NTNU – Trondheim
Norwegian University of
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Life Cycle Assessment of High Speed Rail Electrification Systems and Effects on Corridor Planning

Babak Eslami Ebrahimi

Master in Industrial Ecology
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Supervisor: Helge Brattebø, EPT

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

NTNU
Norwegian University
of Science and Technology

Department of Energy
and Process Engineering

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MASTER THESIS

for

Student Babak Ebrahimi

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Life cycle assessment of high speed rail electrification systems and effects on corridor planning
Livsløpsanalyse av elektrifisering av høyhastighetstog og effekter på korridor planlegging

Background and objective

Significant investments in upgrading and new construction of railway infrastructure are either planned or suggested for the coming decades. The biggest of these being the potential development of a high speed rail network connecting the major cities in Norway, with cost estimates above 1 000 billion NOK. LCA of railway infrastructure in Norway has only started to gain ground in the recent years, and with the main focus being on the large material inputs like concrete and steel, and associated emissions of climate gases.

The student has in his fall project developed an inventory for railway electrification and for associated components and subsystems. The inventory also distinguishes between different design speed systems. The objective of this master thesis is to contribute to the understanding of environmental impacts from electrification components by doing an LCA on a selection of corridor alternatives from the Norwegian high speed rail assessment with an updated and improved inventory for the electrification system. The results should assess the effects of using a more detailed inventory for the electrification system, including the differences due to different systems in tunnels and open sections (which were not differentiated in the original assessment).

The high speed rail assessment only included climate emissions. In the report, the student should evaluate other impact categories, as described in the PCR framework for transport infrastructure, mainly focusing on the effects of the electrification system and the difference between the electrification inventories. Results should also focus on resource use for relevant materials. The occurrence of some materials in a wide range of installations can make the material input significant when added up.

Furthermore, the student should evaluate the effects of route planning options, with respect to both design speed and infrastructure section types.

The following tasks are to be considered:

1. Improve and complement the existing electrification inventory to include missing components of significance. Expand the inventory to include maintenance and operation, as well as end-of-life scenarios.
2. Implement the new electrification inventory for a selection of lines from the Norwegian high speed rail assessment. Compare the results and identify main differences, and in particular the effect of having specific inventories for different section types.
3. Expand the high speed rail corridor results to include the full range of impact categories from

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the PCR framework, with emphasis on the contribution from the electrification system.

4. Identify important material flows related to electrification and their potential environmental impacts
5. Apply the inventory and results to evaluate the impacts on route planning, i.e. how composition of corridors in terms of section types and design speeds affect the results. Identify potential trade-offs.
6. Discuss the overall findings of your work, strengths and weaknesses of your methods and data, and possible practical and/or methodological implications and recommendations of your work.

Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his/her project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analysed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 24th February 2014

Olav Bolland
Department Head

Helge Brattebø
Academic Supervisor

Research Advisor: Håvard Bergsdal, MiSA

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Babak E. Ebrahimi,

Trondheim, July 2014.

Abstract

Different environmental analyses are so far allocated to assess emissions corresponding to high-speed rail infrastructure in era of environmental concern for maximize mobility and accessibility. However, electrification of HSR due to various components is intricate and roughly in detail in existing inventories. Predominantly, this is due to this fact that the existing inventories associated to HSR infrastructure focus on climate gases that lead to concrete and steel as the dominant input materials.

Life cycle assessment (LCA), as a useful tool in evaluation of environmental impacts related to products and/or activities, can be helpful to deliver a better understanding of a defined system and later on can assist in decision making (by comparing alternative cases with each other).

In this thesis, a complete LCA of HSR electrification is performed under PCR guideline that embraces a 60-year lifetime with a functional unit of one kilometer for three life cycle phases that are: construction, maintenance & renewal, and disposal. The results from this study are shown in six-impact categories (with two additional impact categories that are not mentioned in the PCR guideline). In addition, the results from the LCA of HSR electrification are applied to 12 alignments (as a projection of environmental analysis of Norwegian HSR) to illustrate the effect of HSR electrification on corridor planning.

Regardless of results for either the functional unit of one kilometer or corridor planning, the relative results show that construction and maintenance & renewal by far are the main sources of potential impacts, and disposal (due to only transport of materials for their end-of-life treatment) has a fraction of impact through the entire lifetime of HSR electrification in all the six-impact categories. The main input materials associated with high impacts in electrification of HSR infrastructure are: copper, diesel, aluminium (cable), steel (low-alloyed), and UPS (batteries) that for different impact categories and life cycle phases the effect from each input material is varying. Copper projected that it has the highest contribution in impact categories human toxicity, metal depletion, freshwater eutrophication, and terrestrial acidification in both construction and maintenance & renewal. Aluminium (cable), and steel (low-alloyed) perform their highest contributions in impact categories climate change and photochemical oxidation formation in the construction phase; however, diesel shows a high impact in the same impact categories (as they are the same for aluminium (cable) and steel (low-alloyed)) in the maintenance & renewal phase. Moreover, UPS (batteries), due to having (relatively) high amount of lead, corresponds to high impact in impact categories terrestrial acidification, climate change, and photochemical oxidation formation in the maintenance & renewal life cycle phase.

The study also considers the effect of section type and design-speed for the LCA of HSR electrification. It shows that the potential impact (for the most six-impact categories) in a kilometer of tunnel section for system of design-speed Re330 (for the speed up to 330 km/h) is higher than a kilometer of open section for system of design-speed S25 (for the speed up to 250 km/h). In this study, the effect of increase in the resolution of HSR electrification with the previous study of NHSR by Asplan Viak AS in corridor planning is compared that corresponds to increase in potential impacts in all the six-impact categories, which the highest effects are related to impact categories human toxicity, freshwater eutrophication and metal depletion.

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Abbreviations

AP	acidification potential
AT	autotransformer
CADP	Chinese Abiotic Depletion Potential
CC	climate change
CLCD	Chinese Life Cycle Database
COD	chemical oxydation demand
EP	eutrophication potential
EPD	Environmental Product Declaration
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
FE	freshwater eutrophication
FEP	freshwater eutrophication potential
F.U.	functional unit
GHG	greenhouse gas
GSM-R	Global System for Mobile Communications - Railway
GWP	global warming potential
HSR	high-speed rail
HT	human toxicity
HTP	human toxicity potential
ILCD	The International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
JBV	Jernbaneverket (The Norwegian National Rail Administration)
LCA	life cycle assessment
LCI	life cycle inventory
LCIA	life cycle impact assessment
LCGHGA	life cycle greenhouse gas assessment
M&R	maintenance & renewal

MD	metal depletion
MDP	metal depletion potential
NHSR	Norwegian high-speed rail
NTP	National Transport Plan
O.S.	open section
PCR	Product Category Rules
PED	primary energy demand
POF	photochemical oxidation formation
POFP	photochemical oxidation formation potential
RI	respiratory inorganics
TA	terrestrail acidification
TAP	terrestrial acidification potential
T.S.	tunnel section
UIC	International Union of Railways

Chapter 1

Introduction

At the present time, we are reaching to a critical point as the outcome of attempting to sustain and preserve the environment and alleviate unfavorable anthropogenic activities through material and energy consumption. The issues can lead to adverse problems that can be either well understood or less understood, from local to global pollution, because of resource extraction, manufacturing of products, use, recycling, end-of-life treatment and disposal. (Bergsdal 2009, ISO 2006b)

This thesis entitled "Life cycle assessment of high-speed rail electrification systems and effects on corridor planning" is the outcome of graduation procedure for the Master's degree program in Industrial Ecology at the University of Science and Technology (NTNU). The thesis is carried out within MiSA[1] - Asplan Viak AS[2] that has been involved in different environmental analysis projects.

The structure of this chapter tries to make a clear perspective of this thesis topic by the following sections. Section 1.1 brings background information about studies related to railways and high-speed rails. Section 1.2 describes the aim and motivation of this research. Then, section 1.3 concludes chapter 1 by projecting the outline of different chapters in the thesis.

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[1] http://www.misa.no/

[2] http://www.asplanviak.no/

1.1 Background

In consequence of globalization and increase in transportation, there has been an increase in amount of greenhouse gas (GHG) emissions since 1970. (MARTÍN 2011) However, according to a UIC study in 2007, railways only have a contribution of 1.6% (from the operation phase) in GHG emissions from transportation sector. (Community of European and International Union of Railways 2008) In addition, the European Commission in the report entitled “Transport 2050”, as a plan to increase mobility and reduce emissions in 2011, mentioned one of the goals is to shift from road to rail transport. (European Commission 2011)

Despite all attempts that have been done to reveal environmental benefits that can be harness from operation phase of railways, construction phase is a step that is often forgotten to con-sider in the environmental assessment. (Baron, Martinetti, and Pépion 2011) In recent years, we have been a witness of more and more recognitions allocated to environmental assessments associated with transport infrastructure, and life cycle analysis (life cycle assessment, LCA) studies of railway, which projected infrastructure has a remarkable effect in the entire life cycle assessment. (E. Ebrahimi 2014, Stripple and Uppenberg 2010, Bergsdal et al. 2012) Especially by the time that electricity mix for the operation phase of railways has a low carbon footprint. (Grossrieder 2011)

Various criteria should be taken in to account to ease maximize mobility and accessibility in an era of environmental concern. (Chester and Ryerson 2014) High-speed rail[3] (HSR) - with a service speed that exceeds 250 km/h - is considered as a noticeable discovery in passenger transportation system. The first service line started in Japan in 1964 and European passenger kilometer reach to ca. 90 billion in 2006. (Åkerman 2011, Campos and de Rus 2009)

In 2010, the Norwegian National Rail Administration (Jernbaneverket, JBV) through a commissioning from the Norwegian Ministry of Transport and Communications[4] (Samferdselsdepartementet) started a set of feasibility studies upon new HSR in Norway. (Svingheim 2012) The feasibility study covered financial cost, social and environmental impacts of future HSR and showed multiple benefits

[3] Appendix A mentions the story of “From Steam to HSR”

[4] The Norwegian Ministry of Transport and Communications published a white paper entitled “National Transport Plan (NTP) 2014-2023” with the aim of development of a modern transportation system by means of limitation its environmental impact to assist Norway to have a progression towards of being a low-carbon nation. (Norge 2013)

of HSR in Norway. Such advantages are reduction in travelling times, decreasing greenhouse gases (GHG), increasing accessibility between major cities and so forth. (Grossrieder 2011)

1.2 Aim and motivation

So far, various studies have been dedicated to high-speed rail; however, few of them try to assess the environmental performances of HSR electrification (that they will be described in the next chapter). LCA is a useful tool and the results from it can be helpful in decision-making; because, the outcomes of environmental analyses in diverse alternatives could be compared with each other by means of LCA. (Fuglseth 2013) However, definition of systems could vary due to different criteria in the goals and scopes of studies. For instance, the previous project of corridors planning (Bergsdal et al. 2012) focused only on GWP and not other impact categories were considered. The results showed that emissions from the infrastructure are mostly dominated by large material quantities like concrete, steel etc. due to construction of tunnels and bridges. Nonetheless, electrification of railway infrastructure is large and complex that necessitates crudely detailed input material inventories and development of assessment for more than global warming potential.

In addition to the issue of impact categories selection, in the previous study that carried out by (E. Ebrahimi 2014), it became noticeable that different systems of design-speeds in different section types (on a kilometer basis) perform differently due to alteration of required input materials. This problem can be influential to the life cycle assessment of HSR electrification in corridor planning due to different composition of alignments.

The goal of this thesis is to provide environmental information about electrification of high-speed rail and present the effects on selected HSR alignments in Norway as detail as possible. However, the aim of this study is not to compare the results with other means of transportation systems. In addition, this research was not exempted from having limitations. Some of the limitations that this thesis was dealing with will be mentioned, as this study is going further. The goal and scope of this research can be summarized as following:

> *The goal and scope of this study is to evaluate environmental impacts of electrification of high-speed rail infrastructure in the PCR framework. In addition, the study should projects the effect of route planning according to design speeds and section types.*

Research questions

The following questions are aimed to be answered at the end of this thesis.

- What are the contributions of HSR electrification in a kilometer of a railroad?
- What is the share of construction and maintenance in a kilometer and alignment in the LCA of HSR electrification?
- What are the differences between the different design-speeds?
- What is the contribution of HSR electrification in different corridors?
- What are the differences between new electrification and previous study of NHSR (Bergsdal et al. 2012)?

1.3 Outline of Thesis

To perform a satisfactory research on the stated goal and scope of this thesis, the following procedures are taken:

Chapter 2: Literature review

The first stage of this thesis after the introduction is dedicated to review the existing literatures related to the topic of high-speed rail electrification in chapter 2. The chapter also shows what

Chapter 3: Methodology

Chapter 3 describes LCA methodology and background theory of life cycle assessment, together with explanation of SimaPro, ecoinvent database, and product category rules (PCR) guideline.

Chapter 4: Case study and solution approach

The introduction of this chapter starts with a solution procedure that is devote to perform the life cycle analysis by explaining functional units, system boundary, and life cycle phases. In the continuation of the chapter, a structure of LCA of HSR electrification is presented with explanation of collected data (that comprised of components, assumptions, and input materials) that are made for the setup of the life cycle inventory (LCI).

Chapter 5: Results

Based on the explanation from chapter 4 and setup of life cycle inventory (LCI), chapter 5 is devoted to results from life cycle impact assessment (LCIA) under PCR framework. In addition to the LCIA results, two additional sections are dedicated to corridor planning and sensitivity analysis. In the corridor planning the results from the thesis is compared to the NHSR study (Bergsdal et al. 2012) to show the results variations due to higher resolution of this study, and sensitivity analysis projects how responsive the results are to the important input materials.

Chapter 6: Discussion

In chapter 6 discusses the main findings of the research by highlighting whether the study reached its goal or not, and shows what the finding agreements are with the literatures (that is explained in chapter 2). Moreover, the quality of data and emission processes/sources corresponding to important input materials are discussed. Furthermore, a section at the end of the chapter is devoted to implication for development and progression of future study on LCA of HSR electrification.

Chapter 7: Conclusion

The LCA of HSR electrification is concluded in chapter 7 by explaining the essence of this thesis.

Chapter 2

Literature review

Environmental assessment of railways has been done for years and different criteria have been the reasons of evaluations. For instance, some studies evaluated environmental impacts related to railways components such as railway sleepers and tracks, (Werner and Schrägle 2008, Christopher and Stephen 2013, Botniabanan AB 2010c, Ovedal et al. 2012, Kiani, Parry, and Ceney 2008), some were related to structures like bridges and tunnels (MARTÍN 2011, Botniabanan AB 2010d, b) and some have done assessments to describe environmental performance of rolling stocks (Lee et al. 2010, BOMBARDIER 2012, Alstom 2006).

This chapter is aiming to mention some literatures associated with HSR in section 2.1, and at the end, making a summary in section 2.2 to indicate what are the missing parts in these literatures, which are aimed to be covered in this thesis.

2.1 LCA of HSR electrification

As it mentioned before, due to requirement for high-speed rail, studies have been done to show the benefits that can be taken by means of HSR. So far, many studies have been developed upon environmental assessment of HSR. Some tackled benefits that may be harnessed by means of HSR in comparison with other transportation systems (Åkerman 2011, Chester and Ryerson 2014, Mikhail and Arpad 2010) and some evaluated environmental impacts related to infrastructures (Kato et al. 2005, Morita et al. 2011). However, a few of them try to address the environmental impacts related to HSR electrification. In this thesis, an attempt has been made to highlight studies structured on HSR systems and show how many of them delivered assessments according to HSR electrification.

Life cycle assessment of China's high-speed rail systems (Yue 2013): Ye Yue makes an LCA study for a new HSR in China between Beijing and Shanghai for three life cycle stages: LCA of trains, construction of HSR infrastructure, and operation phase of HSR. The study uses LCA software eBalance[5] by means of China's national background LCI database (Chinese Core Life Cycle Database, CLCD) and mentions environmental impacts related to the assessment for different some collected impact categories (AP, CADP, PED, COD, EP, GWP, and RI). The impact assessment methods include CML 2002, ISCP 2010, IPCC 2007 and IMPACT 2002+.

Life cycle greenhouse gas assessment of infrastructure construction for California's high-speed rail system (Chang and Kendall 2011): Brenda and Alissa provid an estimation of life cycle greenhouse gases assessment (LCGHGA) related to construction of a new HSR between San Francisco and Anaheim for a distance of 725 kilometers. The analysis characterizes construction of track bed, HSR electrification, earthwork operation, and bridge and tunnel structures; and shows the emissions. The study tracks emissions from CO_2, CH_4 and N_2O by means of IPCC 2007 impact assessment method in kg of CO_2 eq. for the estimated time horizon of 100 years.

Based on the results of LCGHGA, construction of high-speed rail infrastructure results in 2.4 million metric tons of CO_2 eq. that 69610 tons of CO_2 eq. is associated with electrification of the line.

Environmental budget of the Follo Line – tunnel section (Miljøbudjett for Follobanen – tunnelstrekning): (Ovedal et al. 2012) COWI AS on behalf of the Norwegian National Rail Administration (Jernbaneverket, JBV) was in charge of building a report based on environmental performance of the Follo Line (tunnel section) infrastructure for a distance of 20 kilometers. The project delivered in 2012 that is comprised of life cycle assessment of construction, operation & maintenance, and waste/disposal of infrastructures in a 60-year lifetime. In the assessment, some data came from the early planning study that has been estimated by Asplan Viak AS (such as diesel consumption for the construction, maintenance and end-of-life).

