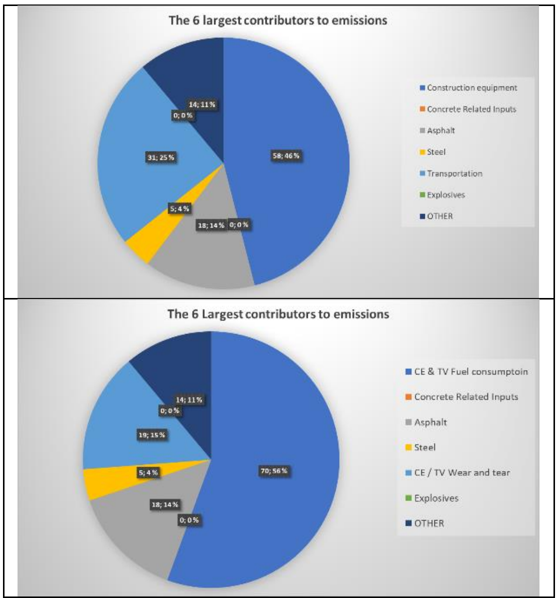

Figure 44: The charts over "Kroken siktutbedring" where the top 6 emission sources for the portfolio are shown

Columns AQ to AX provide the data for the size-comparison diagrams for the comparison of the contributions from A1-A4 and A5.

Columns AZ to BN provides the emission data for the charts that graph the contributions from the 6 emission categories that was found to be the major contributors: construction equipment, concrete, steel, asphalt, transportation, and explosives. In one of the two graphs they are compared as provided, while in the second graph, the emissions allocated to construction equipment and transportation vehicles have been grouped together but separated on emissions caused by burning fuel and emissions caused by wear and tear /depreciation of the vehicles. It turns out that, over the entire portfolio it seems that the ratio between emissions caused by construction equipment and transportation vehicles, are almost the same ratio as the ratio between fuel consumption and vehicle depreciation. As a result, the two graphs seem very similar for most projects to a degree that one might think there is something erroneous with the data from the LCA's. However, by looking at some of the minor projects such as "Kroken siktutbedring" as in figure 44 it is indeed showing different kinds of data.

Rows 41 - 50 Infrastructure type profile

These rows have been attributed to the length of the different kinds of infrastructure types for making a graph that gives a quick overlook on what kind of infrastructure is a large part of the project. It takes in total length, and length of bridge, tunnels and road and graphs them as a percentage of total for the project. Examples of different infrastructure type profiles can be seen in figure 45.

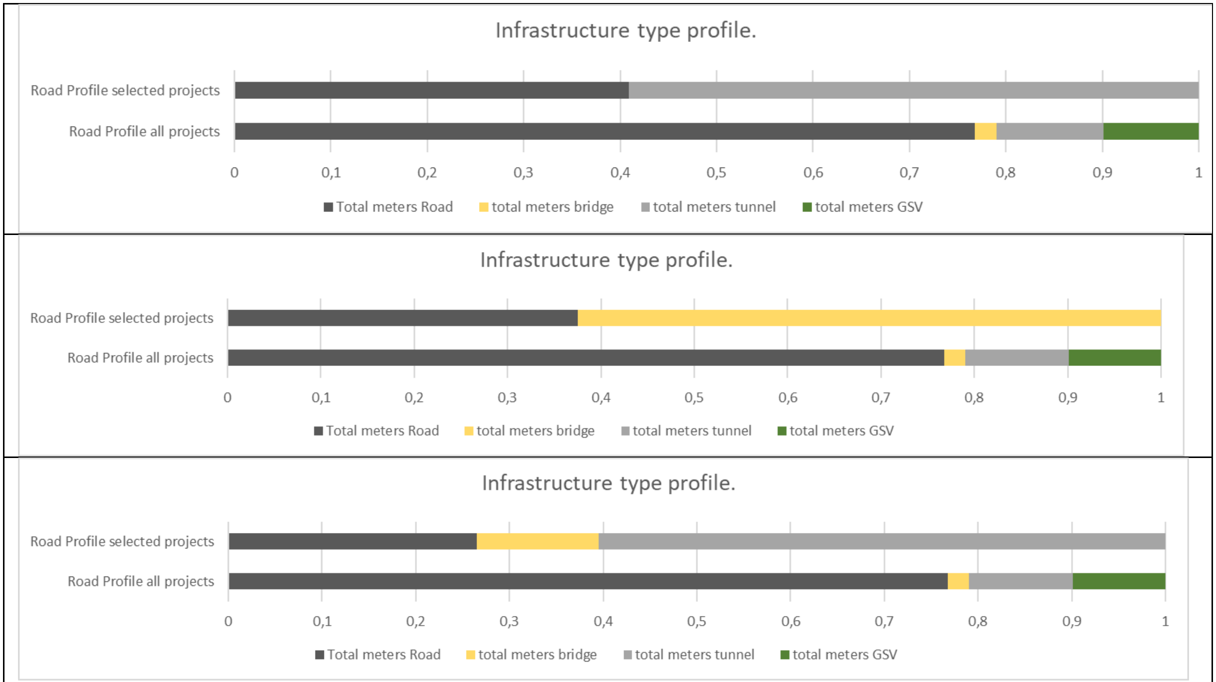

Figure 45: Example of infrastructure type profiles for three projects where tunnels and bridges have been a dominating part of the projects in length. On top: «Berfjorden», in the middle "Hammer bru", at bottom «Åstfjordkryssinga».

Rows 51-60 Quantity of materials

The last bunch of graphs is the 29 pie charts that give information about the quantity of materials used in the selected projects. They work in the same way as the pie charts in rows 11 – 20, but instead of taking in information about the amount of emissions allocated to the materials, it takes in the quantity of the different materials instead. This information can be useful when looking at what emission-cuts could have been possible for each project. For example, the information here was used to look at how much diesel was consumed in all the projects to calculate the emissions allocated to them, and the possible emission-cuts had different percentages of the workload been done with electrical engines rather than ICEs.

Pivot for Statistical Analysis

As there already is a comprehensive guide for making a pivotable, this one will be brief. The pivotable is made the same way as last time, but this time we are only interested in the data we are going to graph for statistical analysis. In addition we are going to remove the bottom line from the pivotable, as it will interfere with our graphs if we do not. To do that right click the pivotable, select options for pivotable (alternativer for pivotabell in Norwegian), go to summary and filters and uncheck sum of columns. (Totaler og filtre, og totalsum for kolonner in Norwegian). We are also here creating slicers, to be copied over to the Statistical Analysis page, one for Projects, Infrastructure type, Tunnel dummy, Bridge dummy, Version number, Minor project type, specified transport distance, total road width, project length and percentage of project is road.

Statistical Analysis

To make the sheet for the graphs we first need to import the data from the pivotable. In the study, we have chosen to do it in the column "AL" and to the right. The trick to make an interactive graph here, is that we need to import the data from the pivotable in such a way that when some datasets are de-selected, we do not want them to be a part of our graphs anymore, so we need to import them without carrying over data.

To do that, we simply use the formula "=HVIS(ERTALL('Pivot for Statistical analysis'!C9);'Pivot for Statistical analysis'!C9;IT())" in Norwegian or "=IF(ISNUMBER('Pivot for Statistical analysis'!C9);'Pivot for Statistical analysis'!C9;NA())" in English. This formula checks for what information is in Cell C9, and if there is no data there it returns "Not available" and this is a value that is skipped for graphs - thus we can graph the same area, and when the dataset changes to reflect a selection, it will not interfere!

We took this formula and dragged it from AL15, to AV 64, and then put up the graphs and imported slicers from the pivot for statistical analysis.

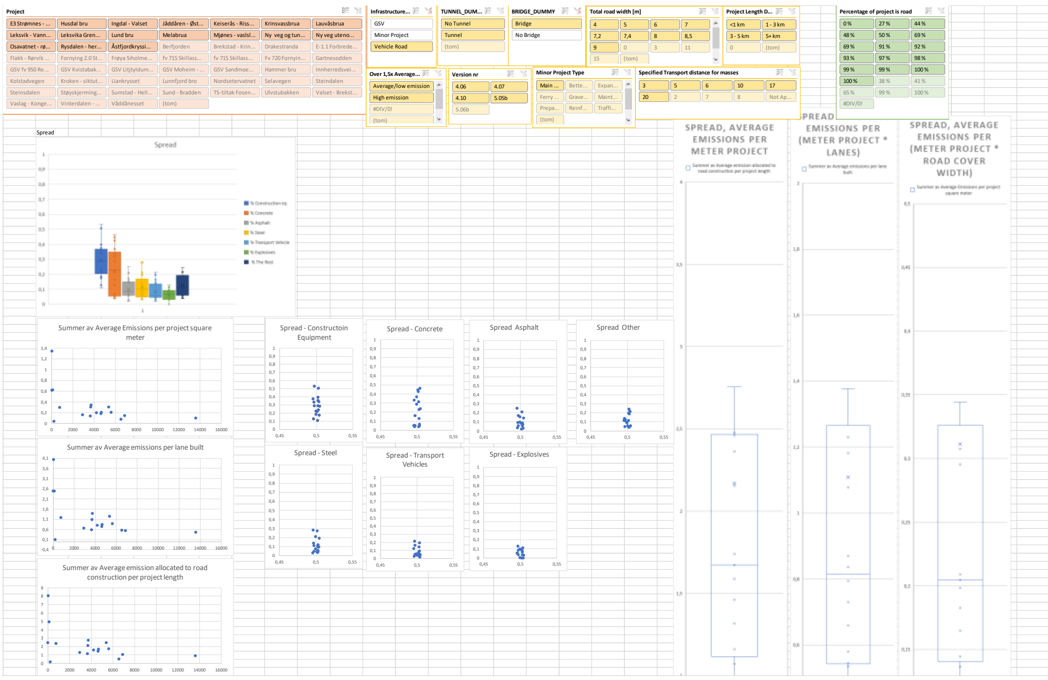

Figure 46: Example of how the spreads look for Vehicle roads with bridges as a part of the project.

B. Appendix B – Data from subsets

Appendix B contains the factsheet from the front-page of the databank for different selections. The figures in this appendix are also reproduceable in the LCA databank.