[5] LCA software that is developed by IKE Environmental Technology Co. Ltd.

However, some parts updated such as power supply, grounding, and telecommunication system.

Environmental budget of the Follo Line – Introduction to Oslo S (Miljøbudjett for Follobanen. 2012. JBV – Innføring Oslo S): (AAS-JAKOBSEN 2012) As a follow-up project for the Follo Line that has been done by Asplan Viak AS (Bergsdal, Graarud, and Holen 2011), AAS-Jakobsen and ViaNova-nettverket were in charge of detailed planning of Oslo section (Introduction to Oslo S) to report environmental performance of the Follo Line. The length of tracks was adjusted to 9.3 kilometers that is 33% increase compare to the main project (Bergsdal, Graarud, and Holen 2011).

The report divided electrification of entrance to Oslo S into five classes: overhead contact system, power supply, signaling, telecommunication and other technical equipment. It presents that ca. 30% of impact is coming from overhead contact systems and about 60% is from power supply.

Life Cycle Assessment of the Follo Line – Infrastructure (New Double Track Line Oslo – Ski): (Bergsdal, Graarud, and Holen 2011) The LCA of the Follo Line – Infrastructure that was completed by Asplan Viak AS on behalf of the Norwegian National Rail Administration (Jernbaneverket, JBV) was the initiated project from the Ministry of Transport and Communications in the National Transport Plan 2010-2019. The aim of the project is to report the climate and environmental impacts of the Follo Line that has the total length of 66 kilometers, which 40 kilometers of the length is passing through a twin-bored tunnel (20 kilometers for each tunnel). (Haugnes 2011)

The study provides a concrete analysis by means of PCR framework in a 60-year of lifetime and provides the results for the entire life cycle that are: construction, maintenance, maintenance waste, and disposal. In addition, the results show that blasting, diesel, concrete and steel are the material that have significant impact in the study. Moreover, components related to the line electrification are also considered.

Environmental analysis - Norwegian High Speed Rail Project (Phase 3): (Bergsdal et al. 2012) Asplan Viak AS, with partnership of MiSA AS, VWI GmbH, Brekke & Strand Akustikk AS and Asplan Viak Internett AS, was hired by the Norwegian Rail Administration (JBV) to conduct the phase 3 of project "Environmental Analysis" for Norwegian high-speed rail. PhD Håvard Bergstal (from MiSA AS) performed the assessment over a 60-year period of GHG emissions (based on the unit of kg of CO_2 equivalent) for HSR infrastructure and transportation, and alternative transportations. The analysis also presents the payback time of different HSR alignment alternatives.

The report is carried out for four corridors (12 HSR alignments in total) and it presents alignments Ø2:P, Ha2:P and N1:Q have a better performance in GHG reduction and payback time.

Life cycle assessment of railways and transports - Application in environmental product declarations (EPDs) for the Bothnia Line: (Stripple and Uppenberg 2010) LCA of the Bothnia Line (Bothniabanen) project was carried out by three organizations[6] through the construction phase of project in order to address energy and environmental aspects and to develop a certified EPD for of the line. The Bothnia Line is a single-track railway located in Sweden that connects Nyland (north of Kramfors) to Umeå. The line has the total track length of 209 kilometers and is designed for a maximum operation speed of 250 km/h. The project performed the assessment in a lifetime of 60 years for seven sub-models of the system by means of KCL-ECO LCA software.

Here, electrification model is the concern of this thesis that is entitles as "*Railway electric power and control system model*". The sub-model is divided into three sub-systems:

- The electric power supply for train operation
- Train control systems
- Telecommunication systems

Life-Cycle Considerations for Environmental Management of the Swedish Railway Infrastructure: (Svensson 2006) Niclas makes a study upon environmental impacts related to material and energy inputs in Swedish railway infrastructure to implement a strategic environmental management. The results from the study answers questions related to environmental impacts from materials by means of five papers. The study shows the relation between material use[7] and material-related

[6] IVL Swedish Environmental Research Institute, Botniabanan AB, and the Swedish Rail Administration

[7] Six materials were considered in this study that are aluminum, concrete, copper, crushed rock, steel/iron and zinc

energy use, and mentions how few products contribute the most. It also presents that railway infrastructure is more energy intensive compare to road infrastructure.

The study makes a good generic environmental assessment of material use and material-related energy use for Sweden and it also mentions what the energy-related use of electrification would be from a line

Carbon Footprint of High Speed Rail: (Baron, Martinetti, and Pépion 2011) The study mentions the carbon footprint of high-speed rail through the construction phase and shows, in accordance with their statistics in 2011, what modules are shared between all HSR systems. The methodology of study is in accordance with PCR for rail infrastructure and rail vehicles and the system boundary is carried out "from cradle to grave", which means it is comprised of conception, construction, operation, and disposal life cycle phases. In addition, the study shows a clear picture of data sources that have been selected from ecoinvent v2.0

"Equipment for energy transmission and telecommunication" is the relevant part of the study to HSR electrification that is consist of catenary post, aerial contact line, substation of the power system, communication/signaling system, transport to construction site, and signalization signs/boards. Furthermore, the study shows the emission from electrical equipment for the construction phase of a single-track in a kilometer is about 3.5 tons eq. CO_2 per year.

However, the study does not distinguish between emissions from open section and tunnel section. Catenary posts also have over one-third of emission compare to the other mentioned components (that gives this hypothesis in accordance with the results from) that the assessment is for a kilometer of open section.

2.2 Summary

This section presents an overview of literatures that have been explained in the previous section by projecting the missing parts of their studies that are aimed to be covered/answered in this thesis. Table 2.1 shows the names' and shortcoming of mentioned studies in section 2.1.

NB. One limitation that all of these studies do have in common is the factor of design-speed that is not taken into consideration. In fact, in a line there are different compositions such as urban area or rural areas and some other regulations related to the speed-design, which could result in alteration of input materials. (Haugnes

2011) In addition, figures in NHSR report show how along each alignment speed changes. (Bergsdal et al. 2012, Atkins 2012)

Table 2.1: Summary of literature review.

Study (reference)	**Limitation(s)**
Life cycle assessment of China's high-speed rail systems (Yue 2013)	Although the study mentions environmental impacts related to some materials for different impact categories, it does not explain that how construction of HSR infrastructure (especially in electrical equipment) is structured. Generally, it does not mention how the assessment has been done for each stage of the study.
Life cycle greenhouse gas assessment of infrastructure construction for California's high-speed rail system (Chang and Kendall 2011)	It only covers steel masts and contact wires as electrification parts of HSR in the study and does not considered other parts of HSR electrification such as tensioning section, grounding, power supply etc.
Environmental budget of the Follo Line – tunnel section (Miljøbudjett for Follobanen – tunnelstrekning): (Ovedal et al. 2012)	In spite of utilization of some data from this report (that are noted in table 4.5, chapter 4), two problems are related to this study. First, it dose not make it clear if the telecommunication system is built based on ERTMS Level2. Second, it dose not adjust use of steel high quality that was used in the LCA of Follo Line report. (Bergsdal, Graarud, and Holen 2011) Based on a communication with PhD Håvard Bergsdal, utilization of steel high quality was overestimated for some parts of assessment in the Follo Line LCA project (Bergsdal, Graarud, and Holen 2011)) that it is needed to be adjusted for the future use of related studies. (Bergsdal 2014)
Environmental budget of the Follo Line – Introduction to Oslo S (Miljøbudjett for Follobanen. 2012. JBV – Innføring Oslo S)	Telecommunication and signaling systems were contributing in a small extent that is the opposite of the results from the other reports, especially in COWI report (Ovedal et al. 2012) that telecommunication due to UPS batteries contribute considerably. Also, it dose not make it clear if the telecommunication system is built based on ERTMS Level2. Moreover, and the study does not have detail data for OCS.
Life Cycle Assessment of the Follo Line – Infrastructure (New Double Track Line Oslo – Ski): (Bergsdal, Graarud, and Holen 2011)	The results of line electrification has a small contribution with respect to the total environmental impact due to the selection of impact categories and the study does not have detail data for OCS. *Despite of small contribution from the Follo Line electrification, it was noted that the results of electrical installations (due to toxic effects) might show different potentials within certain impact categories.*

Environmental analysis - Norwegian High Speed Rail Project (Phase 3): (Bergsdal et al. 2012)	The results of assessment are based on green house gasses emissions and global warming potential, and the study does not consider other impact categories in the assessment of NHSR.
Life cycle assessment of railways and transports - Application in environmental product declarations (EPDs) for the Bothnia Line:	The study is done a concrete assessment for the new HSR line in Sweden; however, it shows the results in all sub-models based on emission sources related to the infrastructure input materials and it does not show the impact assessment associated with the input materials and energy.
Life-Cycle Considerations for Environmental Management of the Swedish Railway Infrastructure: (Svensson 2006)	It does not show the results based on environmental impact categories. Also, the study does not make a clear review of the top materials contribution through the lifetime of infrastructure and does not describe how the effect of materials could vary through different life stages of infrastructure. In addition, it is no clear if the assessment is done for virgin materials, secondary materials or a mix of both.
Carbon Footprint of High Speed Rail: (Baron, Martinetti, and Pépion 2011)	The study does not distinguish between emissions from open section and tunnel section. Catenary posts have over one-third of emission compare to the other mentioned components (that gives this hypothesis in accordance with the results from the semester project (E. Ebrahimi 2014)) that the assessment is only verified for a kilometer of open section.

Chapter 3

Methodology

3.1 Life Cycle Assessment

The first steps towards environmental assessment with the name of life cycle assessment commenced in the late 1960s. The purpose was to address impacts related to products and/or activities, and to have a better understanding. (ISO 2006b) However, due to a requirement for having a holistic perspective for environmental assessment, the new model of LCA started to form in the early 1990s. (Nes 2012)

LCA presents environmental aspects and impacts through life cycle of a product. The life cycle can be production, use, recycling, end-of-life treatment and disposal. A four-steps of an LCA study is shown in figure 3.1. (ISO 2006b)

Goal and scope definition

"The goal and scope of an LCA shall be clearly defined and shall be consistent with the intended application. Due to the iterative nature of LCA, the scope may have to be refined during the study" (ISO 2006a) The first step towards a life cycle assessment is to define what the goal and scope is. Various purposes might be the reasons for the assessment like documentation of environmental impacts from a product, comparing environmental impacts from different products, labeling etc.

(European Commission 2010) The goal of an LCA should make it clear the reason and objective of performing the analysis, and moreover, state who shall be involved and interested in the analysis (audience and stakeholders). (Ibid)

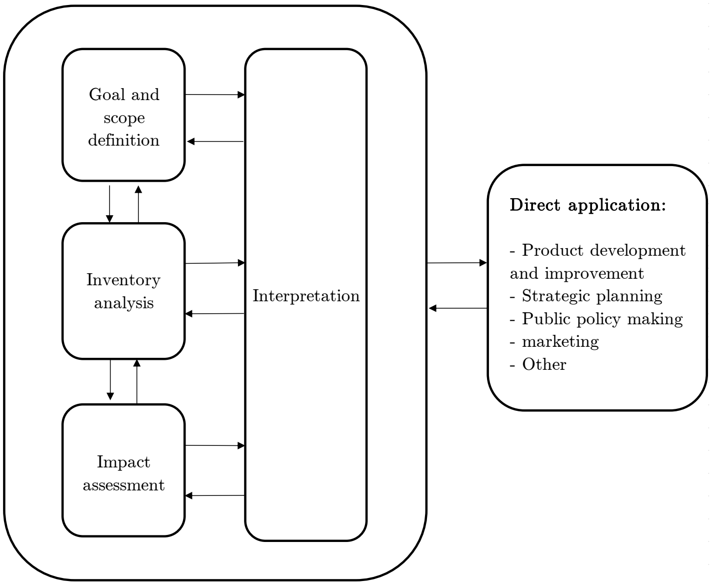


Figure 3.1: Stages of an LCA. (ISO 2006b)

The scope should be so adequate to address the mentioned goal by means of a system boundary, a functional unit, selected impact categories, allocation and methodology. In addition, it addresses the limitation and assumption. (Wolf et al. 2012, European Commission 2010)

The functional unit is stated as "The quantified performance of a product system for use as a reference unit". (ISO 2006a) It shall be identified and specified in detail (such as location, quality and duration of function) to make a basis for comparison among different alternatives and at the same time be neutral to alternatives. (European Commission 2010)

Inventory analysis

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle." (ISO 2006b) LCA is a data intensive study that requires data collection to derive an analysis to quantify input flows and output flows. Sources of an inventory can be databases, statistical data, environmental product declarations, and data from manufacturers and suppliers that are used in a set of unit processes within the system boundary. (Fuglseth 2013, European Commission 2010) If unit processes give several product outputs, allocation procedure or other techniques is needed to designate the environmental inputs or output flows of a process or a product system to product system under study. Utilization of LCA software and databases help to reduce time and complexity of work. LCA databases are typically address the average data for technologies that are generic and not specific for the given product system. (Solli 2004, Fuglseth 2013, Brattebø 2011)

Impact assessment

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the produce." (ISO 2006b) NS-EN ISO 14044:2006 describes life cycle impact assessment (LCIA) in following steps: (European Commission 2010, ISO 2006a)

- Selection of impact categories: Different kinds of impact categories are available that describe environmental effects from a product system for different level. The selection of impact categories either should avoid problem shifting or should be clearly noted in the goal and scope description phase of an LCA i.e. carbon footprint analysis, which only includes greenhouse gas (GHG) emission and global warming. (Brattebø 2011)
- Classification: It classifies which environmental stressors are contributing to which impact categories, in other words, "assignment of LCI results to the selected impact categories". One environmental stressor can associate to different impact categories and multiply environmental stressors can contribute to one impact category.
- Characterization: It describes what the potential of each environmental stressor is with respect to equivalent units of midpoint impact categories. Each impact category has a specific equivalent unit. Calculation of each stressor varies between impact categories i.e. CH_4 has a characterization factor of 25 CO_2-equivalant with respect to global warming potential (GWP_{100}), but has a characterization factor of 0.010 NMVOC[6]-equivalent for photochemical oxidant formation potential ($POFP_{100}$). (Solli 2004, (c) PRe Consultants et al. 2013)
- Normalization, Grouping, and Weighting: Normalization describes various environmental impact categories in dimensionless values relative to some reference information to have a better insight into the relative magnitude for each indicator results. Grouping is allocation of impact categories into one

or more groups that it may include sorting and/or ranking in accordance with the goal and scope. However, in weighting procedure, normalized values are multiplied by a weighting factor.

Interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations." (ISO 2006b) Interpretation phase is a stage that has been involved through the entire LCA and it also interprets the results from the analysis. Interpretation should be clear and understandable for a reader to inform the robustness and any potential limitations (uncertainties, etc.) of analysis. In addition, it should perform conclusions and recommendations from the results. (Brattebø 2011)

3.2 Tools

SimaPro[8] and ecoinvent as a software program and a database, respectively, are used to evaluate the life cycle assessments in this thesis. SimaPro is a commercial tool that carries out life cycle assessments and performs the results in a qualitative and quantitative approach within the system boundary. (Bergsdal, Graarud, and Holen 2011) It allows users to build complex models of products and systems in a systematic and transparent way. (PRé Consultants 2013a) SimaPro also shares the data in two categories: specific data that are flow of materials and energy to a specific analysis, and generic data that are based on average data for technologies. (Fuglseth 2013)

SimaPro is developed by PRé Consultants and is continuously updated for the sake of developing inventory databases and characterization methods. (Bergsdal, Graarud, and Holen 2011) In addition, it lets the users to show the life cycle impact assessment among different methods like ReCiPe[9], CML, EPS, ILCD, Eco-indicator 99 and so forth. (Pré Consultants 2013b)

LCA is a data intensive study that requires high-quality databases. Through decades, many processes have been made and collected in various databases. However, it was a great opportunity to have all processes in one database that can

[8] http://www.pre-sustainability.com/simapro

[9] Here, ReCiPe (H) characterization method in accordance with the guideline is going to be used.

fulfill the correct model of industries. (Nes 2012) ecoinvent database is a comprehensive database with over 10000 processes that is developed and updated by ecoinvent center in Switzerland. (Pré Consultants 2013b) Processes are in a wide spectrum of fields like materials, energy, transport, chemicals, agriculture, etc. The background data in ecoinvent database is modeled based on average European production data and presented in unit processes. (Pré Consultants 2013b, Bergsdal, Graarud, and Holen 2011)

Use of parameters in SimaPro allows for the future development, For instance, having a dynamic model and calculation of various scenarios. Parameters can be defined and entered in three ways in SimaPro: general level, project level and process level. Based on the recommendation from the pilot project for the Follo Line that parameters should be used “either on the project and/or process level”. (Kjerkol, Amlie, and Dahl 2012)

There is no specific way that can be defined to show the results in SimaPro. In fact, depending on the analysis, a variety of ways is exciting to indicate LCIA in SimaPro that can fulfill the requirement. Normally, bar charts are the common way to illustrate assessments, but the indication can be done in pie charts, Sankey diagrams[10] (network tree) and so forth. Figure 3.2 demonstrates SimaPro’s user interface with an example of two graphs that can be made on SimaPro.