All projects

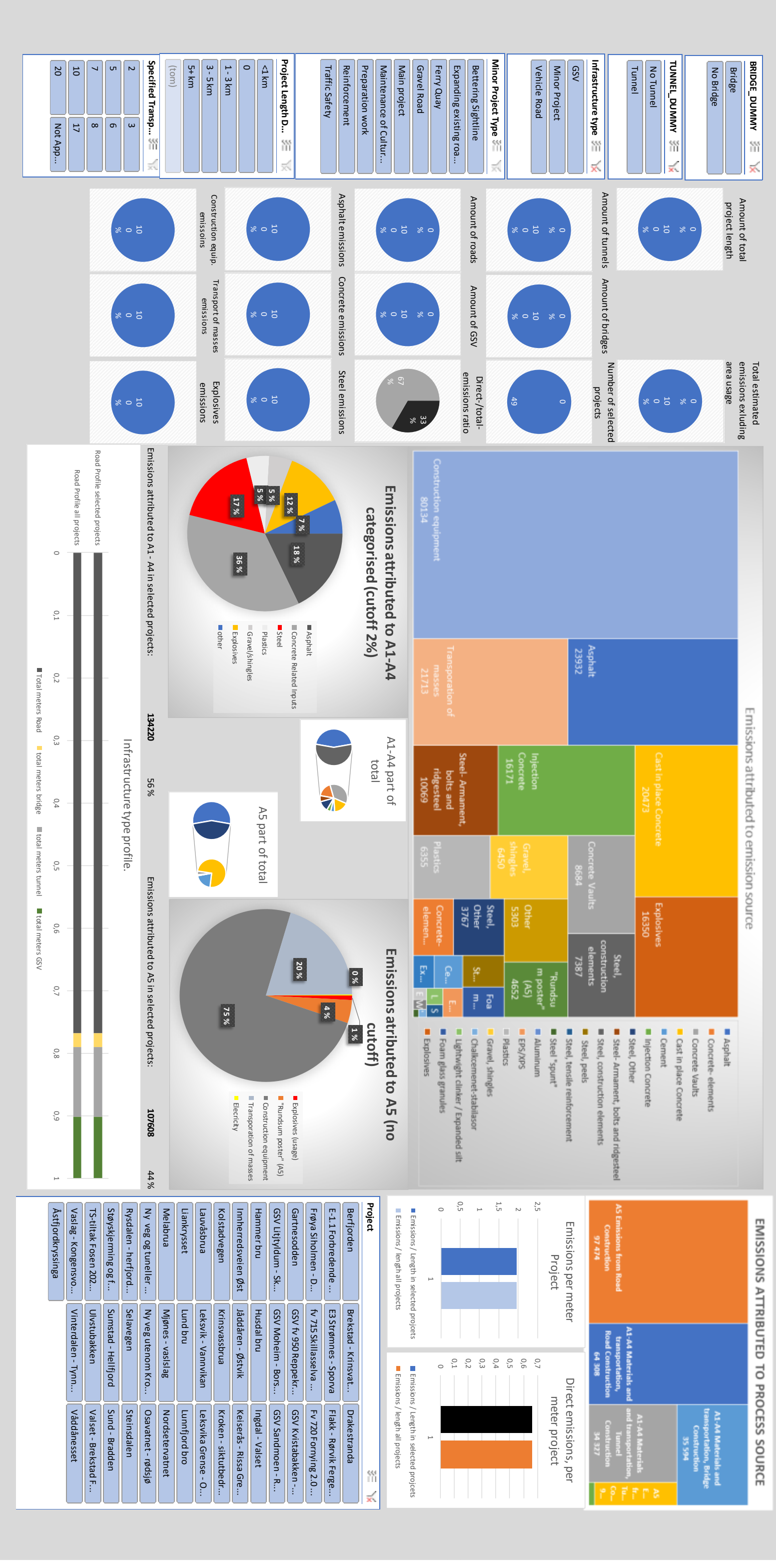

Figure 47: Front page of the LCA databank when the emission profile for all projects is shown at the same time.

Vehicle road – all

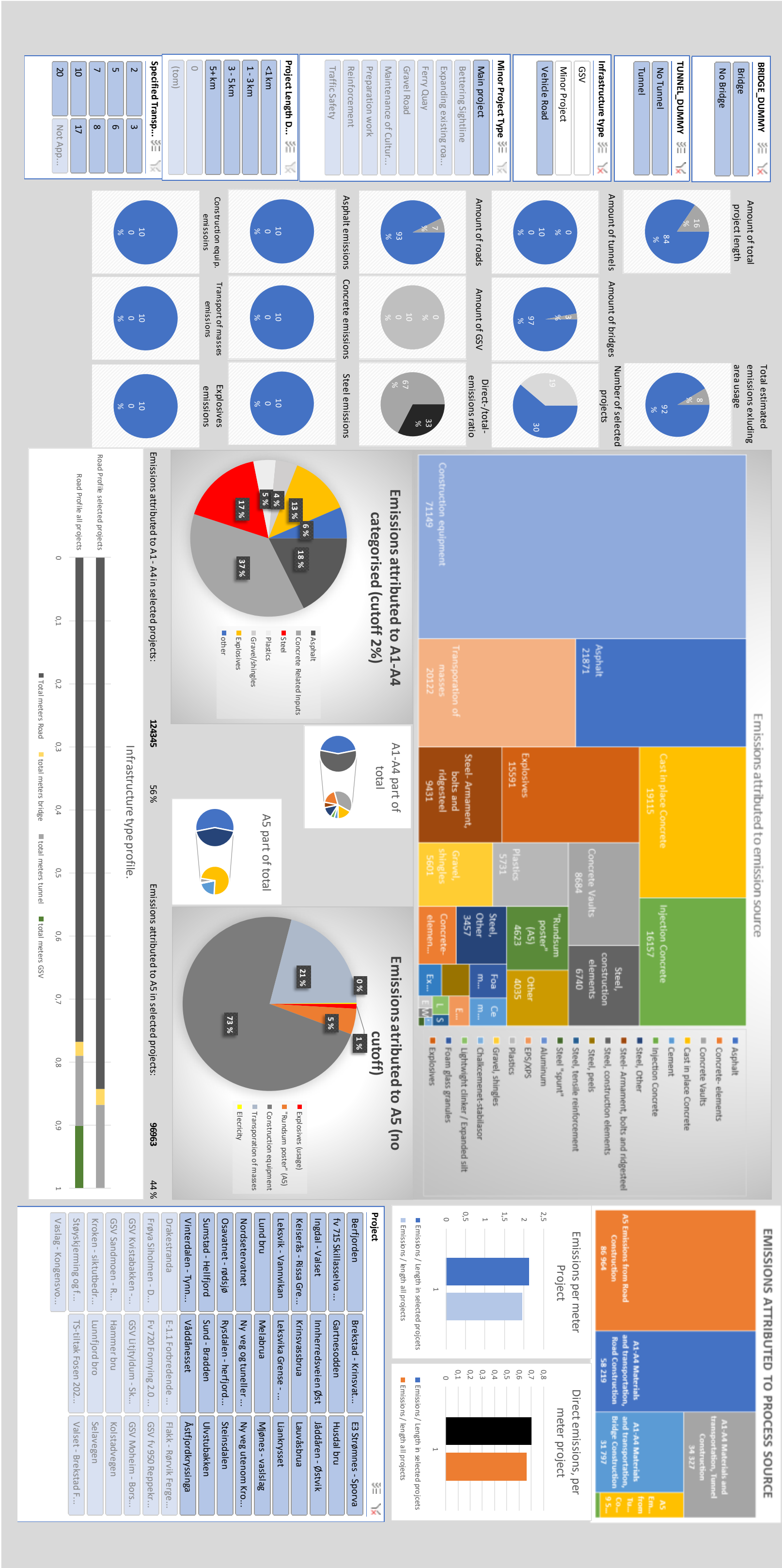

Figure 48: Front page for all the vehicle road projects, we see that out of the 49 projects in the portfolio, only 30 of them are vehicle road projects.

Vehicle road – no tunnel, no bridges.

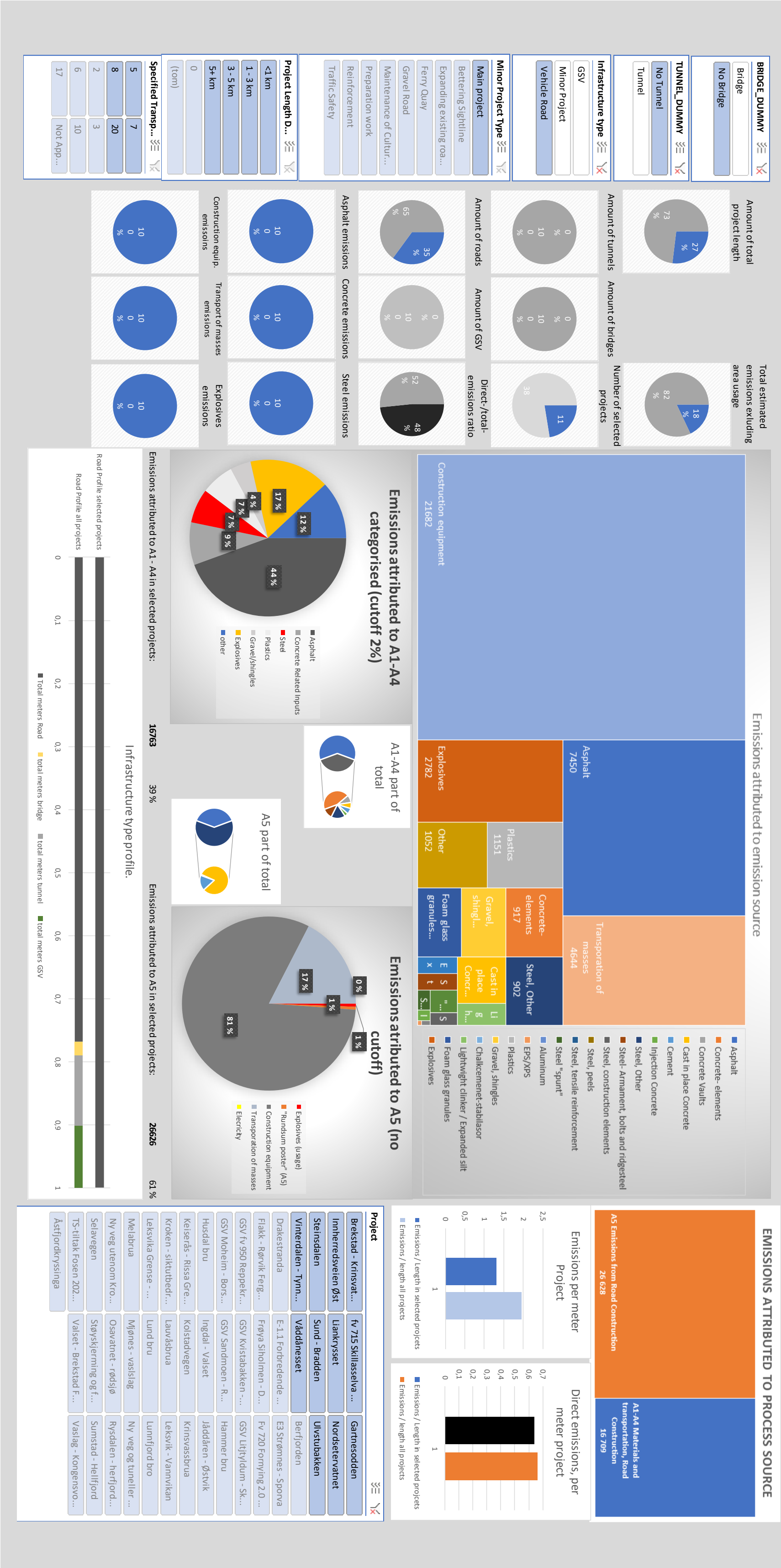

Figure 49: Front page for vehicle roads with no tunnels and no bridges, we see from the emission portfolio that construction equipment is a major emission contributor.

(i) Vehicle road- tunnel, no bridge

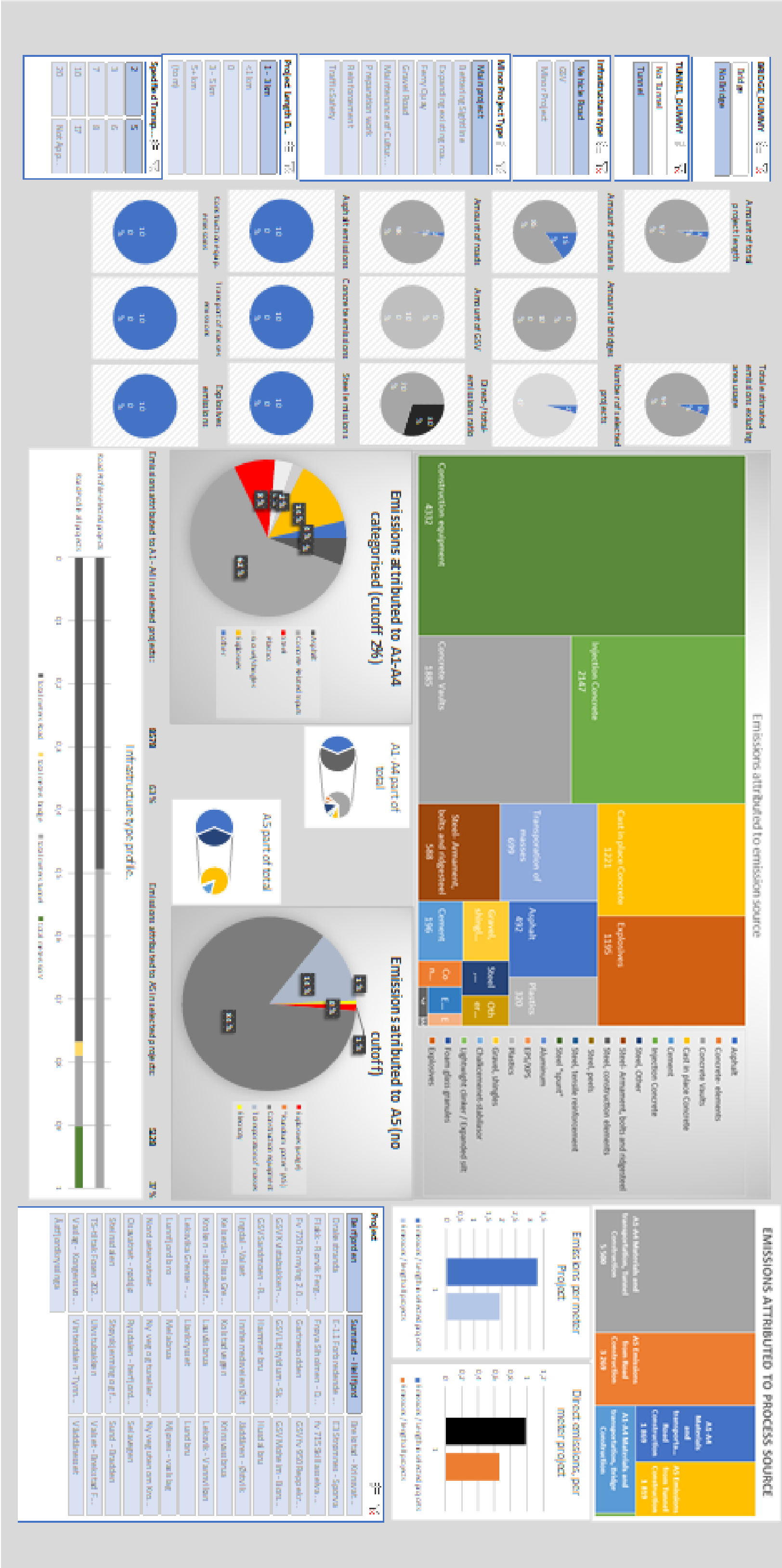

Figure 50: There are two vehicle road projects with tunnels but no bridges. We see that concrete and construction equipment are big contributors to emissions, as well as explosives steel and transportation. We also see in the Infrastructure Profile, that the projects over 5|% tunnels in length.

Vehicle road – bridge, no tunnel

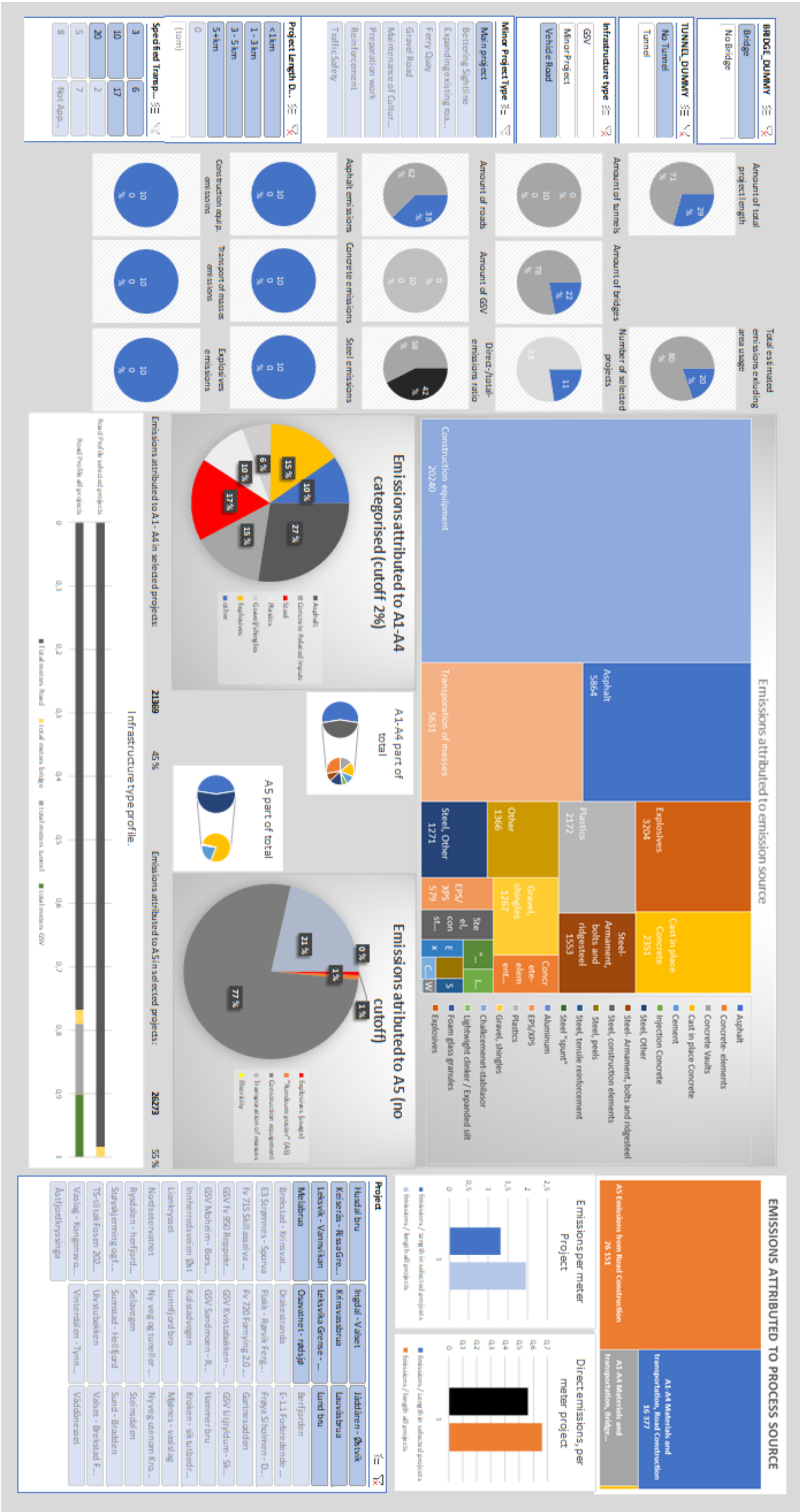

Figure 51: Emission profiles for the 11 projects with vehicle road bridges, but not tunnels. Comparing the amount of the road profile that is bridge, compared with the emissions attributed to bridge in the process source, we see that bridge materials have a proportionally much larger share of the project emissions than the materials attributed to road construction.

(ii) Vehicle road – tunnel, bridge

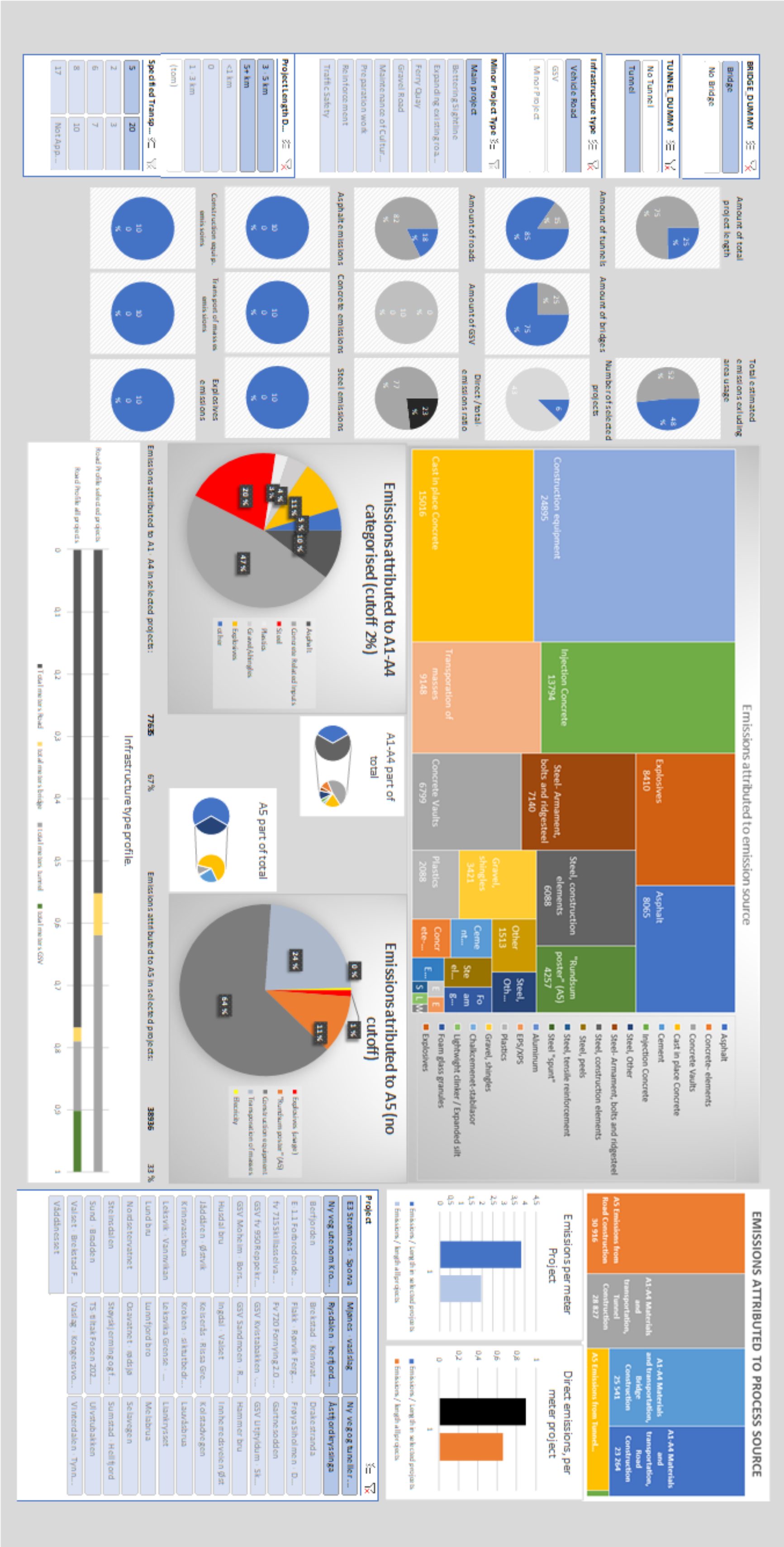

Figure 52: The vehicle roads with tunnels and bridges. We see that the average emission per project length is almost double the average for the entire portfolio here.