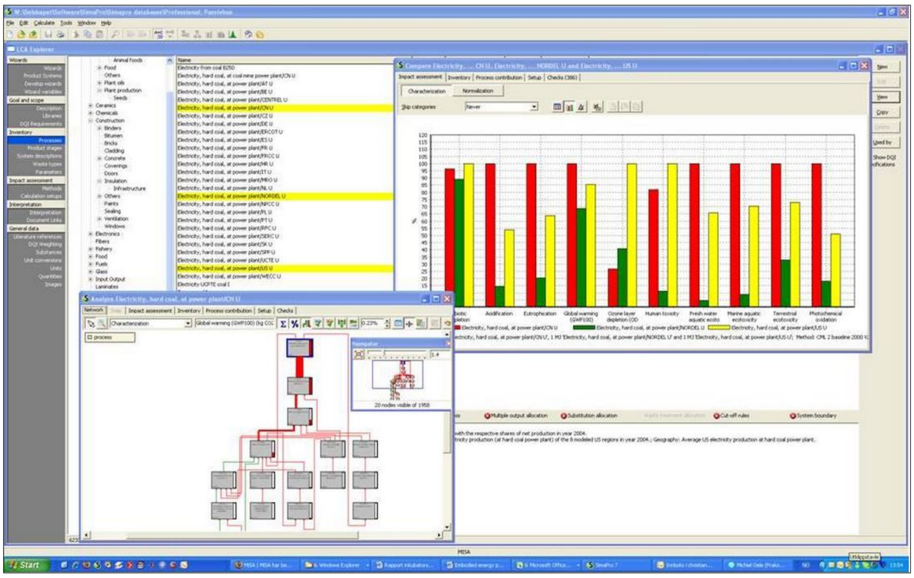


Figure 3.2: SimaPro interface, simulated screenshot from MiSA. (MiSA AS 2008-2014)

[10] In chapter 5 of this thesis (in figure 5-1), a schematic model of a Sankey diagram used in this research is shown.

3.3 Framework and guideline for railway infrastructure

Product Category Rules (PCR) are documents that mention what declarations should be considered by means of common and harmonized rules to ensure that similar procedures are taken to create EPDs. (The International EPD® System 2014, Fuglseth 2013) EPDs represent verified and relevant environmental data of products or services that are drawn up according to the international standards: ISO 9001, Quality management systems; ISO 14001, Environmental management systems; ISO 14040, LCA - Principles and procedures; ISO 14044, LCA - Requirements and guidelines; and ISO 14025, Type III environmental declarations. (The International EPD® System , WSP and Trafikverket 2013)

The LCA study in this thesis is structured in accordance with Product Category Rules of railways (PCR) UN CPC 53212 (subclass: railway electrification structures) that performs the analysis in accordance with a functional unit of 1 km of railway infrastructure (RI) through a lifetime of 60 years for the entire life cycle phases. (WSP and Trafikverket 2013) In fact, this functional unit does not take into consideration topography, states of local construction and so forth. (Bergsdal, Graarud, and Holen 2011) Service life is also included in the period of 60 years according to PCR; however, only those parts of service life are taken into account that happen within the 60-year lifetime.

In consonance with the guideline (WSP and Trafikverket 2013), four impact categories are noted. In addition to the four impact categories, it has been decided (based on a communication with PhD Håvard Bergsdal) to add two more impact categories that are Metal Depletion potential and Human Toxicity potential. Table 3.1 shows the impact categories with their associated details.

NB. ReCiPe (H) is the characterization method used in the analysis of this thesis.

Table 3.1: Overview of six midpoint categories and characterization factors. (Goedkoop et al. 2013)

Impact category			Characterisation factor	
Name	**abbr.**	**unit**	**Name**	**abbr.**
climate change	CC	kg (CO2 to air)	global warming potential	GWP
terrestrial acidification	TA	kg (SO2 to air)	terrestrial acidification potential	TAP
freshwater eutrophication	FE	kg (P to freshwater)	freshwater eutrophication potential	FEP
human toxicity	HT	kg (14DCB to urban air)	human toxicity potential	HTP
photochemical oxication formatio	POF	kg (NMVOC6 to air)	photochemical oxidant formation potential	POFP
metal depletion	MD	kg (Fe)	metal depletion potential	MDP

Figure 3.3 shows a system boundary of full life cycle assessment of railways in respect of PCR to indicate what sub-processes shall be included. (WSP and Trafikverket 2013, Bergsdal, Graarud, and Holen 2011)

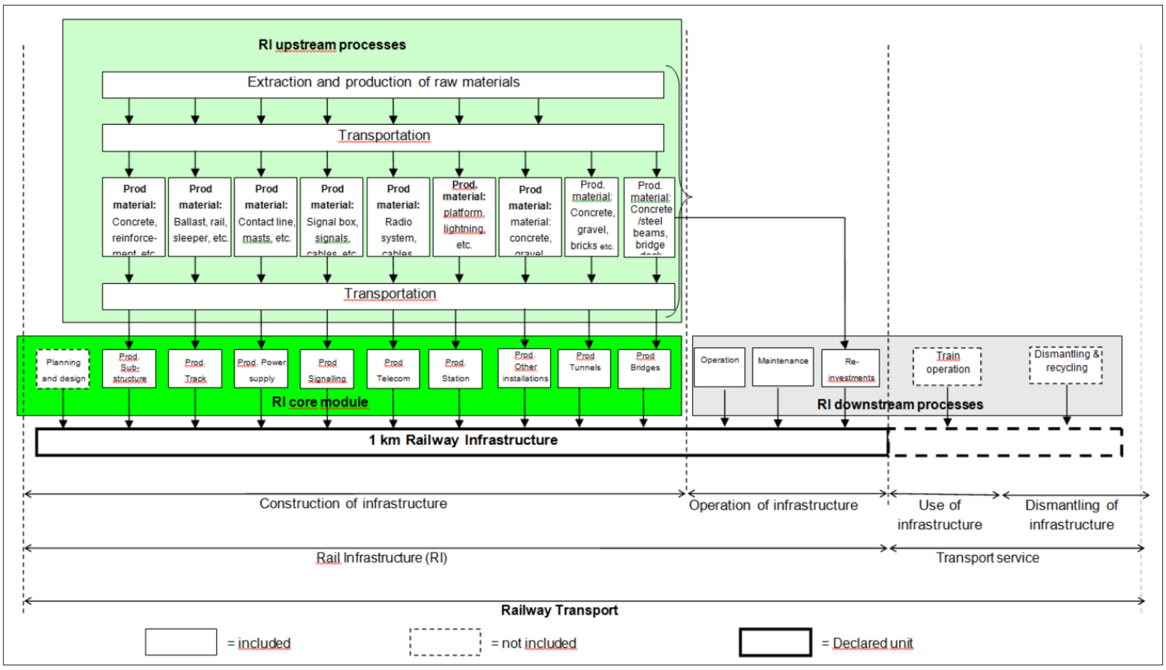


Figure 3.3: Flow chart of the system boundary for railway infrastructure (WSP and Trafikverket 2013)

Chapter 4

Case study and solution approach

4.1 Background

As it was mentioned in the introduction of this study (in chapter 1), JBV was mandated by the Norwegian Ministry of Transport and Communications to assess a set of feasibility studies of high-speed rails (HSR) in Norway. The aim of this assessment from the ministry perspective was to have an insight into, if changing in rail service could "contribute to obtaining socio-economically efficient and sustainable solutions for a future transport system with increased transport capacity, efficiency and accessibility". (Atkins 2012) In 2012, the assessment of 12 alternative alignments after two years completed.(Bergsdal et al. 2012) The center of all corridors (except Stavanger-Bergen (BS1:P) alignment) are anchored in Oslo and from Oslo, they are distributed to north, south, east and west. Table 4.1 shows how each alignment in terms of length and section types are characterized.

The semester project that was delivered by (E. Ebrahimi 2014) showed how the environmental performance of electrical equipment changed by means of design speed and section type variation (open sections and tunnel sections) with functional unit (F.U.) of one kilometer[11]. Nevertheless, in the previous study (entitled "Environmental Analysis of Norwegian High Speed Railway Project-Phase 3"

[11] In accordance with PCR of railway infrastructure. (WSP and Trafikverket 2013)

performed by (Bergsdal et al. 2012), railway electrification was considered in a generic manner that did not distinguished between open sections and tunnel sections and how the factor of variation in speeds can affect the results.

Table 4.1: length and section variations of 12 alignments[12].

	Corridors	Total Length (km)	Open section double track, Re330 (km)	Open section double track, S25 (km)	Tunnel section, unidirectional double track, Re330 (km)	Tunnel section, unidirectional double track, S25 (km)
North	Oslo-Trondheim (Ø2:P)	409.49	232.18	6.08	150.35	20.89
	Oslo-Trondheim (G3:Y)	447.55	169.92	6.08	250.27	20.89
South	Oslo-Stavanger (S2:P)	479.81	187.16	-	292.66	-
	Oslo-Stavanger (S8:Q)	460.53	-	214.53	-	246.00
West	Oslo-Bergen (Ha2:P)	352.20	176.60	-	175.60	-
	Oslo-Stavanger-Bergen (H1:P)	528.60	186.00	-	342.60	-
	Stavanger-Bergen (BS1:P)	230.05	83.80	-	146.25	-
	Oslo-Bergen (N1:Q)	339.10	148.80	72.80	68.20	118.40
East	Oslo-Gothenburg (GO1:S)	194.54	67.93	70.67	49.45	6.49
	Oslo-Stockholm (ST3:R)	180.24	101.22	39.13	28.23	11.66
	Oslo-Gothenburg (GO3:Q)	185.65	138.80	-	46.85	-
	Oslo-Stockholm (ST5:U)	173.23	65.27	63.84	31.35	12.77

This chapter introduces a procedure that is used to solve the life cycle assessment of HSR electrification and effects on corridor planning. Section 4.2 describes the LCA of HSR electrification under PCR framework for this thesis by describing F.U., system boundary etc. Then, in section 4.3, structure and data collection of this study is explained in more detail. At the end, this chapter is closed by summary of assumptions in section 4.4.

4.2 Description of LCA of HSR electrification

In the introduction of this thesis, it is highlighted that the aim of this study is to analyze the environmental performance of HSR electrification by means of PCR guideline, and in addition, reflects the impacts of HSR electrification on corridor planning. Since the PCR for railway infrastructure does not specified what tools should be used in the environmental assessment of railways (WSP and Trafikverket 2013), SimaPro ver.8 is utilized to perform the life cycle assessment of HSR electrification in this thesis.

The LCA model of railway electrification in SimaPro is built base on unit processes, which each process is the smallest building block in an LCA inventory and it can be either linked to or used by other processes. (Goedkoop et al. 2014) In this project, the data from background come from ecoinvent database whereas some parts of the life cycle inventory for the foreground system are documented by me and the rest is used from other related reports, and EPDs.

[12] In appendix H, detail analysis of length variation along some alignment are provided.

4.2.1 Functional unit (F.U.)

It is planned in this thesis to first structure the assessment of HSR electrification based on F.U. of one kilometer of **single-track** with a lifetime of 60 years for different design-speeds and section types in accordance with PCR framework to make a clear picture of components and related material and energy flows. (WSP and Trafikverket 2013) Then, from the results for a kilometer of single-track for different design-speeds and section types, attempt to evaluate the effect of electrification on corridor planning.

For the LCA of corridor planning, F.U. is adapted to the length of each alignment. This means, the results for a kilometer basis of section types and design-speeds are scaled up with respect to composition of alignments (the method of calculation is explained in section 5.2).

4.2.2 System boundary

System boundary of this study is shown in figure 4.1. The layout of different alternatives for this project is divided into four levels. Each level describes how much energy and material is required for the given system processes that are based on unit processes. The graph below is inspired from project (Bergsdal, Graarud, and Holen 2011), which provides a good level of details for a system description[13].

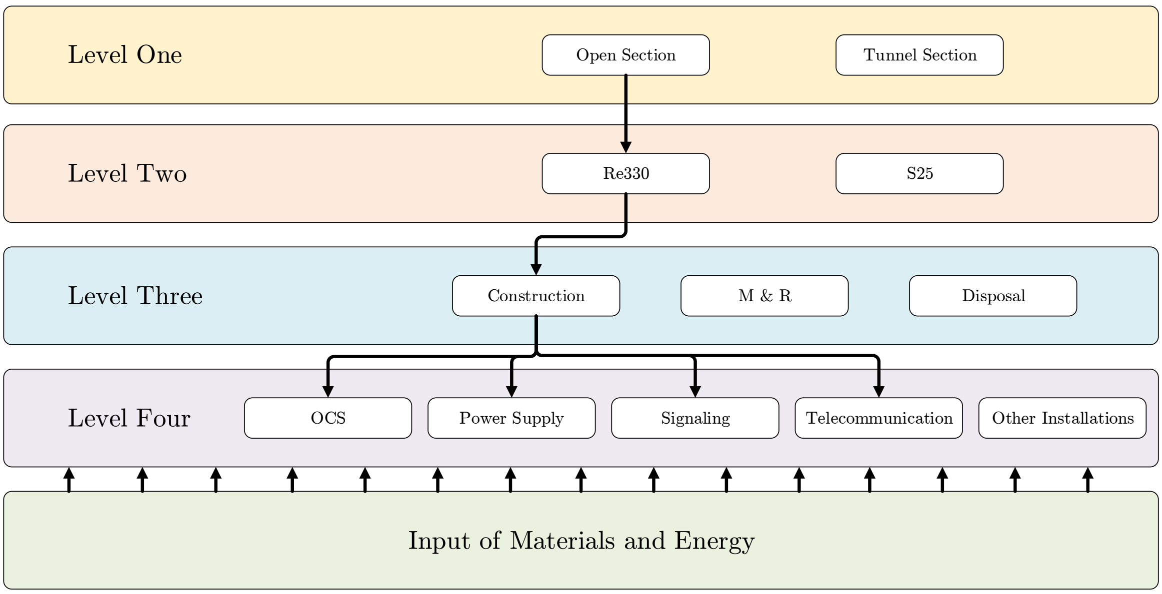


Figure 4.1: Layout of LCA of HSR electrification (for the F.U. one kilometer).

[13] The flows drawn in figure 4.1 is an example of one case that tells about the components contributing in the construction phase of system Re330 for a kilometer of open section.

Figure 4.1 is comprised of following levels:

- Sections Types (Level one)
    - Open section
    - Tunnel section
- Design-speed alternatives (Level two)
    - Re330 (330 km/h)
    - System S25 (250 km/h)
- Life cycle phase (Level three)
    - Construction
    - Maintenance & renewal (M&R)
    - Disposal
- Components (Level four)
    - Overhead contact system (OCS)
    - Power supply
    - Signaling
    - Telecommunication
    - Other installations (considered only for tunnel section)

4.2.2.1 Description of section type

The section type covers two variants; open section and tunnel section. Here, bridge sections are considered as open sections due to sharing similar structure of system design for the LCA of HSR electrification. Each section type covers two variations in design speeds that has different requirement of material use and energy use in electrification of a line. As this study is going forward, it will break down all of these components in detail.

4.2.2.2 Description of design-speed alternative

Different types of design-speeds with respect to the requirement of a line exist in Norway. Systems S35 (140 km/h), S35 MS (160 km/h), S20B (160 km/h), S20A (200 km/h), S25 (250 km/h) are examples of these systems of design-speeds that are used in JBV(Jernbaneverket 1998), which among them only S20 A, S20 B and S25 are considered to be utilized for new railway electrification. The reason is due to this fact that systems S35 and S35 MS are outdated and JBV will build minimum system S20 for new electrifications. (Thor Egil 2013a)

Based on the previous study of Norwegian high-speed rail (Atkins 2012, Bergsdal et al. 2012), new scenarios developed upon NHSR that highlighted the design-speeds of corridors were adapted to maximum and minimum speeds of 330 km/h and 250 km/h, respectively. Therefore, the only design speeds that are fit in this LCA study are system Re330 for speed up to 330 km/h and system S25 for speed up to 250 km/h.

Re330 (which is not a Norwegian system) is a design used by German railway (Deutsche Bahn AG, DB) that is taken into consideration for this thesis. As long as Re330 is not used in Norwegian railroads, it was suggested by JBV as a solution to reach the speed of 330 km/h in the tunnel section for the Follo Line project. (Iversen 2012)

4.2.2.3 Description of life cycle phase

Pursuant to the PCR framework, the LCA shall present a full life cycle analysis that consists of construction, maintenance & renewal[14], and disposal.

4.2.2.3.1 Construction

Construction phase is the early stage towards electrification of a line (in either an open section or a tunnel section). Construction includes all components for HSR electrification such as signaling, telecommunication, power supply, overhead contact system (OCS), and Other installations (other installations are only included in the construction phase of tunnel section that is consist of lighting and fans). All of these components are needed before a line runs.

On the contrary to the other studies that consider construction of tunnels, bridges, earthwork that consists of blasting, transport of rock, sole etc., and so forth; this thesis only focuses on parameters that are related to *provide transmission of electricity by means of high reliability through signaling and telecommunications*.

According to the PCR guideline (figure 3.3), transportation is an inseparable part of an LCA of railway infrastructure. However, as long as no HSR constructed in Norway yet, and not enough information could be obtained from JBV for a normal transport of goods related to rail electrification, it is hard to predict the exact amount of transport. Hence, in section 4.2.4, the model assumed for transport of goods is explained.

[14] Operation phase of an electrified line is not the concern of this thesis due to this fact that this research only focuses on electrification of HSR infrastructure.

4.2.2.3.2 Maintenance and renewal

Different components have different lifetimes through the operation of an electrified line. This perspective opens a new study of life cycle that is maintenance & renewal. To maintain the functionality of an electrified line, utilization of energy and materials are needed in the maintenance & renewal phase. This phase is comprised of annual inspection of the line, transport and replacement of components in accordance with their respective lifetime. (Fuglseth 2013)

The same as construction phase, section 4.2.4 in this chapter explains the procedure assumed for the transport of goods in the maintenance & renewal phase. In addition, lifetime is the other crucial concept in this life cycle phase that will be explained more in detail in section 4.2.3.

4.2.2.3.3 Disposal

The last phase of life cycle in this study is disposal. A disposal phase is a step after replacement of components in the maintenance & renewal phase. In the disposal phase, a generic approach is taken into the calculation of LCA of HSR electrification. In fact, it is assumed materials after replacement are transported in a particular way to a waste treatment plant and the environmental assessment after delivery of items to the waste treatment plant is not taken into consideration.

The reason of having such an approach towards the disposal phase is due to not enough information being involved in the area of HSR electrification that could be invested in this life cycle phase.

4.2.2.4 Description of Components

An electrified HSR model (according to the level 4 of figure 4.1) is comprised of four main components[15] (regardless of section type): power supply, overhead contact system (OCS), signaling system, and telecommunication system. In this project, lighting and fans are grouped in a category of “Other installations” that are only used in tunnel sections. Explanation about components and details of their materials and energy inputs are provided in the following of this chapter.

[15] In the PCR guideline, it has been mentioned that overhead contact systems (OCS) and power supply should be grouped in one category. However, it has been decided to split them into two separated groups due to having a concrete study of OCS in this thesis. Moreover, it was also part of a plan to show how much improvement could be achieved by having higher resolution of OCS compare to the other studies.

4.2.3 Lifetime

Replacement due to wear and tear is dissimilar from components to components. Table below is a reflection of lifetime for different components for this project that is taken from Asplan Viak AS's pilot project (Kjerkol, Amlie, and Dahl 2012).

Table 4.2: Lifetime of components and subcomponents in railways electrification.

Element	Lifetime (year)
Catenary	30
Insulator	30
Fundament (mast)	50
Cantilever	50
Tunnel lighting	30
Tunnel ventilation	15
Mast in open section	50
Soffit posts in tunnel section	50
Tensioning section*	30
Signaling	20
Telecommunication**	10/15/20
Cable (power supply)	50
Transformer***	30/50

* Tensioning section is not included in the pilot project. As a result, it is assumed tensioning section has the same lifetime as the catenary system.

** Due to complexity of telecommunication system, different lifetimes are involving in the system.

*** Due to variation in types of transformers, two types of lifetimes for transformers are existed.

The same structure, as it is used in construction phase in SimaPro, is assumed for the maintenance & renewal phase; however, the calculations are modified for this phase. Because of variation in lifetime of various components in the use-phase, the calculation bellow is applied to assess the environmental impacts related to the maintenance & renewal phase in this thesis. Formula below is an example of total climate change of maintenance & renewal of the HSR electrification that is inspired from Asplan Viak AS pilot project. (Kjerkol, Amlie, and Dahl 2012)

$$TGWP_M = \left(\left(\frac{C1_{GWP}}{L1C_{GWP}} \right) + \left(\frac{C2_{GWP}}{L2C_{GWP}} \right) + \cdots + \left(\frac{Cn_{GWP}}{LnC_{GWP}} \right) \right) * EL$$

- $TGWP_M$ = Total global warming potential from production and transportation of new items through the entire lifetime of M&R
- $C1_{GWP}$ = Total global warming potential from production and transportation of component 1

- $L1C_{GWP}$ = Estimated lifetime for component 1
- EL = Entire lifetime of M&R
- n = Number of components

The same procedure could be taken for calculation of the other impact categories in this thesis that have been mentioned in section 3.3 (in table 3.1).

4.2.4 Transportation

Transportation is an inseparable process in an LCA study. Materials and items in ecoinvent and EPDs include inputs of raw materials, energy and transportation to produce a defined product and deliver to a certain place[16]. (Fuglseth 2013) This section is dedicated to transportation of items to explain how the transportation of goods is modeled for different life cycle phases. Here, the transportation model for construction and maintenance & renewal is the same. However, the transport model for the disposal phase is different,

4.2.4.1 Construction and maintenance & renewal

In these two life cycle phases, the background processes (in ecoinvent) that have a delivery to "regional storage" are considered. Hence, the transport of associated goods is assumed to occur in two ways, via: transport from regional storage to rail sites and transport from rail sites[17] to installation along the line.

As long as no HSR constructed in Norway yet, and not enough information could be obtained from JBV for a normal rail electrification, it could not be possible to provide a map of transport of electrification related-goods. As a result, 100 kilometers of average transport is presupposed as an average model of transportation of material from the regional storage to the sites for both construction, and maintenance & renewal phases of this LCA (Classen et al. 2007). The ecoinvent process that is corresponded to this model is "*Transport lorry >28t*".

The second model of transport is transport from railway sites to installation along the track. The presumed model tells how much of material needs to be transported from the railway sites with respect to the F.U. of 1 km of HSR electrification. Figure

[16] The background processes in ecoinvent contains an average model of transport. Nonetheless, the transport of the items in the foreground system needs to be modeled in detail (if the information is available).

[17] The location of sites are assumed located at the two end of each alignment. For example, for alignment Ø2:P (corridor North) the location of sites are one in Oslo and one in Trondheim.

4.2 shows an example of a line with illustration of depots and location of railway sites on both ends.

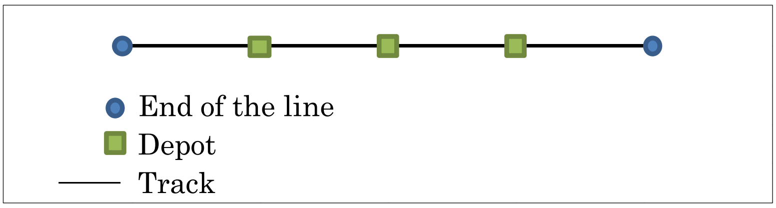


Figure 4.2: Schematic view of a hypothetical line with illustration of depots and end of lines

Appendix B explains the calculation that has been done for the section, but the calculation can be summarized as following. The transport for a kilogram of an item in the construction phase and the maintenance & renewal phase will be ***100*** kilometers of an average transport from the regional storage to the sites and ***1.563*** kilometer of transport from sites to installation along a track (for the F.U. 1 km).

4.2.4.2 Disposal

Transport of goods for the disposal phase is in the opposite direction of transport of materials compare to the construction and maintenance & renewal. This means in the disposal phase, materials need to be dismantled from the line, and then, sent to a waste treatment plant. Appendix B explains the calculation that has been done for the section, but the calculation can be summarized as following. Transport for a kilogram of an item in the disposal phase will be ***1.563*** kilometer of transport from dismantling along the track to the railway sites and ***200*** kilometers of an average transport from the sites to a waste treatment plant (for the F.U. 1 km).

4.3 Data collection

Table below provides a generic view of data with their corresponding sources to provide a good understanding of different components with relative sub-components.

NB. The sub-components that are mentioned in table 4.4 consists of various input material and energy, which due to limitation in space and avoiding impracticality of providing so much data, it is decided to not to provide them in the table. However, the detail information that embraces the flow of material and energy is provided in appendix D.

Table 4.3: Sources of data in this thesis.

Components	Sub-components	Source of information
Overhead contact system (O.S & T.S)	Catenary	Book[18], EPD[19], JBV[20]
	Cantilever	Book, JBV, layouts
	Tensioning section	Book, JBV, layouts
	Support structure	Book, JBV, layouts
	Grounding	COWI report[21]
Power supply	Fan cable	COWI report
	High voltage cable	COWI report
	Low voltage cable	COWI report
	Switchgear - SF6 breaker	COWI report
	11/22 transformer	InfraGuidER [22]
	Transformer (small without oil)	COWI report
	Positive current cable	JBV handbook[23]
	Negative current cable	JBV handbook
	Insulator	Book
	Auto-transformer	COWI report, AAS Jakobsen[24]
Telecommunication	Cabling	COWI report
	Computer	COWI report
	Utility room	COWI report
	Others	COWI report & AAS Jakobsen
Signaling (O.S & T.S)	Cabling	The Follo Line[25]
	Cable casing	The Follo Line
	Optical cable	The Follo Line
	Support structure	The Follo Line
	Signaling lighting	The Follo Line
	Computer	The Follo Line
	ATC equipment	The Follo Line
	Axle Counter	The Follo Line
	Protection class (computer)	The Follo Line
Other installations	Lighting	The Follo Line
	Fans	The Follo Line

[18] (Kiessling 2009) and (Kießling, Puschmann, and Schmieder 2001)
[19] (NICHIGOH COMMUNICATION ELECTRIC WIRE CO. 2009)
[20] (Thor Egil 2013b)
[21] (Ovedal et al. 2012)
[22] (Barton et al. 2010)
[23] (Jernbaneverket 2013)
[24] (AAS-JAKOBSEN 2012)
[25] (Bergsdal, Graarud, and Holen 2011)

Consumption	Diesel	The Follo Line & COWI report
	Machine wear	The Follo Line & COWI report

In the continuation of this chapter, an attempt has been made to provide a comprehensive explanation of components and related material and energy flows.

4.3.1 Overhead contact system

Overhead contact system (OCS) is a link between power supply and trains that distributes electricity and design of it has been influenced by climate, electrical load, structure limitations, operation speed and train deign. (Tingos and Raposa 1996) OCS consists of catenary, cantilever, tensioning section, support structure, and grounding. Figure 4.3 shows a flowchart of overhead contact system that embraces subcomponents.

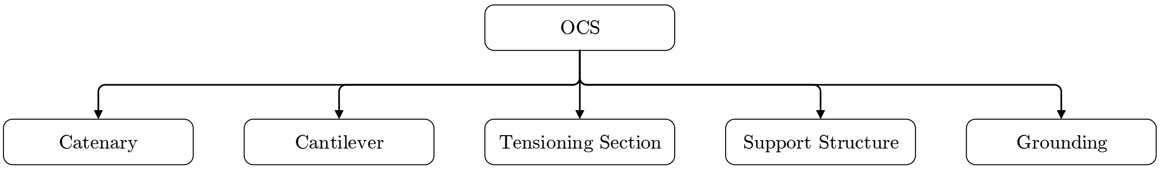


Figure 4.3: Flow chart of overhead contact system.

Figure 4.4 in addition to the flowchart illustrates a layout of some items that are contributing in an OCS like cantilevers, contact wires, insulators, droppers, masts and so forth. In the following of this section all the items that are demonstrated in the flowchart (figure 4.3) are discussed and explained.

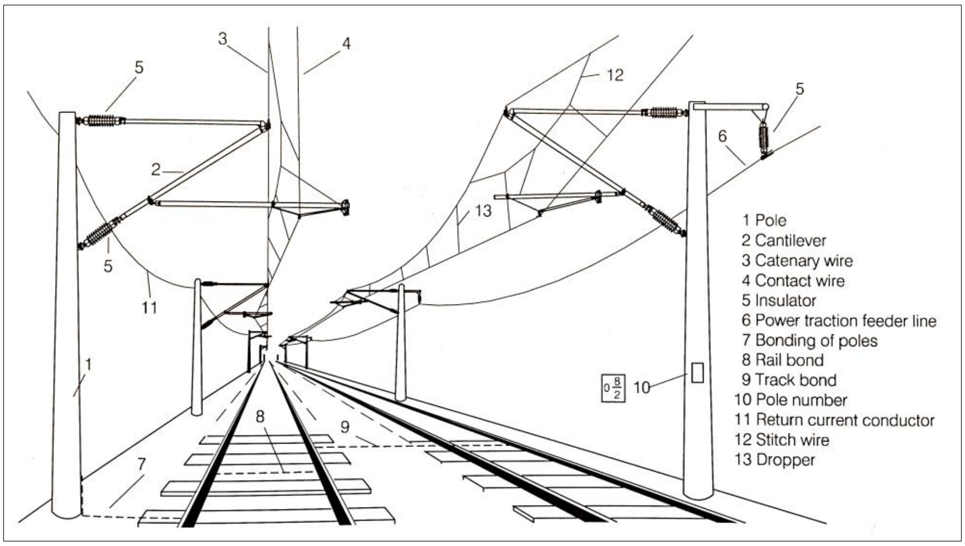


Figure 4.4: Overhead contact system with individual supports. (Kießling, Puschmann, and Schmieder 2001)

4.3.1.1 Catenary

Figure 4.4 indicates a catenary consists of contact wires, messenger wires, droppers and stitch wires for each system of design speeds that will be explained more in this chapter. A schematic view of catenary, in addition to figure 4.4, is shown in figure 4.5 to give a better illustration for readers.

Properties of catenaries need knowledge in operation parameters, which are defined by design and components configurations. (Kießling, Puschmann, and Schmieder 2001) Table 4.4 demonstrates some features of different systems of design-speeds like normal voltage, maximum running speed, maximum span length etc.

Table 4.4: System specification for Re330 and S25 for open section and tunnel section. (Kießling, Puschmann, and Schmieder 2001, Thor Egil 2013b, Siemens AG 2010)

System of design speed	**Open Section**		**Tunnel Section**	
	Re330	S25	Re330	S25
Nominal voltage	15 kV AC / 16.7 Hz 25 kV AC / 50/60 Hz			
Running speed	up to 330 km/h	up to 250 km/h	up to 330 km/h	up to 250 km/h
Ambient temperature	-30 °C to +40 °C			
System height	1.80 m		1.10 m	
Contact wire acc. to EN 50149	AC-120, CuMg0.5	AC-120, CuAg0.1	AC-120, CuMg0.5	AC-120, CuAg0.1
Catenary wire acc. to DIN 48201	120 mm², BzII	70 mm², BzII	120 mm², BzII	70 mm², BzII
Stitch wire acc. to DIN 48201	35 mm², BzII			
Dropper wire	10 mm², Bz			
Contact wire tension force	27 kN	15 kN	27 kN	15 kN
Catenary wire tension force	21 kN	15 kN	21 kN	15 kN
Span length up to	65 m ≤		45 m ≤	
Distance between droppers	10 m ≤			
Mechanical advantage reduction ratio of tension wheel assembly	1;3			
Tensioning length	up to 1400 m		up to 900 m	
Contact wire height	5.30 m			

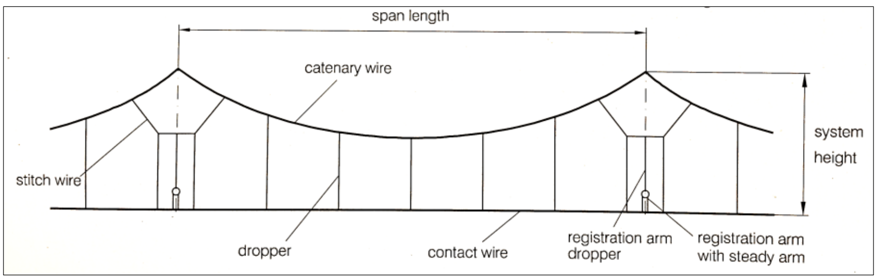


Figure 4.5: Design of a contact line section and span. (Kießling, Puschmann, and Schmieder 2001)

4.3.1.1.1 Contact wire

Contact wires are equipment that transmits electricity to collectors (pantographs). The design of a contact wire is twisted to ensure an uninterrupted transmission of electricity to train's pantographs and uniform wear of pantographs strips. The uniform wear of collector refers to a zigzag (to the left and right) arrangement when a contact wire is arranged in alternating angles to the track axis due to avoiding any notches. (Kießling, Puschmann, and Schmieder 2001, Kiessling 2009, Thor Egil 2013b) The zigzag variation for each system (Re330 and S25) is illustrated in figures 4.6 and 4.7.

For system S25, the model of contact wires is CuAg0.1 AC-120. However, the model of contact wire is CuMg0.5 AC-120 for system Re330. Adding silver (Ag) alloy (with 1% concentration) for S25 and magnesium (Mg) alloy (with 1% concentration) for Re330 improve mechanical tensioning and thermal properties of copper wires, but it has a reduction in electricity conductivity of contact wires. (Kießling, Puschmann, and Schmieder 2001) In this project, assumptions of contact wires with 99% copper and 1% silver for S25 and contact wires with 99.5% copper and 0.5% magnesium for Re330 are assumed. (Pupke 2010)

Table 4.5: Contact wires with their names for the two systems of design-speeds.

System	Contact wire	Dimension (mm2)
S25	CuAg0.1 AC-120	120
Re330	CuMg0.5 AC-120	120

4.3.1.1.2 Messenger wire

Messenger wires are also called catenary wires that are located on top of contact wires. They keep the geometry of contact wires within defined limits by means of droppers. Messenger wires have alloy additives of magnesium (Mg) with 0.5% concentration (CuMg0.5) to improve mechanical tensioning and thermal properties like silver alloy contact wires. CuMg0.5 wires are also called BzII and table below tells the physical properties of messenger wires for the design-speeds.