(iii) Vehicle road – no bridge, no tunnel, - >3km

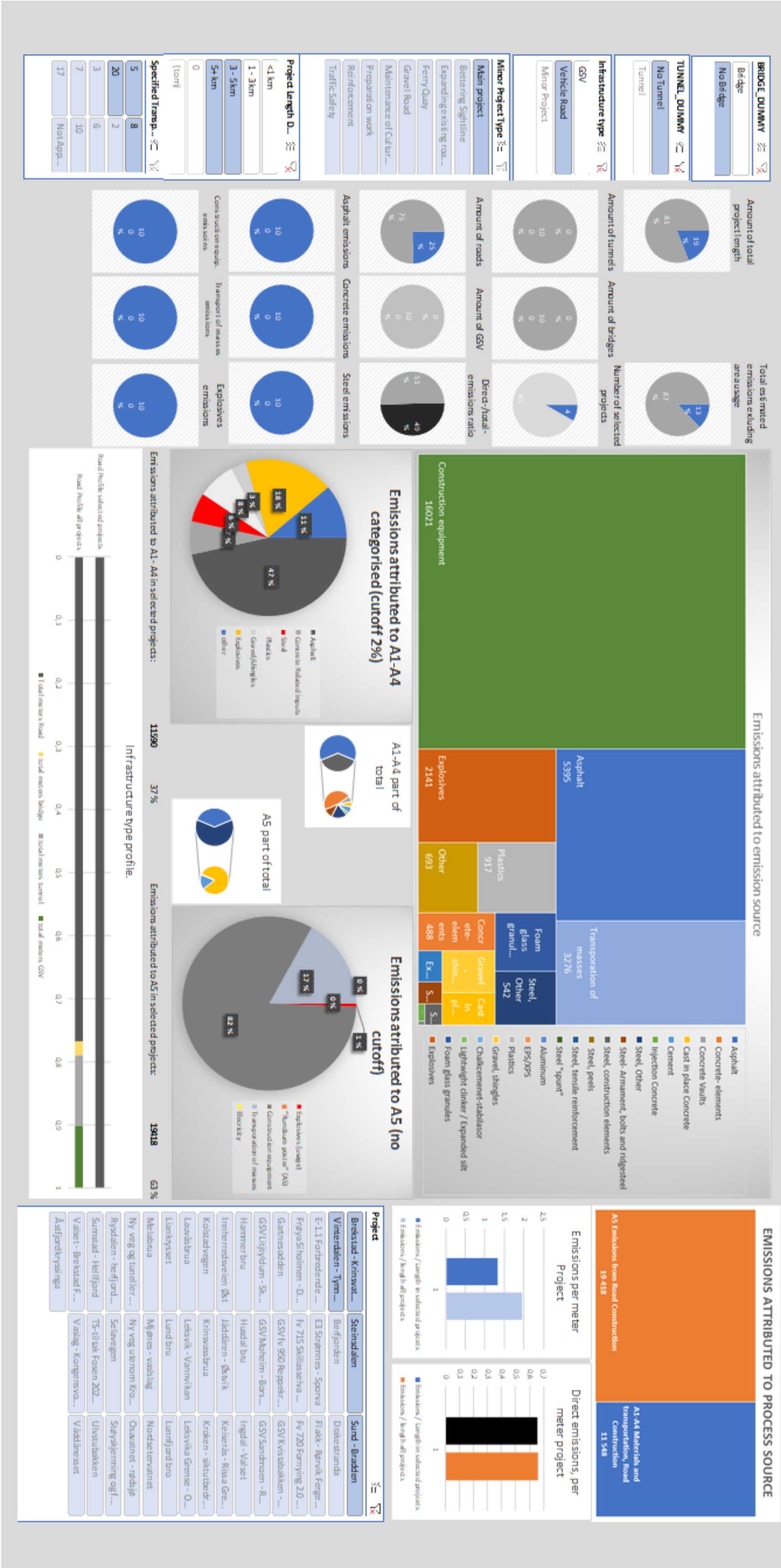

Figure 53: Vehicle roads, 3km+ No tunnel, No Bridge. To be compared with figure 54.

(iv) Vehicle road – no tunnel, no bridge, <3km

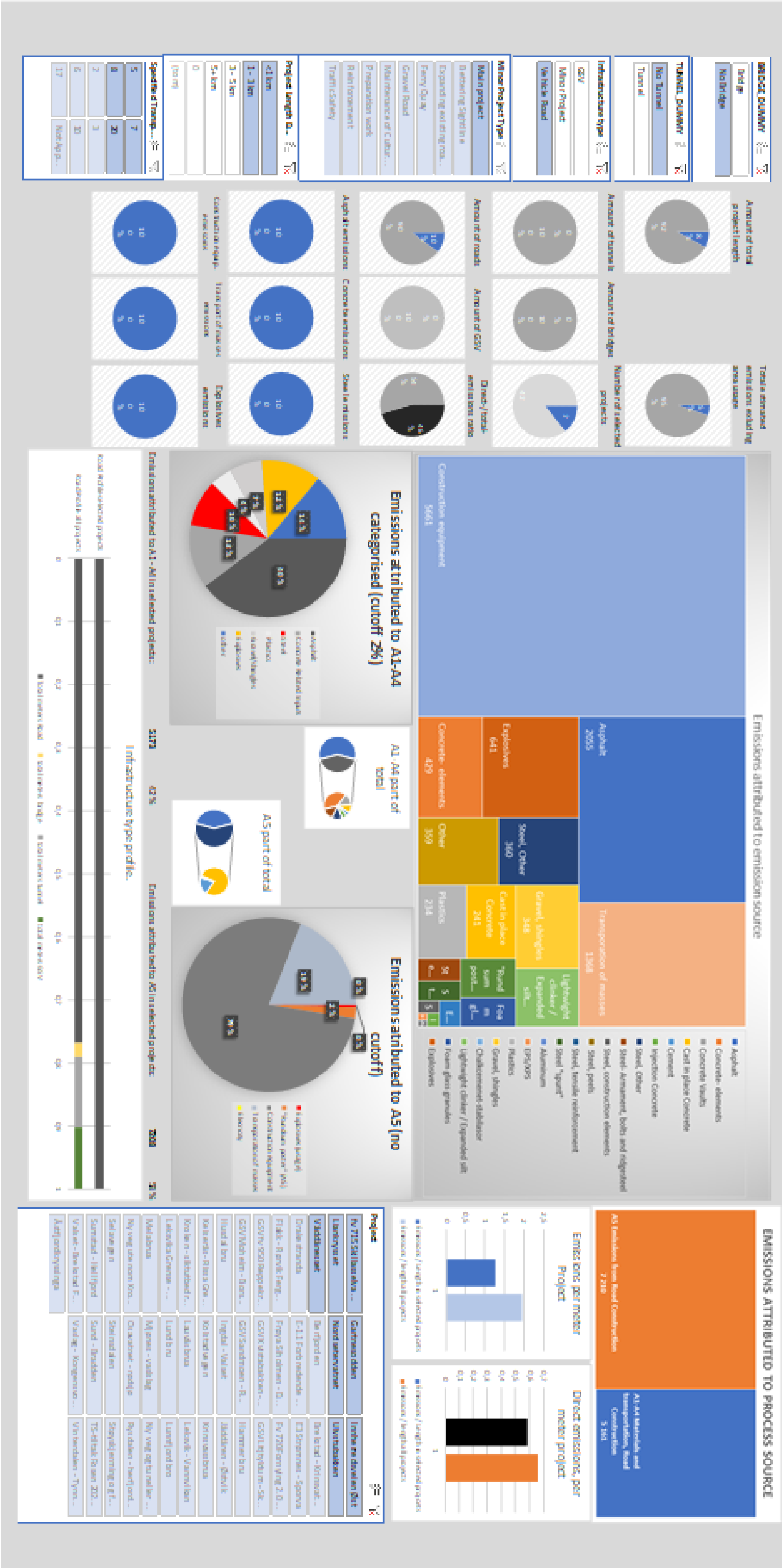

Figure 54: Vehicle road, no tunnel no bridge, there seems to be little difference between projects over and under 3km for these parameters.

GSV – All

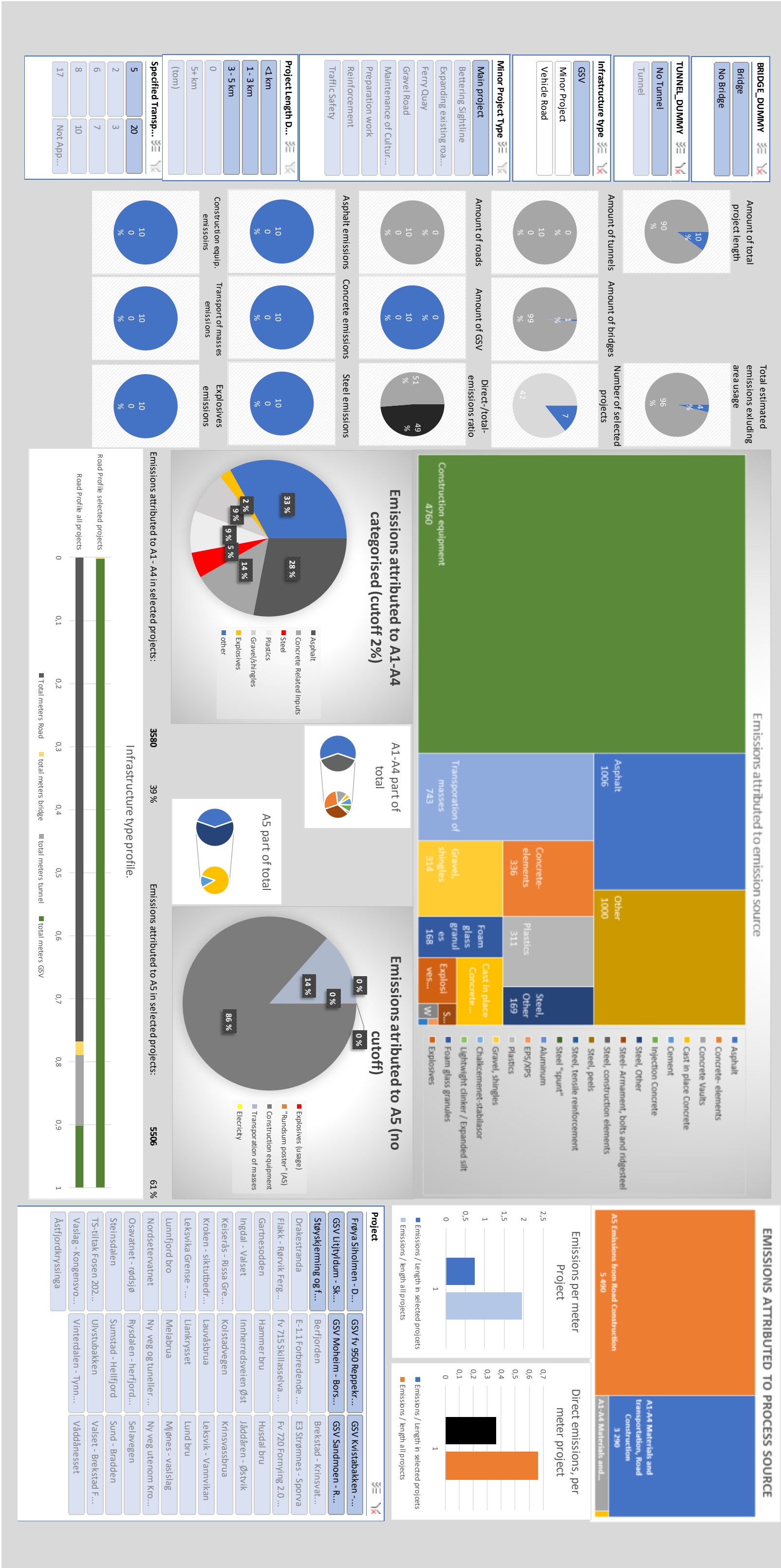

Figure 55: The pavements specifically designed for pedestrians and cyclist have the largest contributions from materials that are not covered by the largest 6 emission contributors for the portfolio. Compared to the rest of the portfolio they also have a very low emission per meter project built.