Table 4.6: Dimensions with names of messenger wires for the two systems of design-speeds.

System	Contact wire	Dimension (mm2)
S25	70 BzII	65.81
Re330	120 BzII	120

4.3.1.1.3 Dropper and stitch wire

Droppers or drop wires are a link between a contact wire and a messenger wire with regular intervals (8 to 12 meters) along the longitudinal span. (Kießling, Puschmann, and Schmieder 2001, Thor Egil 2013b, Kiessling 2009) In all design-speeds the model of droppers are the same and it is 10 BzII with the dimension of 10.02 mm^2; however, height of droppers vary due to different parameters such as design-speed, span length, open section, tunnel section etc. (ibid)

Stitch wires are earmarked as a connection wire between messenger and contact wires. The purpose of their designation is to compensate elasticity and height difference at mid-spans and supports. The usage of stitch wires depends on the specification of a system of catenary. Here, the physical property of stitch wires for the all systems is the same and it is BzII 35. (Kiessling 2009, Kießling, Puschmann, and Schmieder 2001, Thor Egil 2013b)

4.3.1.1.4 Layout of catenaries for different design-speeds in open section

Figures 4.6 and 4.7 show the layout of catenary systems for Re330 and S25 that have been obtained from the book (Kießling, Puschmann, and Schmieder 2001) that consist of an overview of structure of systems in the open section.

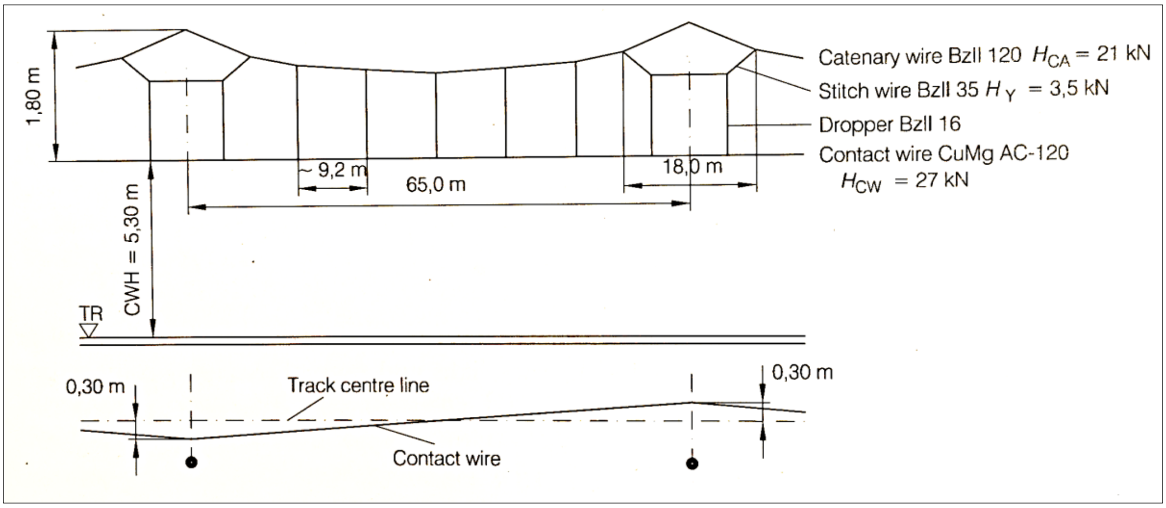


Figure 4.6: Layout of catenary for system Re330. (Kießling, Puschmann, and Schmieder 2001)

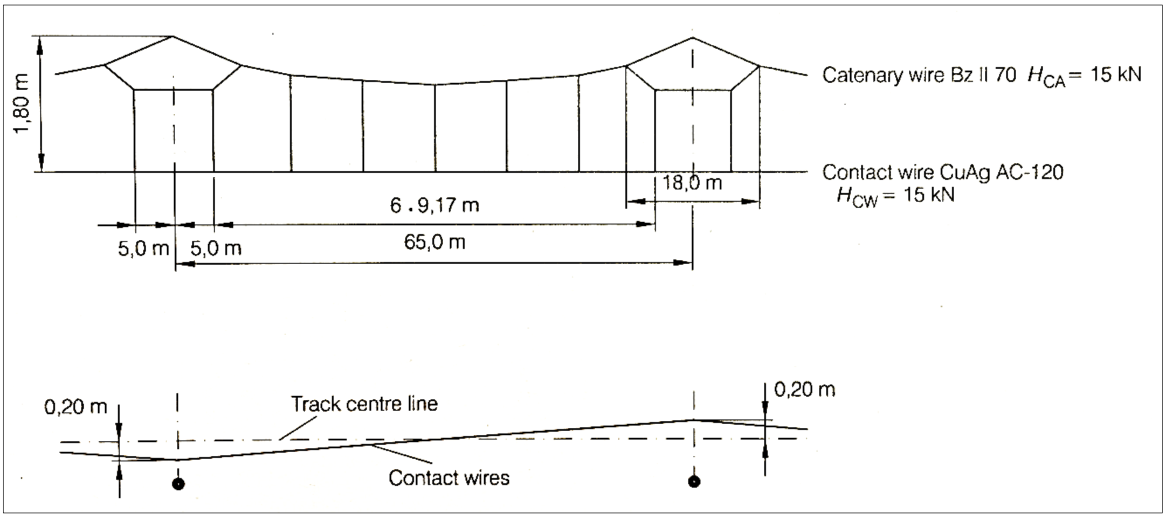


Figure 4.7: Layout of catenary for system S25. (Kießling, Puschmann, and Schmieder 2001)

4.3.1.1.5 Layout of catenaries for different design-speeds in tunnel section

The layout for the tunnel section of each design-speed is done with an assumption that the layout of tunnel section is exactly like the layout of open section but it is adjusted through utilization of some coefficient factors. The coefficient that is used in this project is (1.1/1.8)[26] for S25 and Re330. The coefficient is only multiplied with droppers and stitch wires of the respective systems. The reason of having such hypothesis was because of complexity of designing other catenary systems for the tunnel section, and in the books (Kiessling 2009, Kießling, Puschmann, and Schmieder 2001) all information was useful only for the open section.

Furthermore, contact wires and messenger wires (based on the assumption) stayed the same as open section. It could be seen in the table of input materials in appendix D how the calculations have been done.

4.3.1.2 Cantilever

Cantilevers are fixtures that carry horizontal and vertical forces. They are divided based on their functionalities into contact wire supports and messenger wire supports. Moreover, they are connected to masts via insulators and swivel brackets. In this project, as it was mentioned before, only two systems of design-speeds are taken into consideration. These systems are Re330 and S25. Layout of cantilever for system S25 is provided in appendix C, which is assumed to be the same layout

[26] The coefficent refers to table 4.4 that says the systems height decrease from 1.8 meters in the open section to 1.1 meters in the tunnel section.

for system Re330 due to not having related information from JBV. The contact wire support shown in figure 4.8 is comprised of the registration arm dropper, the registration, contact wire steady arm, the windstay and the drop bracket. The zigzag mode is applied to contact wire by means of push-off supports and pull-off supports. The catenary wire support includes the cantilever tube, the top anchor and messenger wire support clamp. (Kießling, Puschmann, and Schmieder 2001)

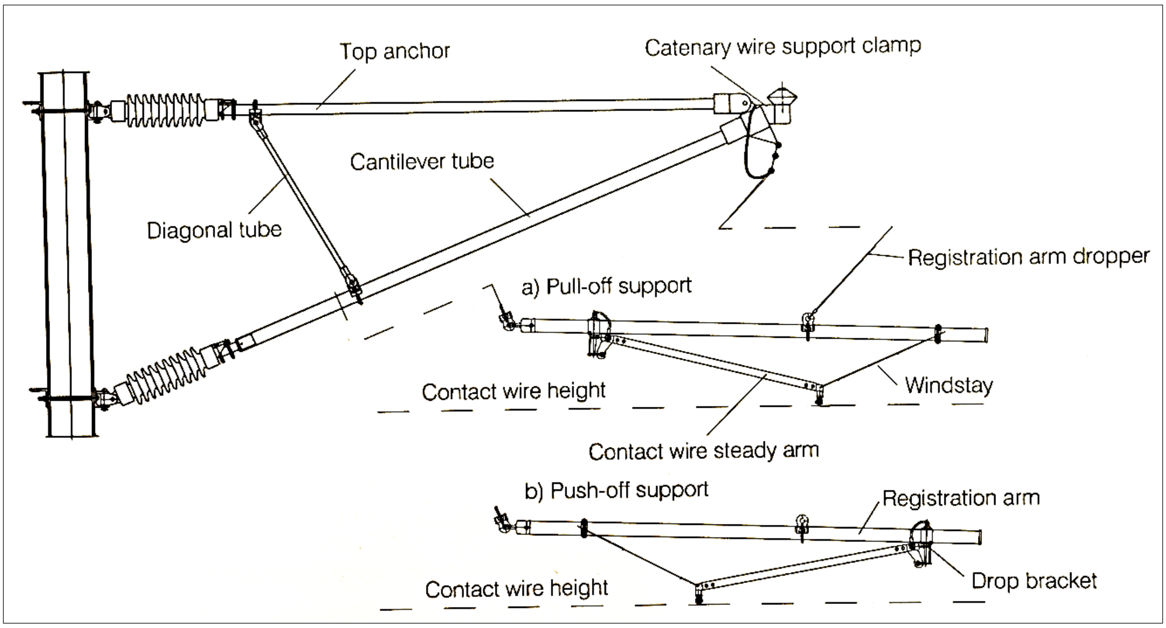


Figure 4.8: A model of cantilever with push-off and pull-off supports. (Kießling, Puschmann, and Schmieder 2001)

Moreover, some tables are provided in appendix D to show how calculation is done for cantilevers for both tunnel section and open section of two systems of design-speeds.

4.3.1.3 Tensioning section

Due to temperature variation and movement of pantograph on contact wires, tensioning mechanisms are introduced to tension overhead contact system (at a possible horizontal tensile force) up to permitted tolerances. (Siemens AG 2010, Kießling, Puschmann, and Schmieder 2001) Tensioning system, in general, is comprised of mid-point anchors, overlaps, automatic flexible tensioning and fixed termination that are shown in figure 4.9 (here, the topic of fix termination is not taken into consideration). (Kiessling 2009)

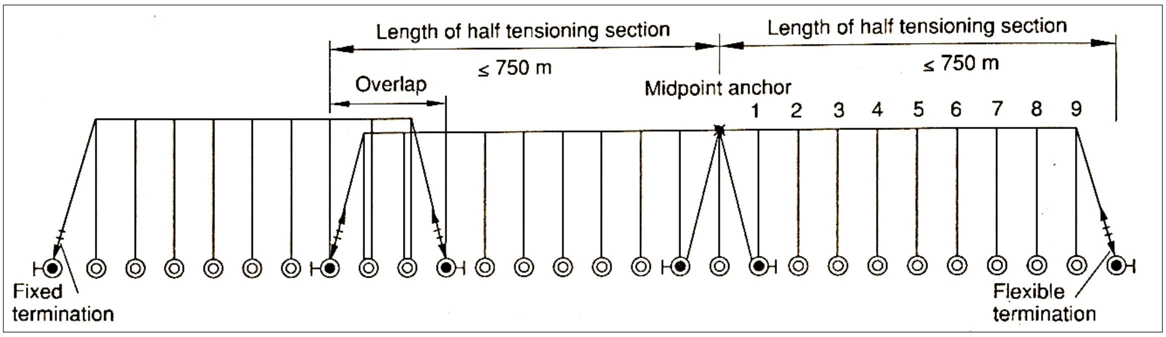


Figure 4.9: Layout of a tensioning section with corresponding components. (Kiessling 2009)

4.3.1.3.1 Flexible tensioning

Automatic flexible tensioning systems are considered as a typical solution that tension OCS at both ends of a line with tensioning section length of 750 meters (or less in open section)/450 meters (or less for tunnel section). The mechanisms of automatic tensioning consist of tensioning wheel, steel wires, weights, guide straps, hook bolts, support bars and so forth, that are mounted on masts (in open section) or on the wall of tunnels (in tunnel section) at one end and fixed anchored at the other end of each tensioning section length. Figure 4.10 shows a generic view of flexible tensioning in open section and tunnel section.

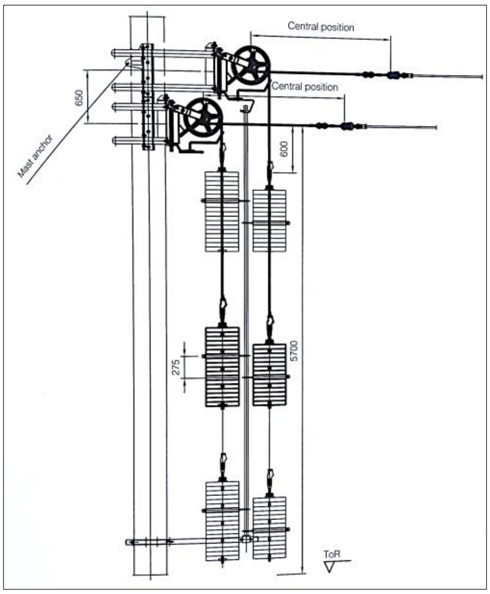


Figure 4.10: Sectioning device in an open section (picture on the left side) (Kiessling 2009), and tensioning device in a tunnel section (picture on the right side) (Dr. Fockenberg 2013)

On high-speed overhead contact system rail, contact wires and catenary wires are tensioned separately to ensure maintenance and allow different tensile forces. In tunnels, tensioning mechanisms are required to have a criterion of space-saving design. (Kießling, Puschmann, and Schmieder 2001) Table 4.4 shows the tensioning force and tensioning length of each design-speed in different section type. In addition, the layout of with corresponding sub-components is shown in appendix C.

4.3.1.3.2 Mid-point anchor

Mid-point anchors or fixed anchor points are used when OCS is tensioned by automatic flexible tensioning mechanisms. Mid-point anchors are applied at both ends of tensioning section length (figure 4.11) and the design of them should provide enough force that is in an opposite direction and higher than the force from automatically tensioned OCS. Mid-point anchor wires are made of either steel or bronze wires that rigid catenary wires to neighboring masts by means of insulators as shown in figure 4.11.

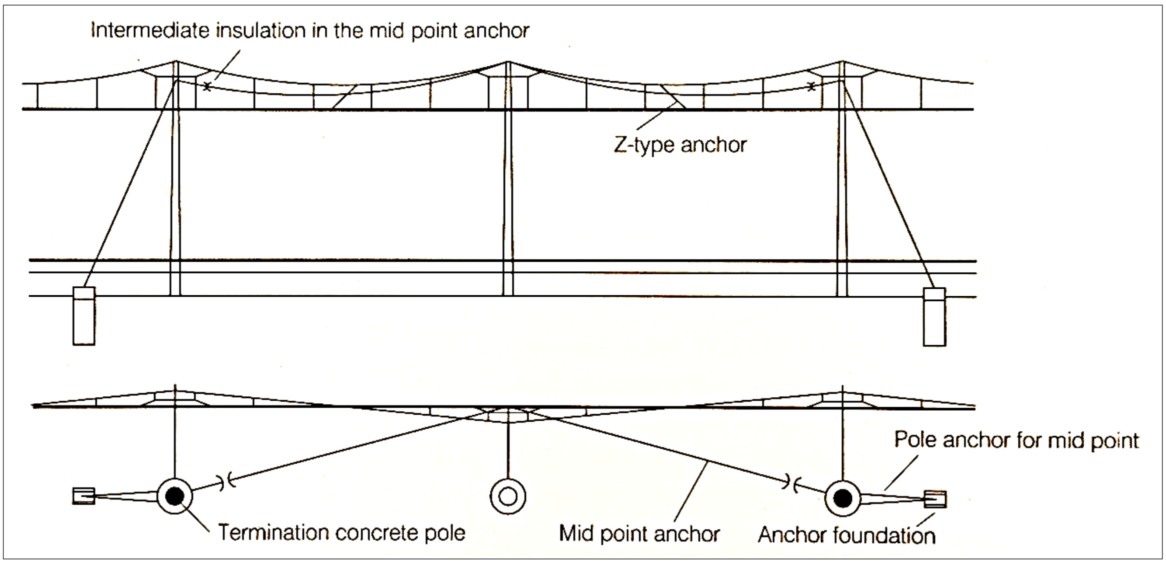


Figure 4.11: Layout of mid-point anchor in an open section. (Kiessling 2009)

4.3.1.3.3 Overlap

An overlap is the place between two tensioning sections where one overhead contact system ends and the other starts and it is characterized by two parallel overhead contact systems that smooth the transition path for pantographs in a short distance. (RMweb 2013, Kiessling 2009) The transition happens in the middle of each overlap and the structure of overlaps is designed with different span lengths (figure 4.12). Overlaps compensate requirements such as providing uninterrupted electricity supply or contact loss, solving the restrictions on length of OCS and maintenance improvement of OCS. (Jain 2014, Kiessling 2009)

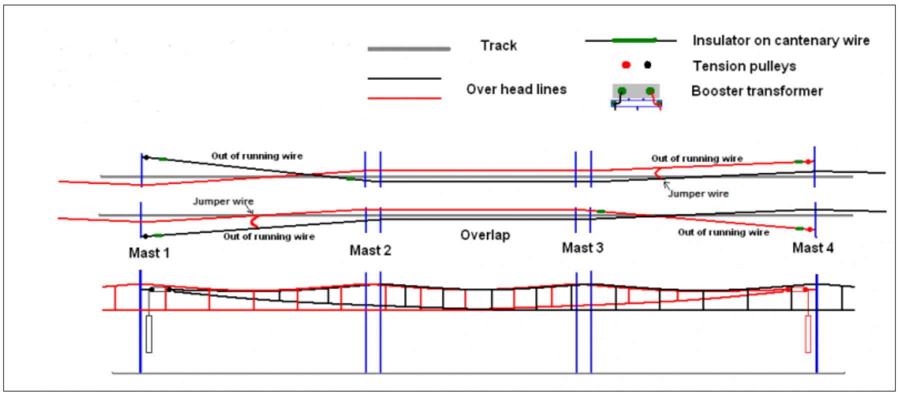


Figure 4.12: Layout of transition in overlap in an open section. (RMweb 2013)

Calculation methods and input materials numbers that have been done in this study are provided in appendix B and C, respectively.

4.3.1.4 Support structure

Support structure is the other parameter for OCS that is comprised of masts, foundation, and insulators. Head spans and portals are also part of support structure, but they are not included in this project due to study of LCA of a single-track. (Tingos and Raposa 1996)

4.3.1.4.1 Mast

Masts or poles are vertical structures that their height and design depend on different factors like requirement height for pantographs, design speed etc. In JBV, there are different types of masts such as HEBs, B types and H types. The common types of masts are all types of HEB (200, 220, 240, 260, 280 and 300), B3, B6, H3 and H5. (Jernbaneverket 2002) In this project model of HEB200 with height of 9.5m is assumed. However, mounting cantilevers by means of masts due to rectangular tunnels is impossible. The solution is soffit posts that cantilevers are mounted on the wall. Figure 4.13 shows the utilization of soffit posts in a tunnel section. (Kießling, Puschmann, and Schmieder 2001)

In this project, only one type of support in tunnel section is used, with an assumption that the support has a height of 2m and bolted on the wall of tunnels. Appendix C shows the layouts of masts and a soffit post that are used in this project.

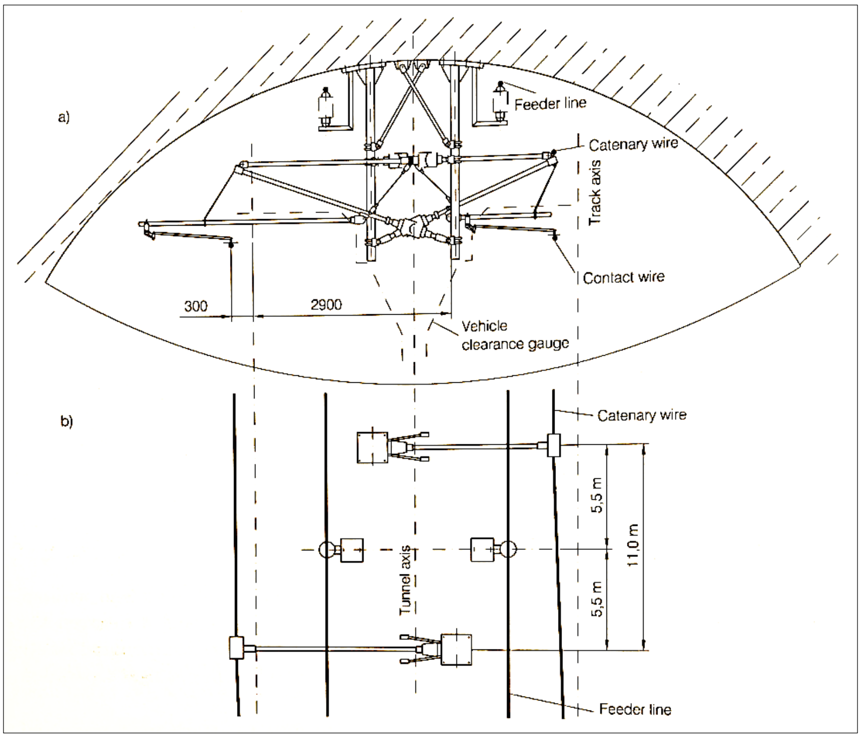


Figure 4.13: Supports in rectangular tunnels with cross section view and view from the top.

4.3.1.4.2 Fundament

Fundaments are concrete blocks that support masts, and their types are determined from soil properties and types of poles. In an email from (Thor Egil 2013b) the model of fundaments are mentioned as cylindrical with a diameter of Ø555mm and height up to 4.5m. Information about the calculation is provided in appendix D and the height of 4m is assumed for fundaments in this thesis.

4.3.1.4.3 Insulator (glass made)

Insulators are barriers for electricity to eliminate the probability of short circuit in electricity transmission and they are placed between cantilevers and masts. (E. Ebrahimi 2014) Utilization of glass insulators for cantilevers is assumed in this study due to observation of a line (Trondheim train station) and images from JBV annual reports. (Jernbaneverket 2011) The model of glass insulator that is made in this project is from EB-elektro with weight of 3.9kg each. (ELEKTRO 2013) It is assumed that the material base of glass insulators is lead-antimony[27] (with 50% of weight of an insulator) and glass (with 50% of weight of the total). The details about the materials and energy inputs are provided in appendix D.

[27] With 2% antimony per kilogram and the rest is lead. (Clark 2009)

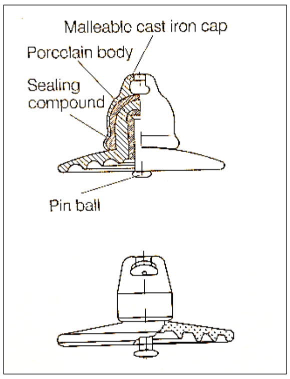


Figure 4.14: A schematic view of an insulator (cap and pin insulator). (Kießling, Puschmann, and Schmieder 2001)

4.3.1.5 Grounding

The purpose of grounding is to ensure that the earthing of all electrical systems designed and constructed so that the system functionality is fulfilled and safety against leakage currents is protected. (Jernbaneverket 2014) Here, grounding is comprised of hanging thread (hengetråd), cross-connector through each crossover (tverrforbinder gjennom hver tverrforbindelse), connections to the lengthwise (tilkoblinger til langsgående), and grounding in technical rum in cross-connectors (jording i tekniske rom i tværforbindelser) that all are collected from the COWI report (Ovedal et al. 2012).

4.3.2 Power supply

Power supply makes a link between traction substations, catenaries and other equipment, which periodically gets electricity in high voltage (110 kV) from traction substations and changes it to the defined voltage for catenary. Power supply consists of high voltage cable, autotransformers, and positive feeding cables etc. that are along the right-of-way. (Tingos and Raposa 1996) Information for high voltage cable, low voltage cable, transformer (small without oil), switchgear - SF6 breaker, 11/22 transformer and autotransformer in this section are coming from different reports (Ovedal et al. 2012, AAS-JAKOBSEN 2012, Barton et al. 2010) that calculation of all of them are adjusted to the functional unit of one kilometer. Based on the structured inventory in this study (via observations of mentioned reports) the electric power is converted to lower voltage in substations by means of 11/22 transformer and switch gears and transmitted to transformers (small without oil) and autotransformers by means of high voltage cables. After transform of electricity in transformers, the electricity goes to either rolling stocks or other uses such as fans, lighting etc. Figure 4.15 shows a flowchart of power supply that embraces subcomponents as following.

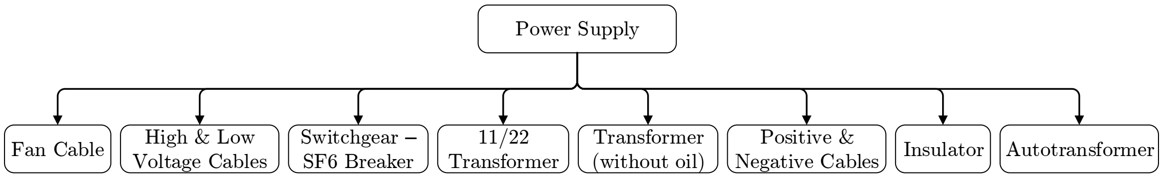


Figure 4.15: Flow chart of power supply.

Here, the explanation is being done for the traction electricity supply that consists of autotransformer, the positive and negative cables, and the insulators.

4.3.2.1 Autotransformer and cabling

An autotransformer system is utilized where the load and current are high or the distance between locations to contact substations is long. (Kießling, Puschmann, and Schmieder 2001) To enhance power supply in the future progression and at the same time reduce impedance of railways within JBV, autotransformer systems have been developed. (Thor Egil 2013c) The AT system is a combination of autotransformers (ATs) and two autotransformers conductors (positive and negative conductors). (Jernbaneverket 2011)

On contrary to conventional transformers (booster transformers), autotransformers are made of only one winding and the reason of application of these transformers instead of conventional ones is due to this fact that ATs can maximized the distance between substations (omformerstasjoner) up to 120 km[28]. (Jernbaneverket 2011, Thor Egil 2013c, Jernbaneverket 2013) ATs are located with ca. 10 km[29] intervals along the railroads and have connection +15kV on positive conductors, 0kV on return tracks and -15kV on negative conductors (figure 4.16). (Jernbaneverket 2011, Gidlund and LAKfGn 2009)

4.3.2.1.1 Positioning in open section

Positive and negative conductors should be mounted on a horizontally symmetrical position on top of OCS poles at the height of approx. minimum 9.5 meters with one meter gap between them. The dimension of positive and negative conductors is between 240mm^2 to 400 mm^2 (The cross section of feeders should not be greater

[28] The conventional system has a distance of approx. 40 km between feeding stations. (Jernbaneverket 2010b)

[29] Maximum distance must not exceed 12 km.

than 400 mm²) and are made of aluminum. Position of positive feeder on the masts must always be on the furthest right side of in the direction of train propulsion. (Jernbaneverket 2013)

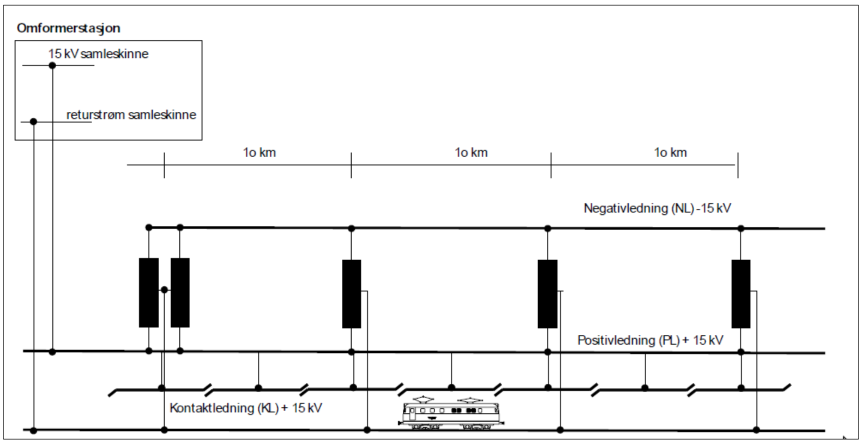


Figure 4.16: An AT system with split contact line. (Jernbaneverket 2010a)

4.3.2.1.2 Positioning in tunnel section

Position of current cables in a tunnel can be either mounted on the wall or buried in the ground of tunnel that is close to the wall. (Jernbaneverket 2010b) In this project the model of buried on the ground is used.

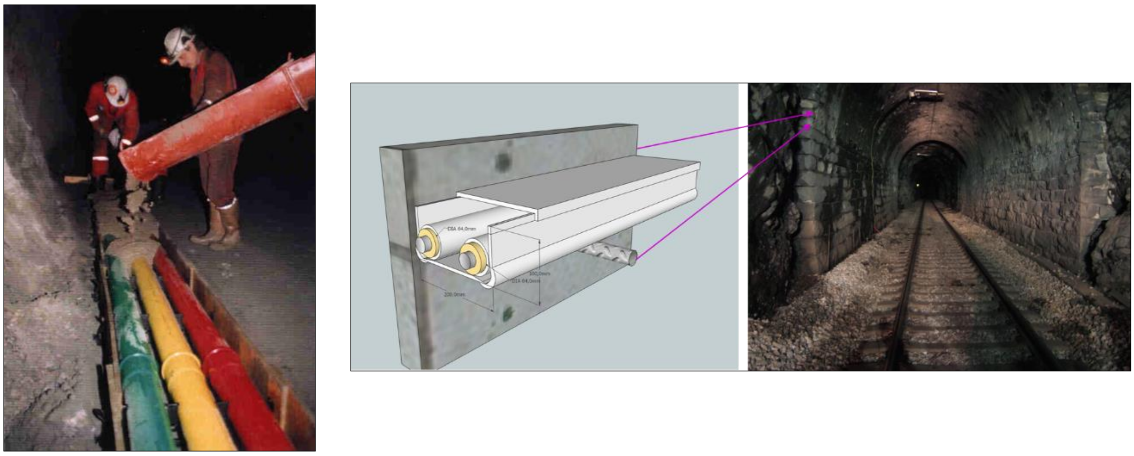


Figure 4.17: Burying current cables in the ground of tunnel (picture on the left side), mounting current cables on the wall of tunnel in the Bergen Line (Bergensbanen) (picture on the right side). (Jernbaneverket 2010b)

4.3.2.2 Insulator (porcelain made)

Insulators for power feed are placed on the top of mast (between current conductors and mast) to avoid short circuit along electricity transition. Insulators here are assumed that are made of porcelain, but with the same weight assumption (3.9kg) as insulators in OCS (glass insulators). In fact, instead of glass, porcelain is used that has 50% of weight of porcelain insulators. The metal side (which is the same as glass insulator) is lead-antimony and has 50% of weight of porcelain insulators (with 2% antimony per kilogram and the rest is lead)[30]. (Clark 2009) Figure 4.14 is a schematic view of an insulator with aim of providing better insight into the topic of insulators.

4.3.3 Signaling and telecommunication

Signaling system introduced to railways with the aim of increasing the reliability of system by controlling railway traffic to prevent probability of collision. (E. Ebrahimi 2014) Depending on the national needs and preferences, signaling systems are designed that might vary from one railway network to another. This issue can consequence to the international level by increasing cost, delay and reducing quality of transport. (Kichenside 2008)

A set of directives from The European Union with an aim to standardize railway-signaling system are issued to facilitate the trains of one country to cross the borders without interruptions and complications of signaling systems. In other words, *interoperability*. Interoperability of railways by the definition means "the ability of a rail system to allow the safe and continuous operation of train, under achievement of specific performances" that it can be referred to technical or operational issues (which here the focus is railway-signaling system). The problems of different signaling and traffic systems are achieved by means of the European Rail Traffic Management System (ERTMS) that consists of three levels; ERTMS Level 1, ERTMS Level 2, ERTMS Level 3. (Kichenside 2008, Profillidis 2006)

The Ministry of transport and communications, as a solution for the future of signaling system in Norway entitled "The Implementation Plan", announced their decision towards renovation of Norwegian railway-signaling system by means of ERTMS Level2. (Jernbaneverket 2009) JBV noted that the implementation is planned to start in 2015 and it can perform a better environmental performance due to reduction in material use, energy consumption, and repairment and maintenance (due to less material requirement in total). (Holter 2013)

ERTMS Level 2 is a digital radio-based signal (GSM-R) and train protection system (European Train Control System, ETCS) that no longer requires optical signals

[30] The assumption that is made is that the insulator is made of 50% porcelain and 50% lead-antimony.

along the sidelines. (Barton et al. 2010, Stripple and Uppenberg 2010) UIC also recommends ERTMS by mentioning the operational benefits that can be harnessed from it such as less on-board equipment, cost effectiveness, capacity, interoperability etc. (Uic 2009)

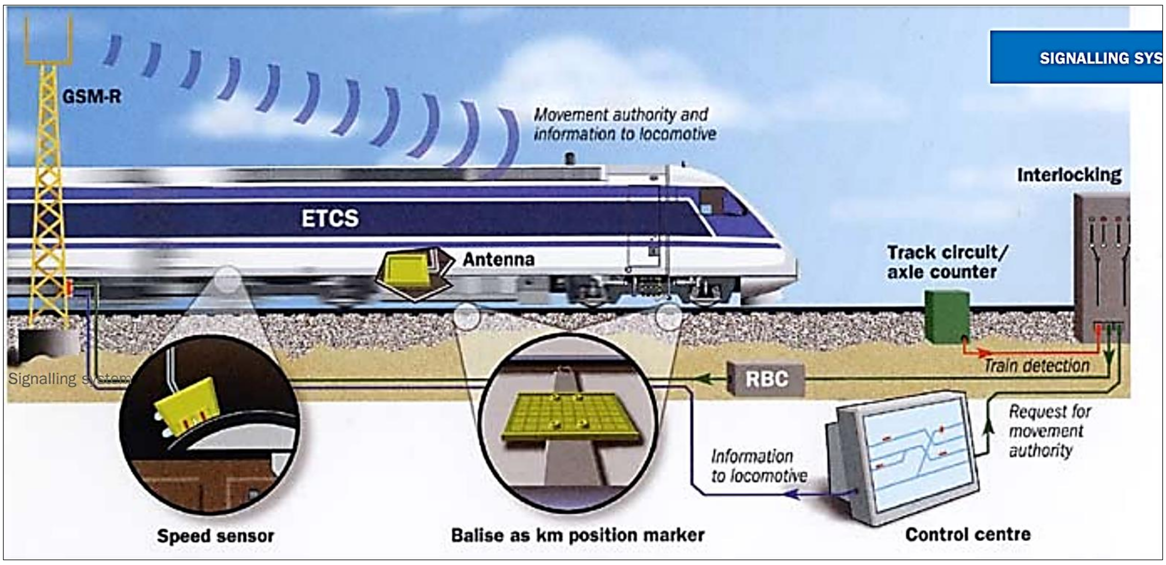


Figure 4.18: Signaling system of ERTMS Level 2 from the Bothnia Line (Botniabanan AB 2010a)

In addition, in the description of the Follo Line (Follobanen) project by JBV, it is mentioned the system of signaling planned to be based in ERTMS Level 2. (Haugnes 2011) Hence, it became the decision of this thesis to enhance the data from the Follo Line (Bergsdal, Graarud, and Holen 2011) and COWI (Ovedal et al. 2012) projects for the evaluation of environmental assessment related to signaling and telecommunication of HSR electrification in this thesis.