(v) Minor projects – all

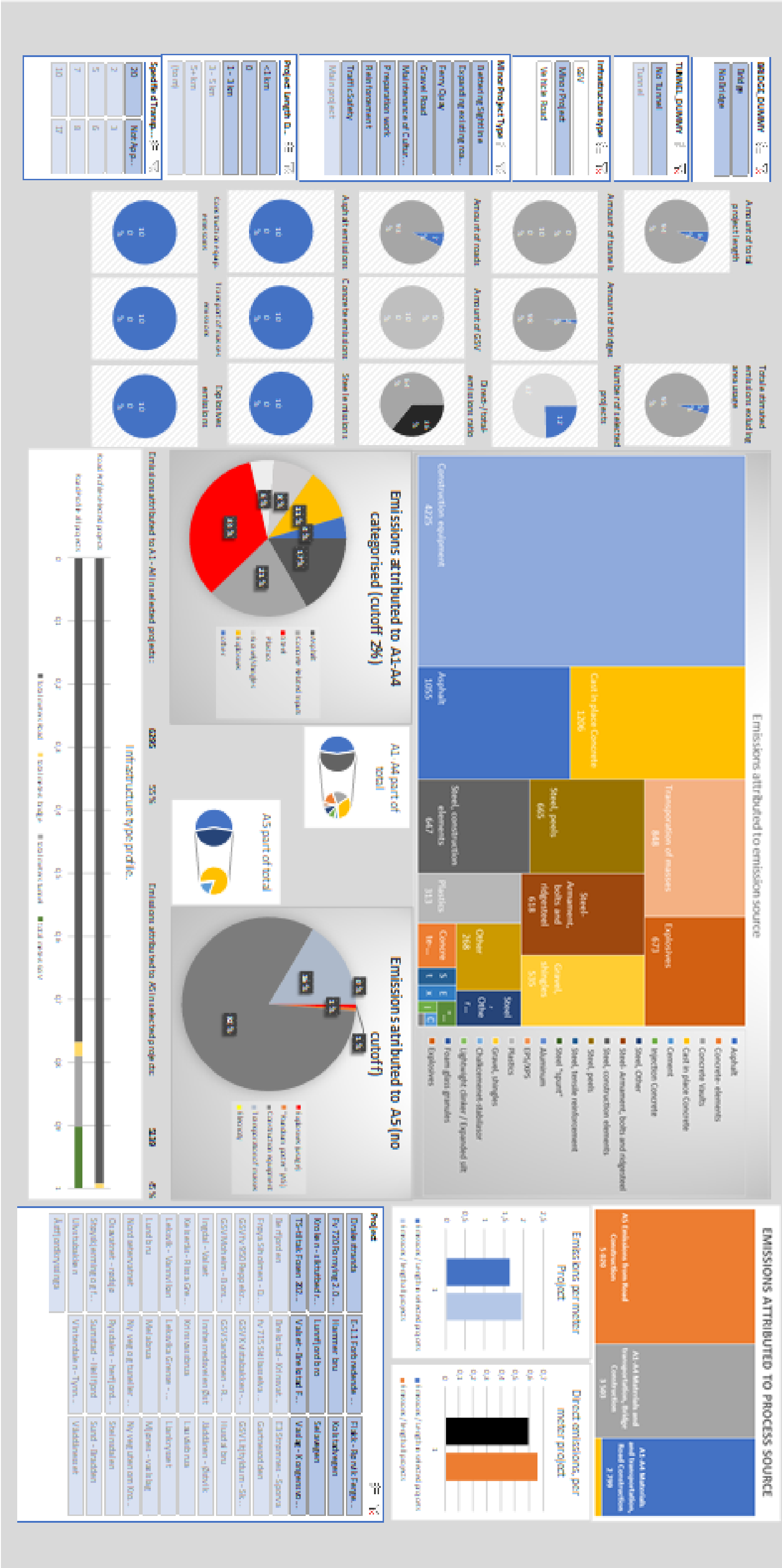

Figure 56: All in all, the minor projects make up 5% of the emissions in the portfolio, most of it relates to construction equipment but also a lot of steel and concrete.

(vi) All projects – transport length 10+km

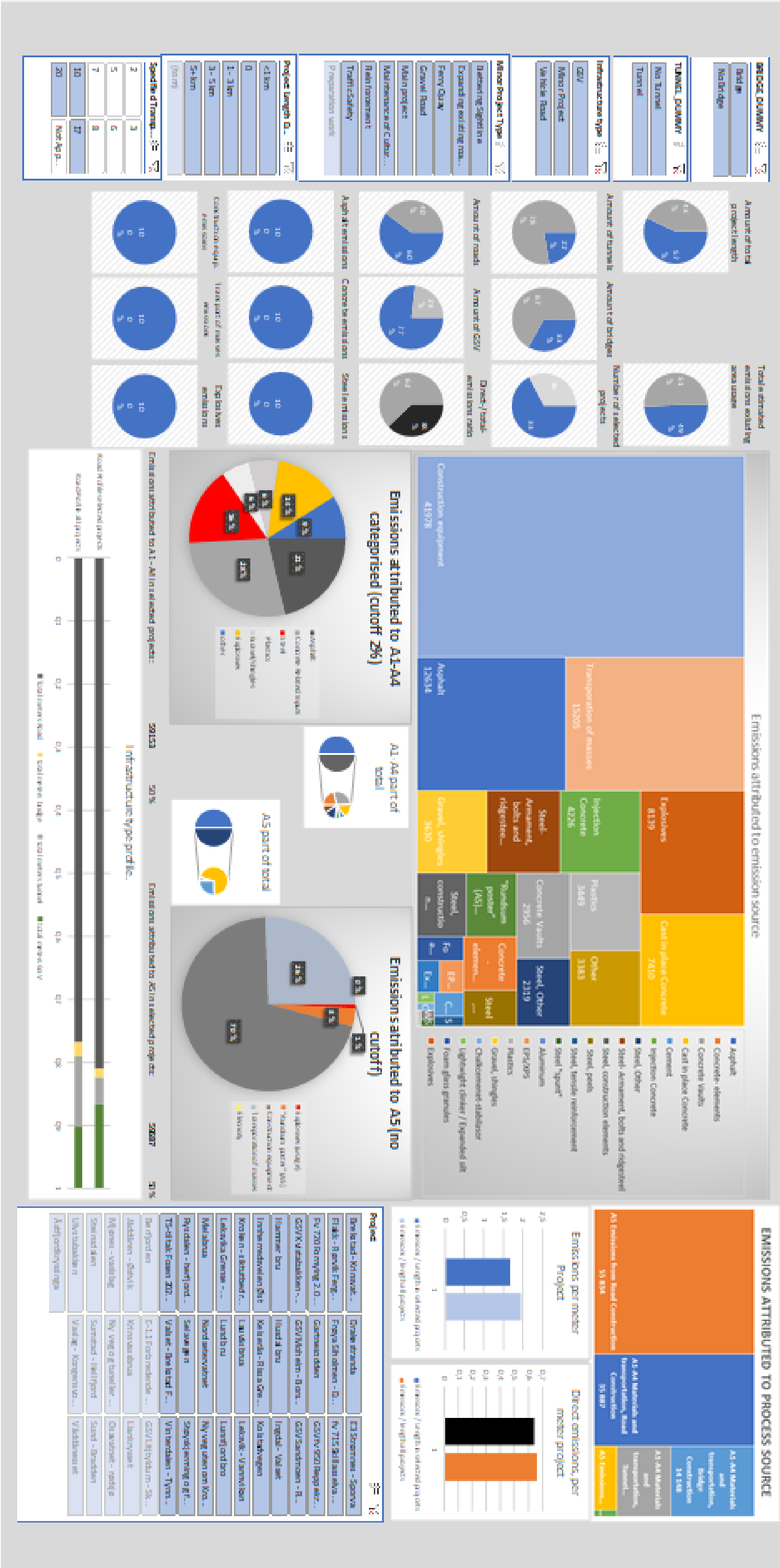

Figure 57: Emission profile for projects with >10 km transportation distance, curiously enough these projects have sub average emissions per project meter.

All projects – transport distance <10km

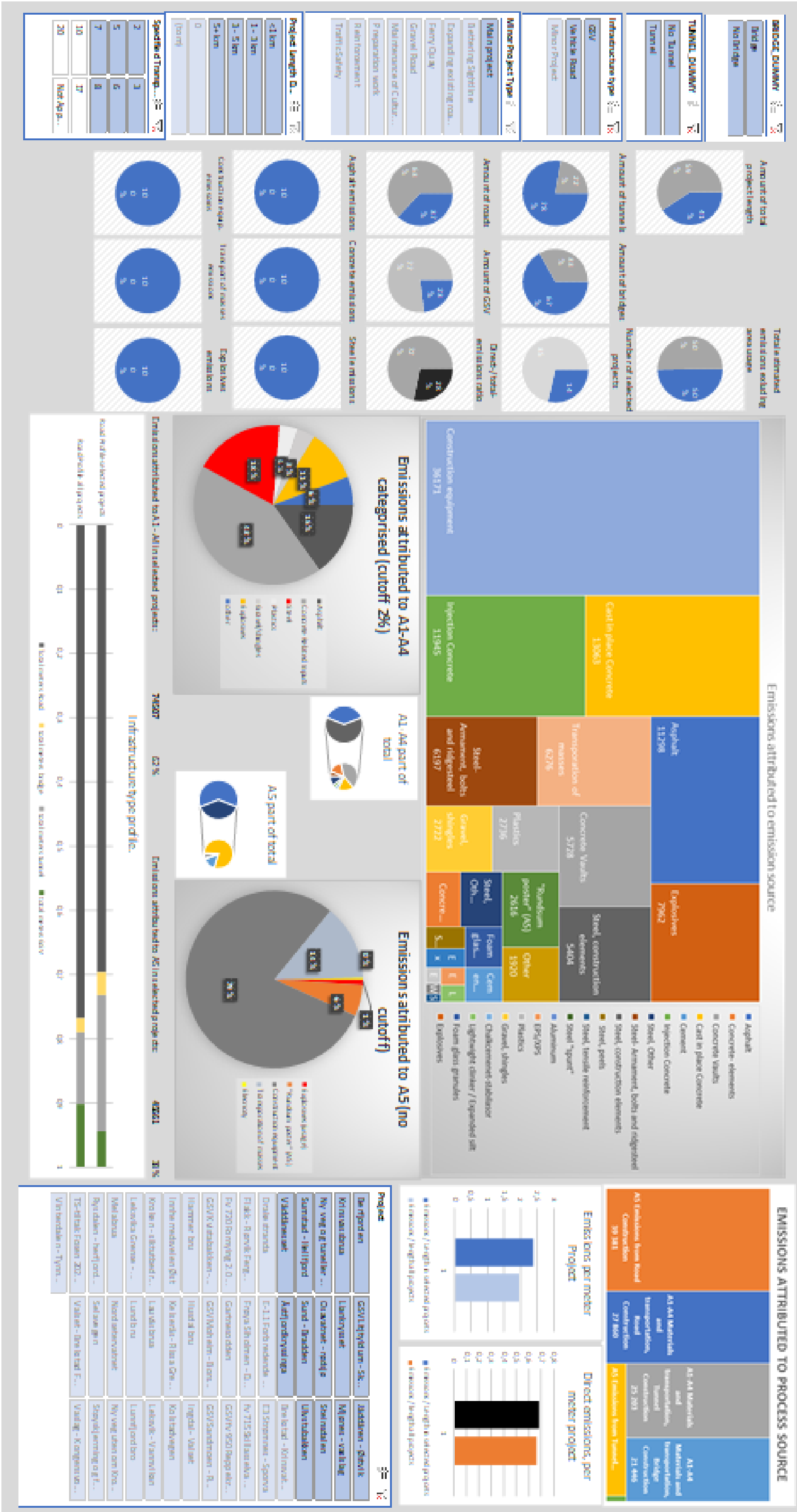

Figure 58: For projects with specific transportation distance less than 10 km, transport of masses is noticeably a smaller contributor than earlier. But this could also be due to the selection having above average emissions in total.