Moreover, in order to sense how the system of description of ERTMS Level2 in this project is different from the Swedish ERTMS L2, in chapter 5 (Section 5.3.6) a sensitivity analysis is done to give a better illustration upon the LCA of signaling and telecommunication between this study and the Swedish tool “Klimatkalkul”[31].

In appendix D, the way that calculation has been done for signaling systems is shown. Figures 4.19, 4.20, and 4.21 show flowcharts of signaling - open section, signaling - tunnel section and telecommunication, respectively, that embrace their respective subcomponents.

[31] www.trafikverket.se

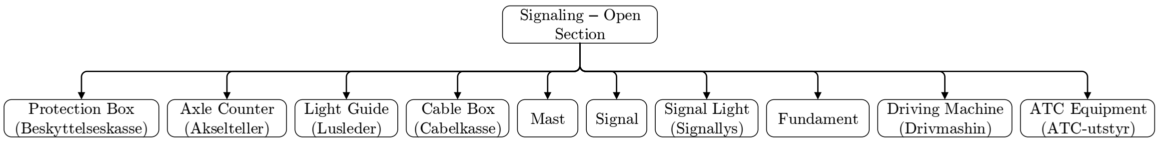


Figure 4.19: Flow chart of signaling system in an open section.

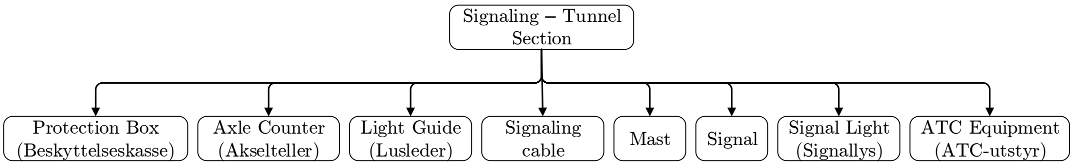


Figure 4.20: Flow chart of signaling system in a tunnel section.

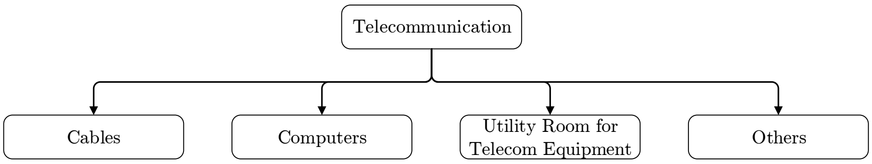


Figure 4.21: Flow chart of telecommunication system.

4.3.4 Other installations

In this thesis, based on the Follo Line project (Bergsdal, Graarud, and Holen 2011), it has been decided to include information of ventilation fans and lighting (emergency lighting, nødlys) for the tunnel section. The collected information from the project is adapted to the functional unit of a kilometer in the tunnel section. In addition, the steel type of the input material for both lighting and fans is replaced with "steel (low-alloyed)".

4.4 Summary of assumptions

List of input materials and energy that are used in this thesis are provided in appendix D that shows the detail of HSR electrification inventory. However, it is decided to reiterate some of mentioned important information in this thesis as following.

Overhead contact system

- It is assumed that the structure of HSR electrification in bridge sections is the same as open section.
- The span length in open section and tunnel section for the overhead contact system is assumed to be 60 and 40 meters, respectively (; however, the effect of curve radius along the line is not considered).

- The same structure of grounding for both open section and tunnel section is presumed.
- The same type of cantilever structure is assumed for the two systems of design-speeds (Re330 and S25).
- The specification of input materials in the tensioning sections is varying from open section to tunnel section and from system Re330 to system S25.
- Mast Type HEB200 with the height of 9.5 meters is assumed.
- However, electricity consumption and breakers are not considered in the LCA of HSR electrification.

Power supply

It is assumed that power supply is the same for open section and tunnel section. However, utilization of “steel (high quality)” in sub-components such as “auto-transformer”, “transformer (small and without oil)”, “trafo 11/22 transformer”, and “switchgear - SF6 breakers” are replaced by “steel (low-alloyed)”.

Telecommunication

It is assumed that telecommunication for open section and tunnel section is sharing the same structure due to this fact that not enough data could be collected from JBV or other consulting companies. Hence, the data from COWI report (Ovedal et al. 2012) for telecommunication is used for both section types. However, utilization of “steel (high quality)” in sub-components such as “technical room for telecom”, “racks for telecom”, “computers (tele)”, “technical room for UPS”, and “racks for UPS” are replaced by “steel (low-alloyed)”.

Signaling

Signaling is divided into signaling in open section and tunnel section that do have different structure of information, and the all data are collected from the Follo Line report (Bergsdal, Graarud, and Holen 2011) and adapted to the F.U. of one kilometer. In addition, the steel type of “mast” in signaling is replaced by “steel (low-alloyed)”.

Other installations

As it mentioned, the Follo Line (Bergsdal, Graarud, and Holen 2011) is the only source of information in this part of HSR electrification, and the steel type is modified to “steel (low-alloyed)”

Chapter 5

Results and analysis

Before starting to explain the results, it can be useful to point out the flow of mass related to materials/items as a projection to chapter 4. Figure 5.1 illustrates a generic mass flow of main materials[32] that are contributing in the railway electrification for system Re330 based on F.U. of one kilometer[33] through the entire lifecycle (60 years) for a single-track. As it could be seen, the figure shows the complexity of study that flows are starting their paths from a background process (on the left side of figure). Here, the background process resembles background unit processes (developed by ecoinvent) that are the foundation of this life cycle impact assessment (LCIA) nourishing HSR electrification processes.

The thickness of each arrow shows the strength (amount) of mass (that is kilogram base) flowing from one unit process to other unit processes. The mass flows through a cascade effect (going from one process to others) are aggregated that at the end reach to the end-points. Here, end-points are divided into section types, which each section type also is divided into construction, maintenance & renewal, and disposal. The details of mass flow are provided in appendix D that embraces data for construction, and maintenance and renewal for two systems of design-speeds (Re330 and S25) in open section and tunnel section.

[32] However, diesel (with some input material that has low mass value) is not shown.

[33] System S25 is decided not to show due to share of great similarity with Re330 that could not be pointed out in a Sankey diagram. However, the detail is provided in appendix D.

In a reflection to the explanation of system in (chapter 4), figure 5.1 also addresses that end-of-life is comprised of only transportation from renewal of material/items to a waste treatment located in 200 km from railway sites.

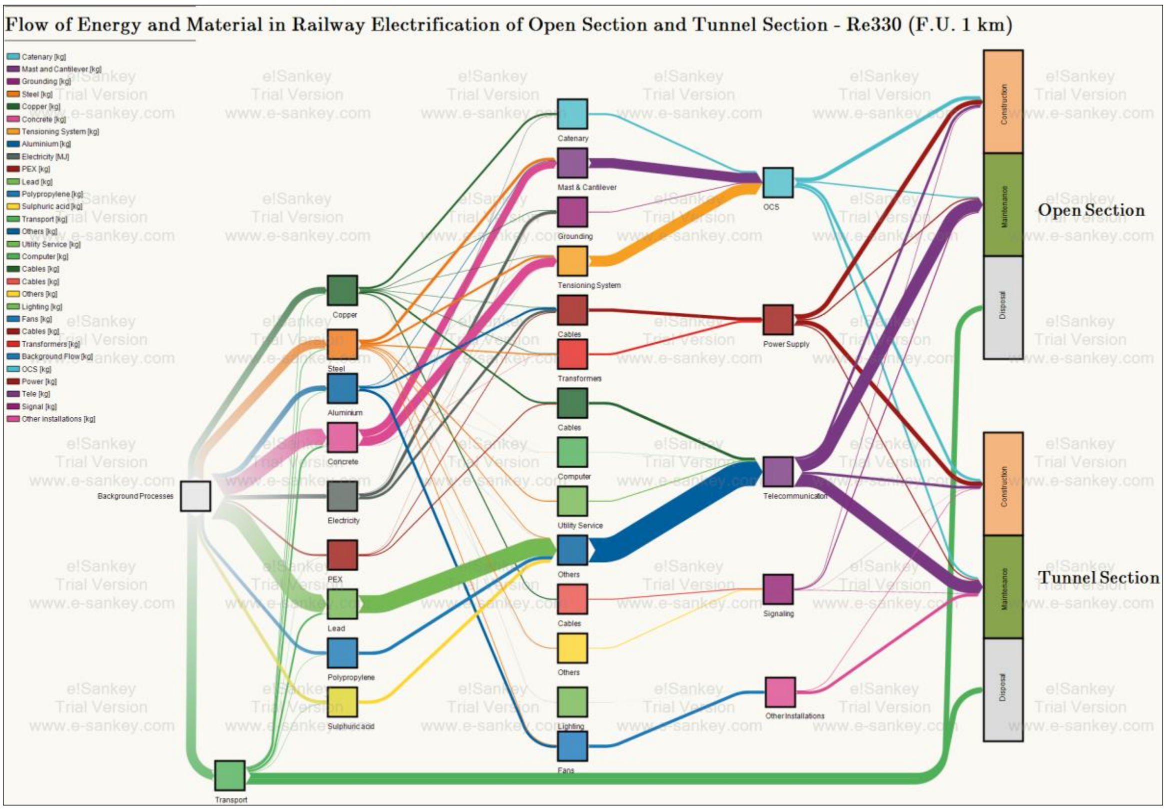


Figure 5.1: Flow of energy and material in railway electrification for a F.U. of one km Re330 in open section and tunnel section[34].

The structure of this chapter will indicate the results of railways electrification by means of life cycle impact assessment (LCIA) based on the collected data that have been explained in chapter 4. The life cycle of this study covers life cycle of manufacturing, transportation, construction, maintenance & renewal, and disposal. However, it is not taken into consideration operation phase of an electrified railroad and end-of-life treatment of components after their lifetime.

To have a better discussion around important impact categories, the description of results here is based on PCR guideline[35]. This includes impact categories as following:

- Climate change (kg CO_2 equivalents)
- Terrestrial acidification (kg SO_2 equivalents)
- Freshwater eutrophication (kg P equivalents)

[34] The Sankey diagram is drawn in e!Sankey (trial version) software (www.e-sankey.com).

[35] With additional two impact categories that are noted in chapter 3.

- Human toxicity (kg 1.4-DB equivalents)
- Photochemical oxidation formation (kg NMVOC[6])
- Metal depletion (kg Fe equivalents)

Structure of results

To avoid impracticality of results projection in so much detail that lead to confusion, the structure of LCA model of high-speed rail electrification based on functional unit of one kilometer is presented in figure 5.2[36]. The figure shows the level of details by breaking down the section types (at level one) to individual input material (at level four). In addition, as an example of six different impact categories that has been mentioned, global warming potential is only considered to be shown in the figure; however, the potential impacts of other impact categories will be explained in the upcoming sections. Moreover, the column presents the relative potential impacts.

The figure 5.2 demonstrates a cascade effect that starts from section type at level one and goes to design-speed, life cycle phase, components, and individual input materials. The column on far left of the figure shows the section types that are either a kilometer of open section or a kilometer of tunnel section. The other column on the left side illustrates the design-speed that can be either Re330 or S25. Here, open section of system Re330 is considered as an example. After design-speed, the next column is life cycle phase that presents three life cycle of this study that are construction, maintenance & renewal, and disposal. Components are the next column that project how the emissions are distributed. Finally, the column on far right presents environmental impact (GWP) from components for the individual input materials.

In this chapter, based on the explanation in chapter 4, the main results of LCIA for open section and tunnel section is going to be shown and analyzed in accordance with the functional unit of one kilometer in sections 5.1. In continues, section 5.1.1 will break down open section of Re330 to their sub-processes and illustrates materials/items that contribute in the F.U. of a kilometer. Then, section 5.1.2 does the same technic, as section 5.1.1, for the F.U. of one kilometer in tunnel section. In section 5.2, the effect of HSR electrification on corridor planning is demonstrated, and alignment Ø2:P as an example of 12 different alignments shows how the emissions are with respect to the composition of the line (alignment Ø2:P). In

[36] The figure is inspired from "Life Cycle Assessment of the Follo Line – Infrastructure (New Double Track Line, Oslo – Ski)". (Bergsdal, Graarud, and Holen 2011)

addition, a set of sensitivity analyses is applied in section 5.3 to find out how sensitive the results from our analysis are for critical parameters.

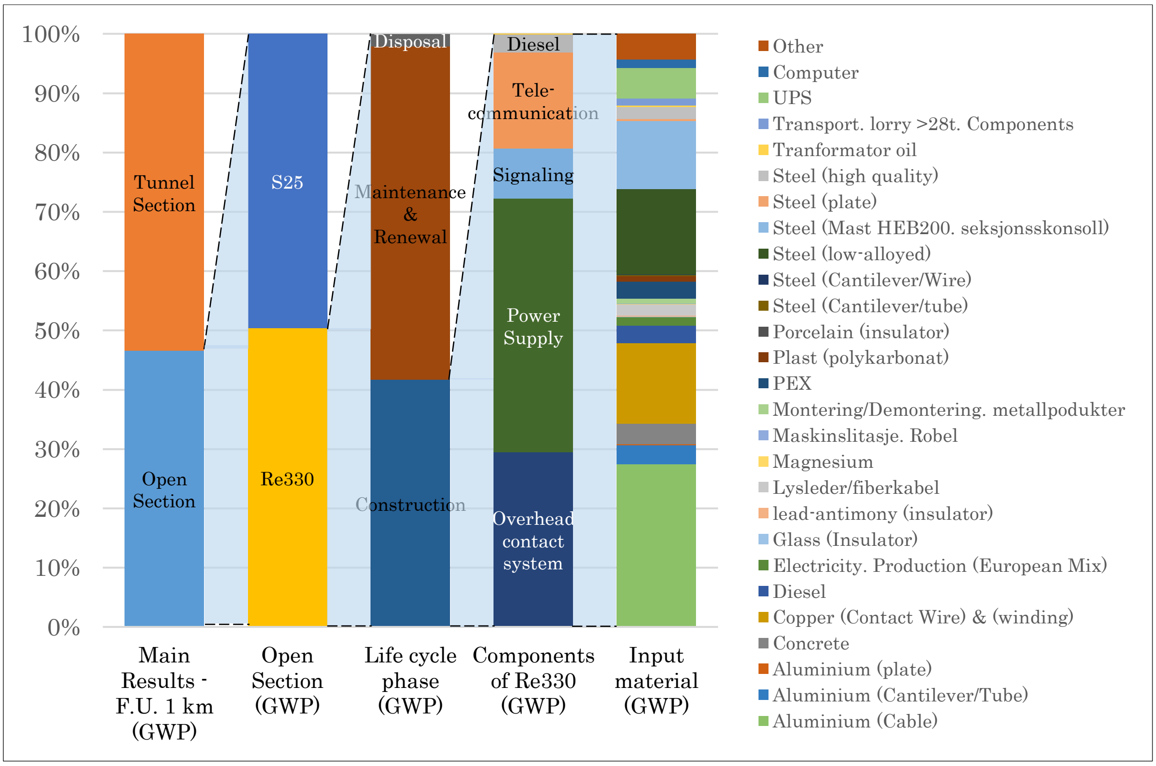


Figure 5.2: Breakdown of results from a section type (level 1) to design-speed alternatives (level 2), life cycle phases (level 3) and components (level 4) and input materials that trace to open section, Re330, construction, in the F.U. of one km.

5.1 Main results (F.U. 1 km)[37]

A general LCA model of railway electrification for a kilometer of open section and tunnel section of different design-speeds is shown in figure 5.3. The figure illustrates the relative environmental impacts of each system with respect to six impact categories. In addition, table 5.1 provides quantitative results related to figure 5.3. Moreover, the table presents cumulative energy demand (CED) based on the F.U. of one kilometer of HSR electrification that show tunnel sections (for the both design-speeds) have the highest energy demand compare to open sections.

Based on the outcomes from the figure, all the emissions are relatively close to each other and there are slightly differences in their potential impacts. If impacts from human toxicity and metal depletion are not considered, system Re330 in a kilometer of tunnel section has the highest impact. Moreover, S25 in open section has the lowest potential impact (except in metal depletion potential).

[37] The results only focuses on Re330; but, the results of S25 is provided in appendix E.