C. Appendix C – Spread - including outliers

Larger pictures of the figures illustrating the spread before the outliers were removed. The graphs in this appendix are also reproduceable in the LCA databank

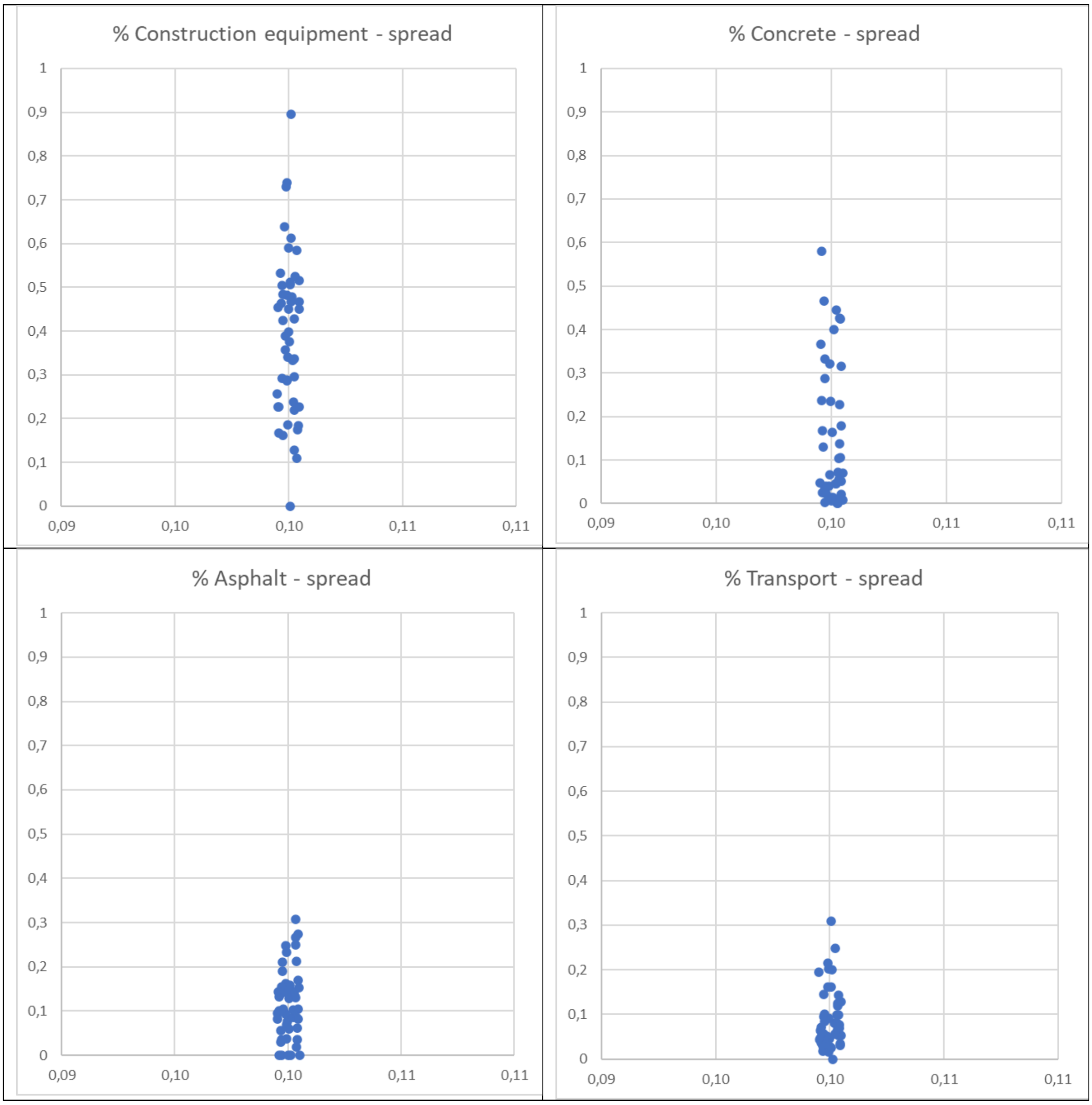

Figure 59: Spread for the emission categories construction equipment, concrete, asphalt and transportation vehicles, for the entire portfolio.

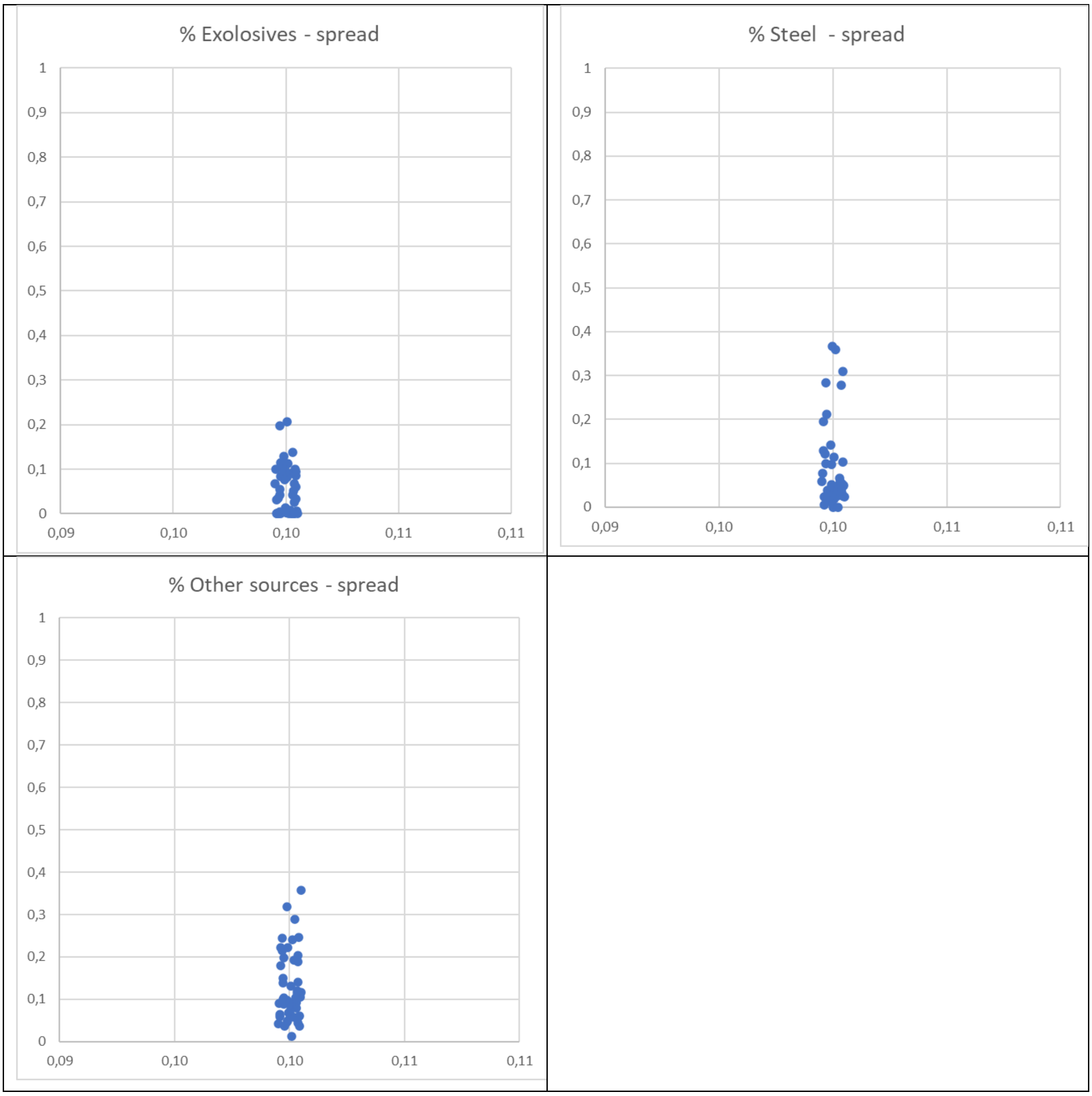

Figure 60: Spread for the emission categories explosives, steel and the remaining other sources, for the entire portfolio.

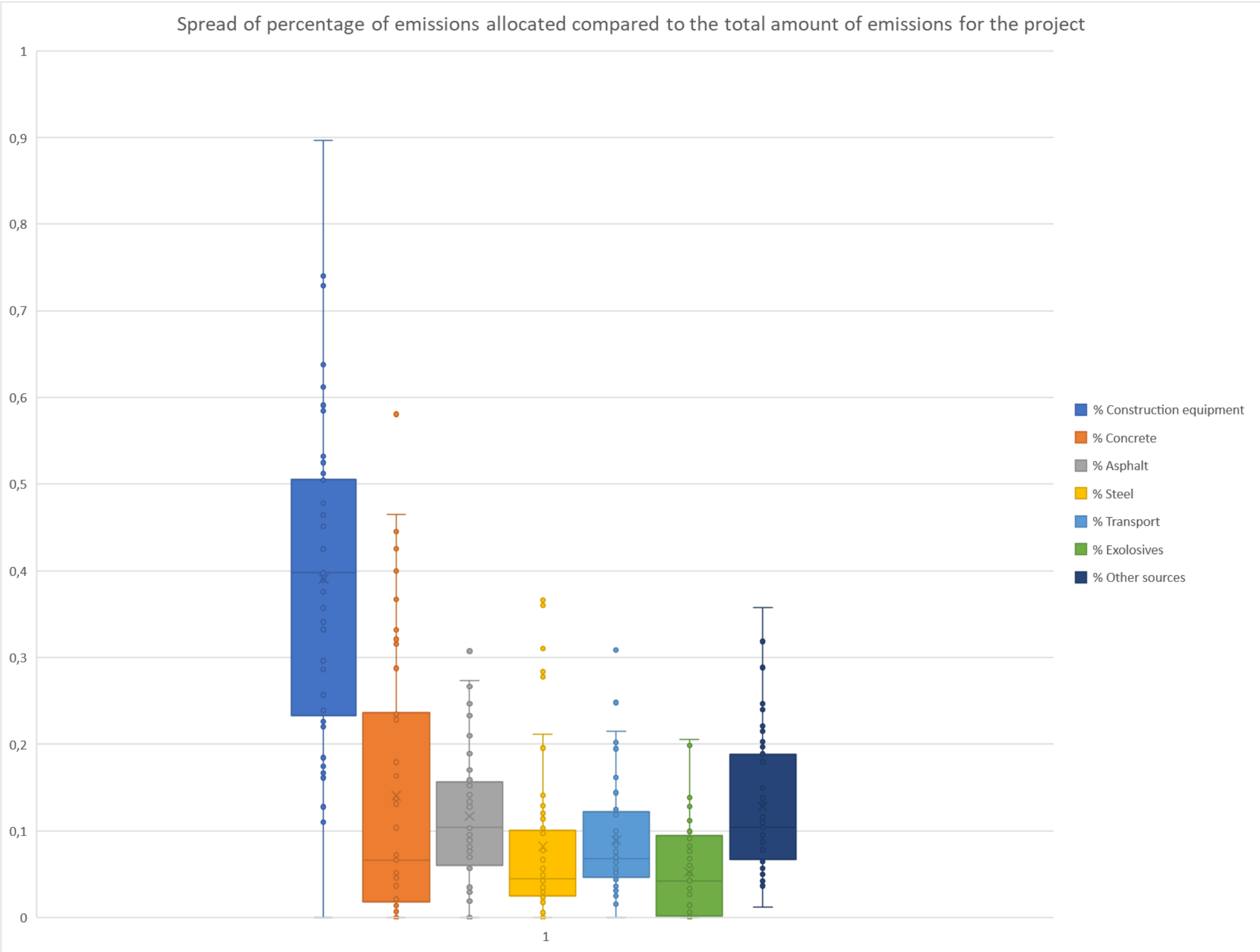

Figure 61: Spread of the 6 largest emission contributors and the remaining other contributors.

Table 22: The spread for the 6 largest emission contributors. Each row is the emission profile for an individual project.

% Const. eq.	% Concrete	% Asphalt	% Steel	% Transport	%Explosives	% The rest
0%	40%	0%	36%	0%	0%	24%
11%	43%	2%	28%	5%	0%	11%
13%	33%	4%	28%	3%	5%	14%
16%	58%	0%	13%	6%	0%	6%
17%	23%	8%	37%	5%	1%	10%
17%	47%	3%	10%	2%	0%	22%
18%	18%	10%	31%	3%	9%	10%
19%	29%	15%	21%	6%	0%	10%
22%	45%	9%	4%	6%	9%	6%
23%	37%	10%	8%	4%	10%	9%
23%	1%	25%	4%	5%	10%	32%
23%	1%	15%	2%	31%	21%	8%
24%	23%	9%	5%	14%	7%	19%
26%	43%	3%	5%	7%	10%	6%
29%	24%	14%	20%	5%	3%	6%
29%	16%	6%	11%	16%	8%	13%
29%	32%	8%	10%	8%	9%	4%
30%	1%	15%	5%	13%	1%	36%
33%	10%	27%	6%	12%	0%	12%
34%	4%	9%	14%	21%	13%	5%
34%	7%	7%	10%	9%	11%	22%
36%	13%	6%	12%	6%	3%	24%
38%	5%	25%	3%	12%	5%	11%
39%	1%	23%	1%	20%	10%	5%
40%	4%	21%	4%	3%	8%	20%
43%	17%	13%	2%	7%	0%	18%
43%	32%	4%	5%	2%	8%	7%
45%	1%	21%	3%	6%	3%	20%
45%	1%	16%	2%	16%	9%	10%
45%	11%	6%	3%	10%	0%	25%
46%	0%	14%	4%	25%	0%	10%
47%	0%	13%	7%	10%	14%	9%
47%	1%	16%	3%	20%	11%	1%
48%	7%	31%	4%	6%	0%	4%
48%	0%	0%	2%	15%	20%	15%
48%	14%	13%	4%	7%	0%	14%
50%	5%	10%	0%	6%	0%	29%
51%	5%	8%	6%	19%	7%	4%
51%	5%	13%	3%	8%	1%	19%
51%	4%	19%	2%	9%	4%	10%
52%	2%	27%	3%	3%	6%	6%
53%	5%	17%	5%	5%	3%	11%
58%	7%	9%	5%	8%	4%	8%
59%	2%	11%	3%	10%	11%	4%
61%	2%	10%	1%	4%	0%	22%
64%	2%	14%	2%	8%	0%	9%
73%	1%	13%	2%	2%	0%	9%
74%	7%	0%	2%	5%	0%	12%
90%	1%	0%	0%	3%	0%	7%

D. Appendix D - Spread without outliers.

Larger pictures of the spread figures, after the outliers are removed. The figures in this appendix are also reproduceable in the LCA databank.

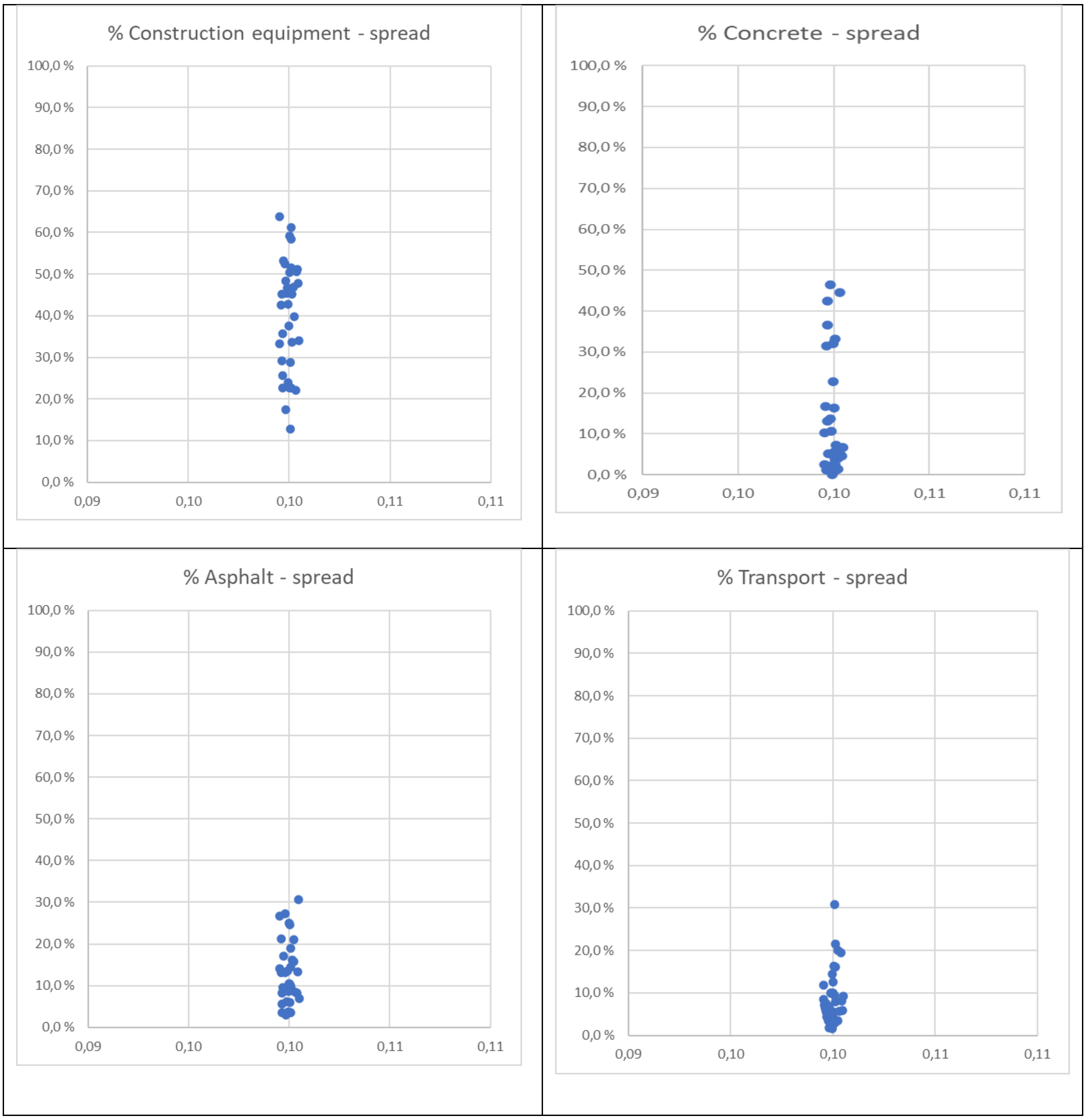

Figure 62: Spread for the emission categories Construction equipment, Concrete, Asphalt and Transport vehicles.

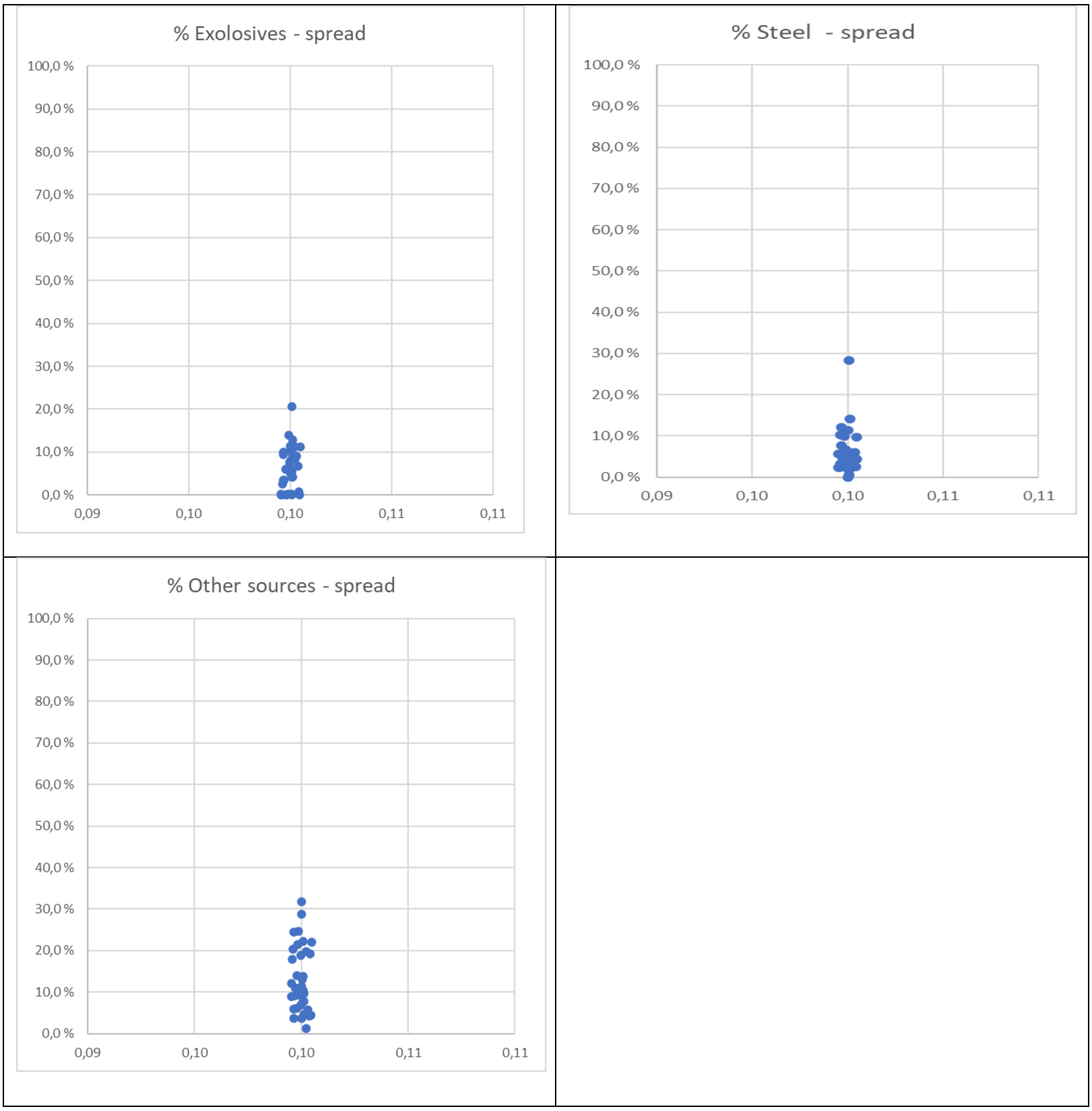

Figure 63: Spread for the emission categories Explosive, steel, and the other sources.

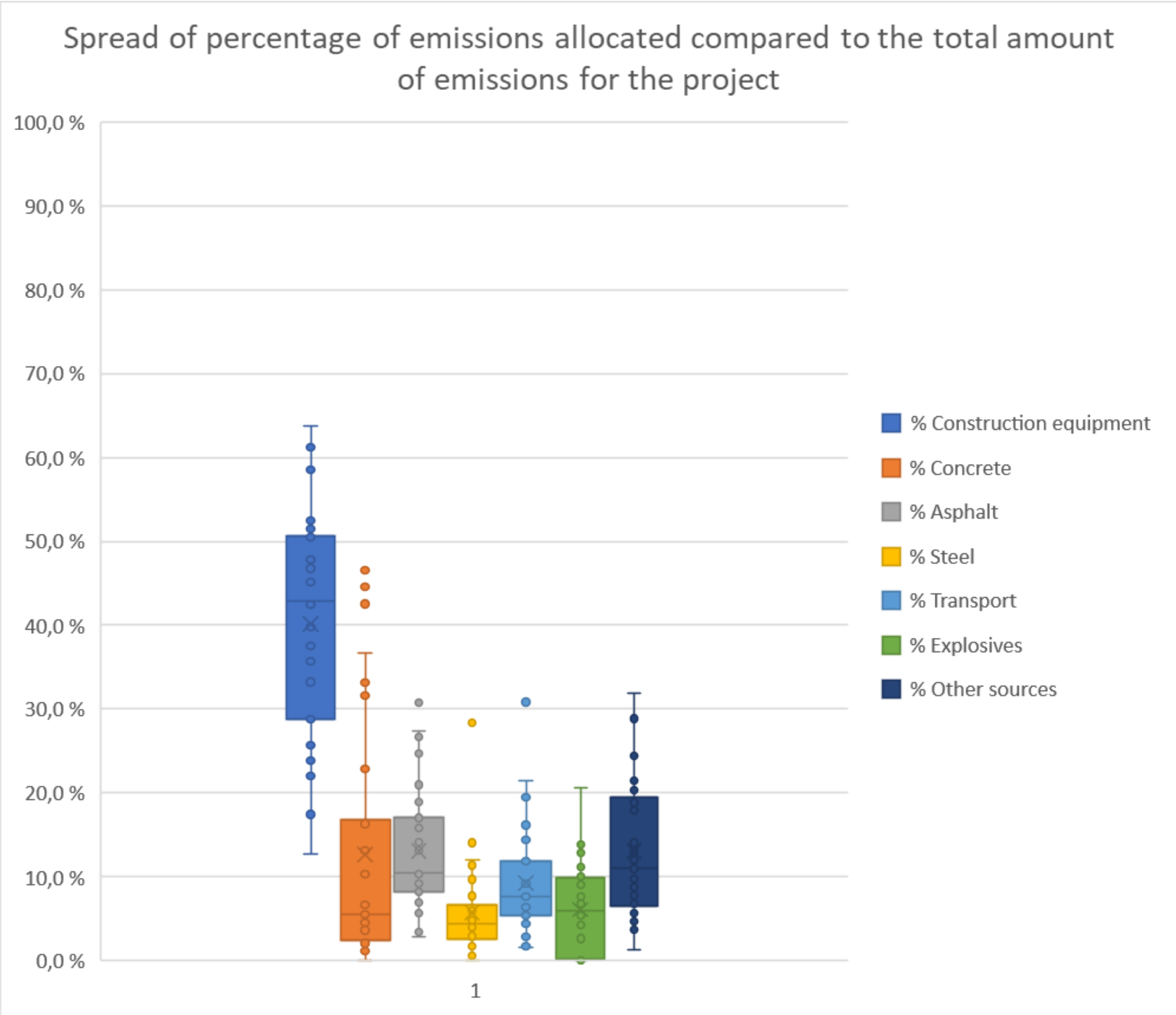

Figure 64: Spread for the remaining portfolio after removing the outliers, we see some significant changes after the outliers are removed.

Table 23: Table for spread of average values for emissions per meter project. Values marked in green are the 7 outliers with lowest average emissions for each category, and the values marked in orange are the 7 outliers with highest average emissions for each category (the rows that have empty road length, are pedestrian and cycling projects):

Total Length of Project	**Road length**	**Average emission allocated to road construction per project length**	**Average Emissions per project length * cover width**	**Average emissions per project length * lanes built**
220	200	**0,19545455**	**0,03909091**	**0,09772727**
833,333333		**0,3384**	0,1128	**0,3384**
500	500	**0,484**	0,121	0,484
1200	1200	**0,53666667**	**0,07666667**	**0,26833333**
6550	6505	**0,54503817**	**0,07569975**	0,54503817
1840		**0,60923913**	0,20307971	0,60923913
2800		**0,63035714**	0,21011905	0,63035714
880		0,69318182	0,23106061	0,69318182
240		0,69583333	0,23194444	0,69583333
1000	1000	0,741	**0,092625**	**0,3705**
3800		0,83289474	**0,27763158**	0,83289474
625	625	0,8656	0,17312	0,8656
13600	13457	0,89691176	**0,09965686**	**0,44845588**
7435	7435	0,90006725	**0,11250841**	**0,45003362**
1800		0,92833333	0,23208333	**0,92833333**
2690	1100	0,96877323	0,13839618	0,48438662
2400	2400	1,02166667	**0,09287879**	**0,34055556**
3440	3440	1,0377907	0,12972384	0,51889535
6901	3030	1,06998986	0,14459322	0,53499493
3651	3650	1,16023007	0,13649766	0,58011504
2940	2932	1,3170068	0,16462585	0,6585034
750	750	1,43866667	**0,28773333**	**1,43866667**
4650	3197	1,46021505	0,18252688	0,73010753
2454	2454	1,50529747	0,18816218	0,75264874
8230	8230	1,57910085	0,19738761	0,78955043
4231	2010	1,5873316	0,19841645	0,7936658
4688	4560	1,67235495	0,20904437	0,83617747
1490	969	1,7	0,2125	0,85
5633	1495	**1,73797266**	0,20446737	0,86898633
4400	4400	**1,75204545**	**0,29200758**	**0,87602273**
3700	3624	**2,15378378**	**0,3076834**	**1,07689189**
754	700	**2,36206897**	**0,29525862**	**1,18103448**
5380	3711	**2,45892193**	**0,30736524**	**1,22946097**
1300	1300	**2,47769231**	0,16517949	0,82589744
3730	3434	**2,7536193**	**0,34420241**	**1,37680965**

Table 24: Datable used to find the spread of percentage of emission that come from the 6 large contributors to road construction infrastructure projects. The same datatable, paired with all the other information from each project can be found in the databank:

%Constr. Eq.	% Concrete	% Asphalt	% Steel	% Transport	% Explosives	% The rest
17,4%	46,5%	2,9%	9,9%	1,7%	0,0%	21,5%
22,7%	1,4%	14,5%	2,1%	30,9%	20,6%	7,8%
47,8%	6,7%	30,7%	4,4%	5,9%	0,0%	4,4%
33,2%	10,4%	26,7%	5,6%	11,9%	0,2%	12,0%
33,7%	4,0%	9,2%	14,1%	21,5%	12,8%	4,7%
63,8%	2,5%	14,1%	2,4%	8,4%	0,0%	8,8%
61,2%	2,4%	10,0%	0,6%	3,6%	0,0%	22,2%
50,5%	4,6%	10,3%	0,0%	5,6%	0,2%	28,9%
42,5%	16,8%	13,2%	2,4%	7,2%	0,0%	18,0%
22,7%	1,3%	24,7%	4,2%	5,1%	10,1%	31,8%
51,2%	4,7%	13,4%	2,6%	8,1%	0,8%	19,3%
46,8%	0,0%	13,5%	6,7%	10,0%	13,9%	9,2%
50,7%	4,7%	8,2%	5,9%	19,5%	6,8%	4,2%
59,1%	2,3%	10,5%	2,9%	10,0%	11,5%	3,7%
45,4%	10,6%	6,1%	3,0%	9,9%	0,2%	24,7%
25,7%	42,5%	3,5%	5,4%	7,0%	10,0%	5,9%
45,1%	1,2%	21,2%	3,2%	6,4%	2,7%	20,3%
52,5%	2,1%	27,3%	2,5%	3,4%	6,0%	6,2%
22,0%	44,5%	8,5%	4,5%	5,7%	9,1%	5,7%
37,6%	5,5%	24,9%	3,0%	12,5%	5,1%	11,4%
39,8%	4,0%	21,0%	3,8%	3,4%	8,3%	19,7%
58,5%	7,2%	8,9%	5,3%	8,0%	4,3%	7,9%
29,1%	31,6%	8,2%	10,3%	7,6%	9,5%	3,7%
46,8%	1,4%	15,9%	3,5%	20,0%	11,2%	1,2%
51,5%	3,7%	18,9%	1,8%	9,5%	4,3%	10,4%
22,6%	36,7%	9,6%	7,7%	4,4%	9,9%	9,1%
34,1%	6,6%	6,9%	9,7%	9,2%	11,3%	22,1%
42,8%	32,1%	3,8%	5,2%	1,6%	7,7%	6,8%
12,8%	33,2%	3,6%	28,4%	2,9%	5,4%	13,8%
45,1%	1,2%	16,2%	2,2%	16,2%	9,4%	9,7%
53,2%	5,2%	17,0%	4,9%	5,4%	3,4%	11,0%
35,7%	13,1%	5,7%	12,1%	5,6%	3,4%	24,4%
23,9%	22,8%	8,6%	4,6%	14,4%	6,8%	18,9%
48,3%	13,8%	13,1%	3,9%	6,8%	0,0%	14,1%
28,8%	16,3%	5,9%	11,4%	16,2%	8,2%	13,1%

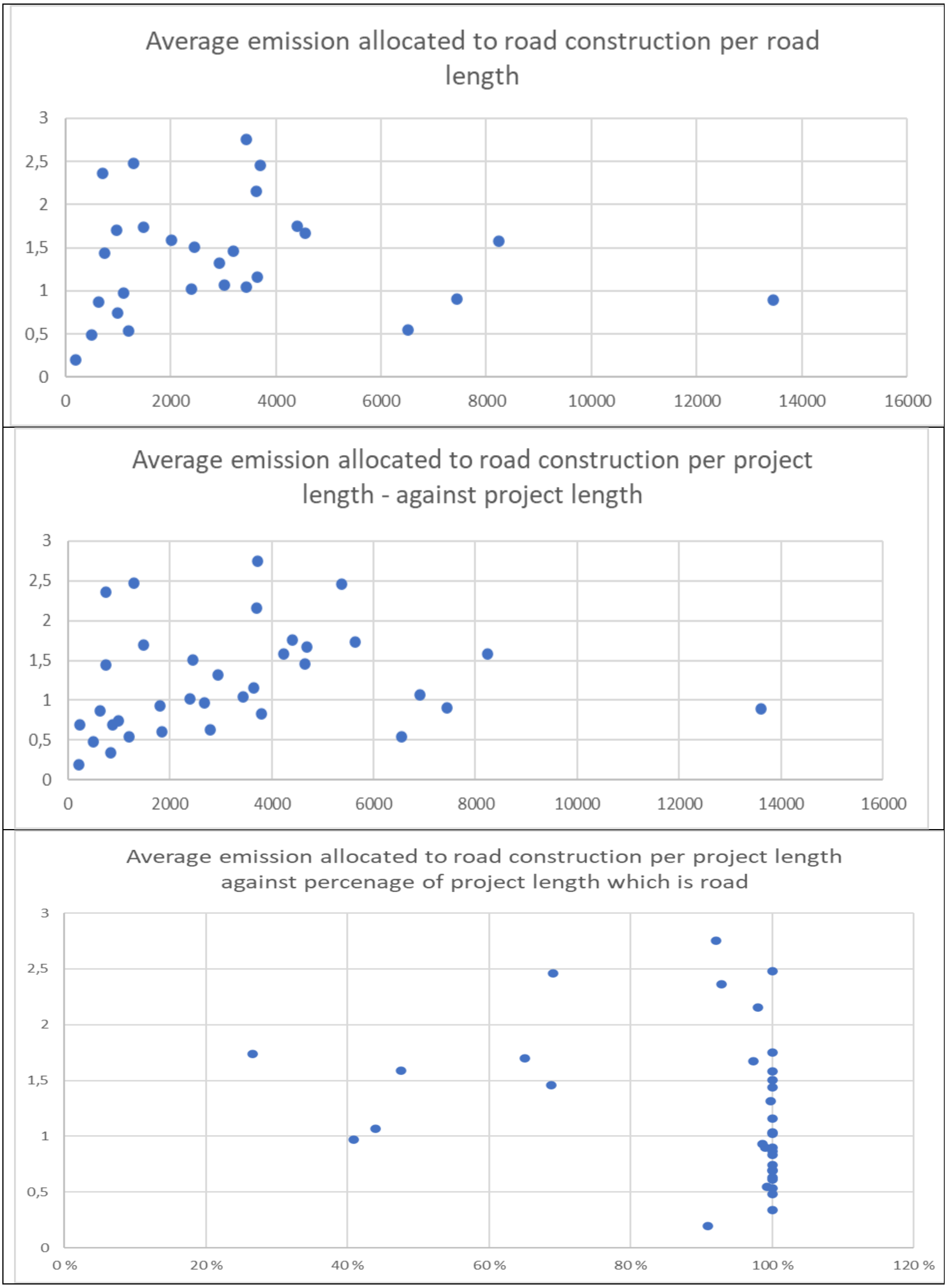

Figure 65: Here we have plotted the average emissions from road construction per road, against road length, per project length and against road: tunnel/bridge percentage.

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Emissoin Profile of Norwegian County Roads

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Kunnskap for en bedre verden