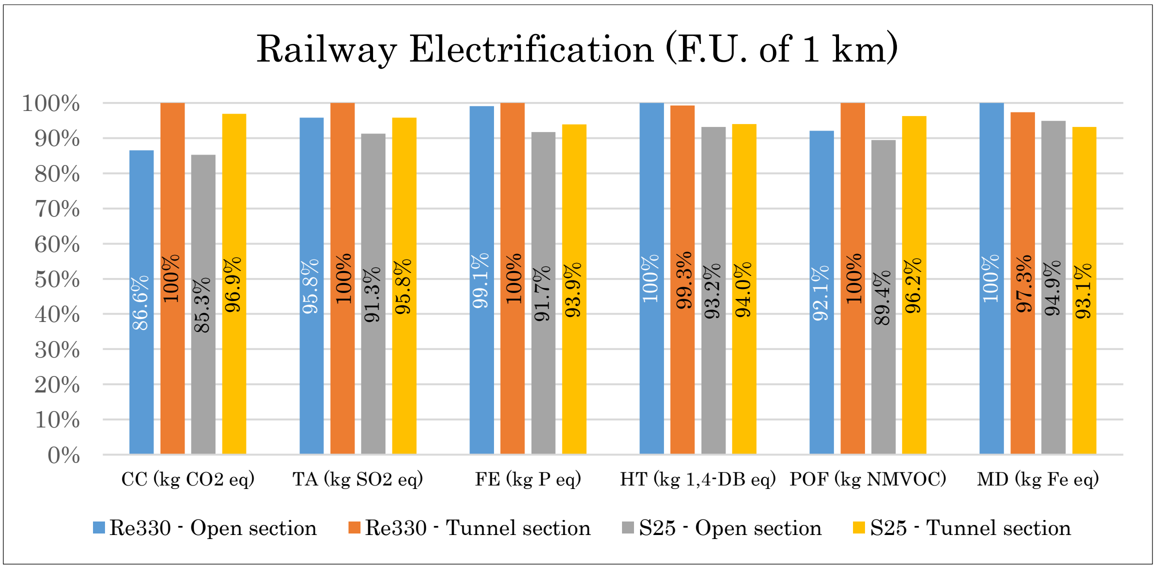


Figure 5.3: Life cycle impact assessment of HSR electrification (F.U. of 1 km)

- Tunnel section (for both Re330 and S25) has the highest impact in impact categories climate change and photochemical oxidation formation.
- It can be seen that tunnel section has a relative high contribution via system Re330 in terrestrial acidification. Nevertheless, system S25 in tunnel section and system Re330 in open section show the same potential impact in TA.
- The pattern of impact assessment is the same as TA in freshwater eutrophication, but with this difference, that Re330 in open section is the second highest contributor.
- Nevertheless, Re330 in open section is the highest contributor in human toxicity and metal depletion impact categories.

Table 5.1: Total results of life cycle impact assessment for the functional unit of one kilometer

Category	Open Section		Tunnel Section	
	Re330	S25	Re330	S25
Climate change (kg CO_2 eq)	3.30E+05	3.25E+05	3.82E+05	3.70E+05
Terrestrial acidification (kg SO_2 eq)	4.43E+03	4.22E+03	4.62E+03	4.43E+03
Freshwater eutrophication (kg P eq)	1.14E+03	1.05E+03	1.15E+03	1.08E+03
Human toxicity (kg 1,4-DB eq)	2.42E+06	2.23E+06	2.40E+06	2.25E+06
Photochemical oxidant formation (kg NMVOC)	2.08E+03	2.02E+03	2.26E+03	2.17E+03
Metal depletion (kg Fe eq)	7.34E+05	6.78E+05	7.14E+05	6.65E+05
Cumulative Energy Demand (TJ)	6.09E+00	6.01E+00	7.03E+00	6.89E+00

5.1.1 Life cycle phase - open section

Figure 5.4 presents the results of life cycle phase of open section (that is the break down of open section bar chart in figure 5.3) corresponding to the six impact categories. It could be seen that over 90% of emissions are coming from construction and maintenance & renewal. Maintenance & renewal show over 50% of contribution of potential impacts. In addition, table 5.2 provides quantitative results related to figure 5.4.

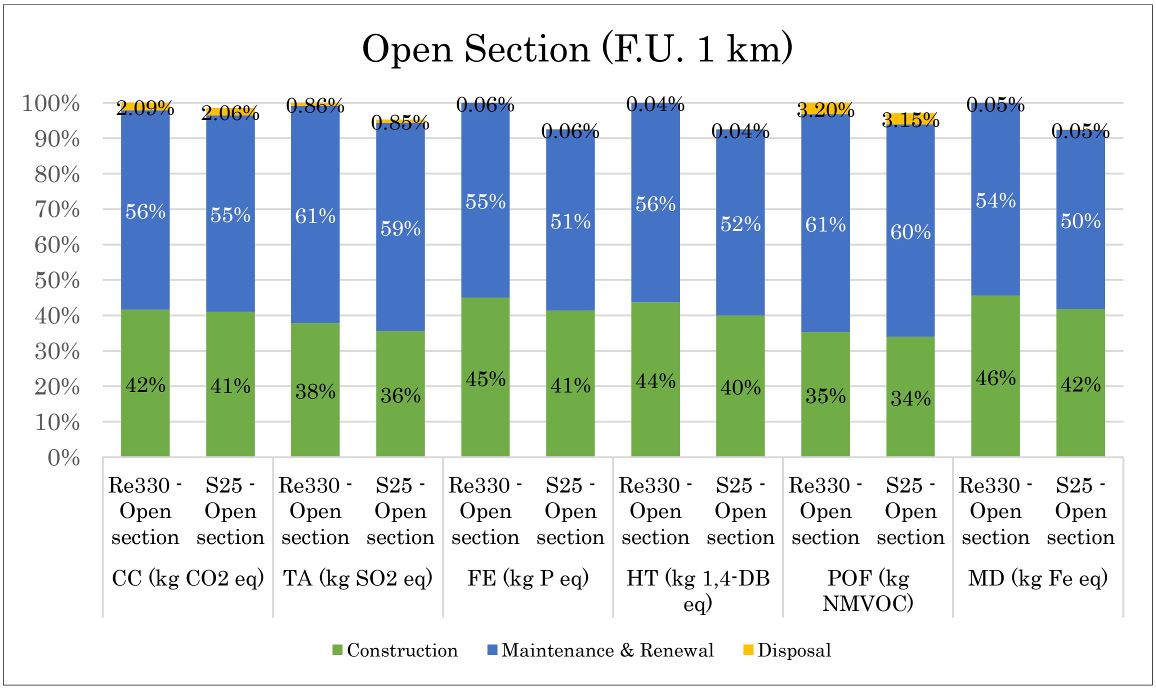


Figure 5.4: Life cycle impact assessment of different life cycle phases for two design-speeds in open section.

- The two design-speeds are following the same pattern in each impact category; however, Re330 has the highest environmental impacts compare to S25.
- The highest environmental impacts from disposal and maintenance & renewal are coming from photochemical oxidation formation impact category with a bit over 3% and 60% contributions, respectively (that are related to system Re330).
- The lowest potential impact from construction after POF is corresponded to terrestrial acidification with about 38% of contribution.

Table 5.2: Life cycle impact assessment of different life cycle phases for two design-speeds in open section.

Category	Re330			S25		
	Construction	Maintenance	Disposal	Construction	Maintenance	Disposal
CC (kg CO2 eq)	1.38E+05	1.86E+05	6.89E+03	1.35E+05	1.83E+05	6.79E+03
TA (kg SO2 eq)	1.68E+03	2.71E+03	3.82E+01	1.57E+03	2.61E+03	3.77E+01
FE (kg P eq)	5.13E+02	6.25E+02	6.61E-01	4.71E+02	5.82E+02	6.51E-01
HT (kg 1,4-DB eq)	1.06E+06	1.36E+06	8.74E+02	9.67E+05	1.27E+06	8.62E+02
POF (kg NMVOC)	7.34E+02	1.28E+03	6.65E+01	7.05E+02	1.25E+03	6.55E+01
MD (kg Fe eq)	3.35E+05	3.99E+05	3.73E+02	3.07E+05	3.71E+05	3.68E+02

5.1.1.1 Components of Re330 - open section

As a correspondence to figure 5.2, level four is associated with components. The three life cycle phases in figure 5.4 are broken down to their components in figure 5.5. As it could be seen, the structure of all three life cycle phases are comprised of six components that are: overhead contact system, power supply, signaling, telecommunication, diesel and machine wear. In addition, table 5.3 provides quantitative results related to figure 5.5.

NB. Machine wear has the lowest impact in construction and maintenance & renewal phases that leads to not to be observed in the bar chart.

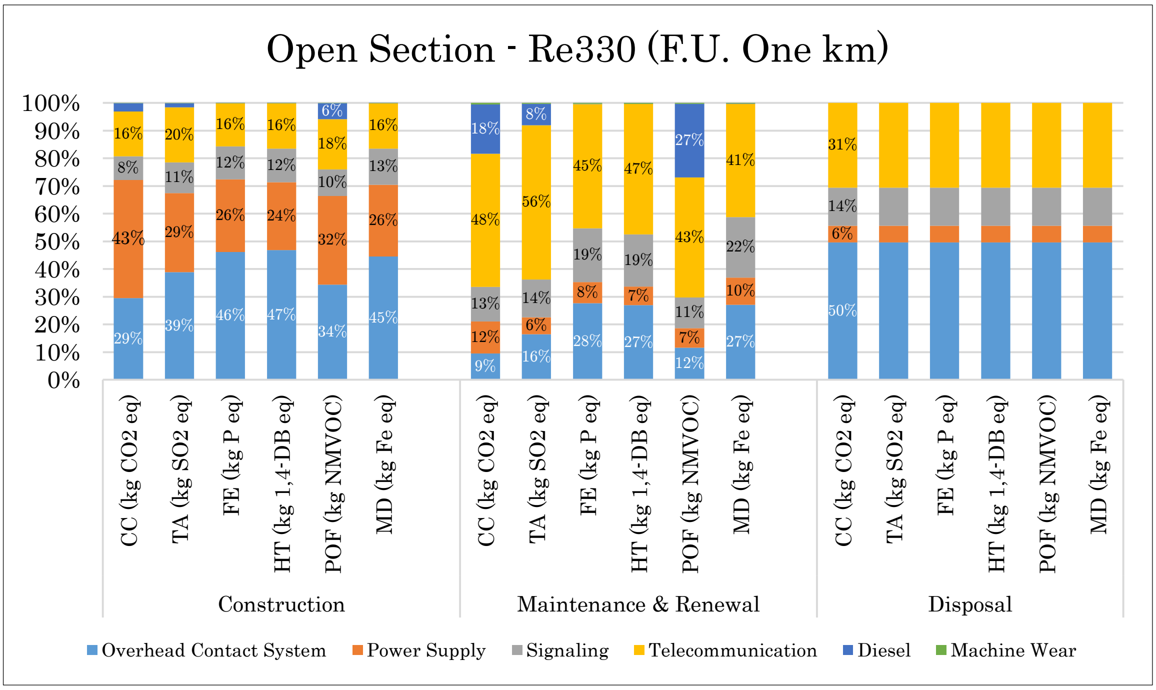


Figure 5.5: Life cycle impact assessment of system Re330 components in open section for different life cycle phases.

Here, the results of life cycle phases are described more in detail.

<u>Construction phase</u>

- Overhead contact system has slightly less than 50% of impact in impact categories freshwater eutrophication, human toxicity, and metal depletion
- The second most contribution is coming from power supply; however, it has the highest impact in global warming potential with 43% of impact.
- Telecommunication and signaling are the third and fourth contributors with approximately 18% and 12% of potential impacts, respectively.

- The highest impact from diesel is observed to occur in POF with 6% of contribution.

Maintenance & renewal phase

- On contrary to construction phase, telecommunication is ca. a dominant in all six-impacts categories.
- It could be seen; overhead contact system has the second greatest impact in FE, HT and MD with approx. 27% of contribution.
- However, diesel shows that it is the second highest contributor in CC and POF with 18% and 27% of potential impacts, respectively.
- Signaling shows the highest impact in metal depletion impact category with 22% of contribution and the lowest impact in photochemical oxidation formation impact category with 11% of potential impact.
- Power supply demonstrates overall 10% of contribution in the all six impact categories.

Table 5.3: Life cycle impact assessment of system Re330 components in open section for different life cycle phases.

Life Cycle Phase	Category	Overhead Contact System	Power Supply	Signaling	Telecommunication	Diesel	Machine Wear
Construction	CC (kg CO2 eq)	4.06E+04	5.89E+04	1.17E+04	2.23E+04	4.13E+03	1.20E+02
	TA (kg SO2 eq)	6.52E+02	4.80E+02	1.85E+02	3.33E+02	2.61E+01	1.10E+00
	FE (kg P eq)	2.37E+02	1.34E+02	6.09E+01	8.03E+01	1.23E-01	2.11E-01
	HT (kg 1,4-DB eq)	4.95E+05	2.59E+05	1.29E+05	1.74E+05	1.76E+02	4.45E+02
	POF (kg NMVOC)	2.53E+02	2.35E+02	7.08E+01	1.33E+02	4.24E+01	5.07E-01
	MD (kg Fe eq)	1.49E+05	8.66E+04	4.36E+04	5.50E+04	2.57E+01	1.25E+02
Maintenance & Renewal	CC (kg CO2 eq)	1.76E+04	2.14E+04	2.33E+04	8.94E+04	3.31E+04	8.91E+02
	TA (kg SO2 eq)	4.45E+02	1.67E+02	3.70E+02	1.51E+03	2.10E+02	8.16E+00
	FE (kg P eq)	1.73E+02	4.73E+01	1.22E+02	2.80E+02	9.87E-01	1.56E+00
	HT (kg 1,4-DB eq)	3.66E+05	9.08E+04	2.57E+05	6.39E+05	1.41E+03	3.29E+03
	POF (kg NMVOC)	1.48E+02	9.04E+01	1.42E+02	5.54E+02	3.40E+02	3.75E+00
	MD (kg Fe eq)	1.08E+05	3.89E+04	8.72E+04	1.63E+05	2.06E+02	9.28E+02
Disposal	CC (kg CO2 eq)	3.43E+03	4.11E+02	9.49E+02	2.11E+03	-	-
	TA (kg SO2 eq)	1.90E+01	2.28E+00	5.26E+00	1.17E+01	-	-
	FE (kg P eq)	3.28E-01	3.94E-02	9.09E-02	2.02E-01	-	-
	HT (kg 1,4-DB eq)	4.34E+02	5.21E+01	1.20E+02	2.67E+02	-	-
	POF (kg NMVOC)	3.30E+01	3.96E+00	9.15E+00	2.03E+01	-	-
	MD (kg Fe eq)	1.85E+02	2.22E+01	5.14E+01	1.14E+02	-	-

Disposal phase

As it is mentioned in chapter 4, the disposal phase only consists of transport of materials at the end of their lifetime to a hypothetical waste treatment plant in a distance of 200 kilometers from railway sites. Thus, in this phase of impact assessment the environmental performance looks the same for the six impact categories (due to contribution of only transportation).

As long as the unit of transport is tonne kilometer (tkm), the weight of components is playing a key role. Therefore, overhead contact system with 50% and telecommunication with 31% of contributions have the first and second highest potential impacts, respectively (due to the mass of their input materials).

NB. Diesel and machine wear are not contributing in the disposal phase due to this fact that they are excluded from this phase.

5.1.1.1.1 Construction of individual input materials, Re330 - open section

Figure 5.6 is corresponding to the far left column in figure 5.2 that represents the individual input factors and materials for construction of Re330 in a kilometer of open section. As it could be observed, on contrary to other impact categories that only one or two input materials are dominants, different materials are contributing in climate change impact category.

- Aluminium (cable)[38] with 27.5% of contribution has the highest impact in CC, and it is followed by steel (low-alloyed) and copper (wire) with 14.4% and 13.6% of contribution, respectively.
- Aluminium (cable) also presents a performance of being a second contributor in POF and TA by 13% and 9.4%, respectively.
- However, copper (wire)[39] is the most important contributor in TA, FE, HT, POF and MD. The potential impact is above 79% in FE, HT and MD, and it demonstrates a performance of 62.6% and 39.2% of impact in impact categories TA and POF, respectively.
- Steel (mast HEB200) on contrary to the result from (E. Ebrahimi 2014) shows a performance of 11.5% and 7.7% in CC and POF, respectively. The reason of reduction in performance is due to alteration in the background process from chromium steel "that is called as steel (high-quality)" to reinforcement steel "that is called as steel (low-alloyed)"[40].

[38] In this study aluminium (cable) is the total sum of aluminium, aluminium (cable) and kobling (aluminium) that are modelled on SimaPro. However, in appendix D all of them are named by the name of "Aluminium (cable)".

[39] In this study copper (wire) is the total sum of copper (Contact Wire) & (winding), kobber (signal) that are modeled on SimaPro. However, in appendix D all of them are named by the name of "Copper (Contact Wire) & (winding)".

[40] In appendix D (on pages D12 and D13), a detail of these processes is shown.

- The other input material that has a bit of potential after the crucial ones is UPS that has a contribution in impact categories terrestrial acidification, photochemical oxidation and climate change.

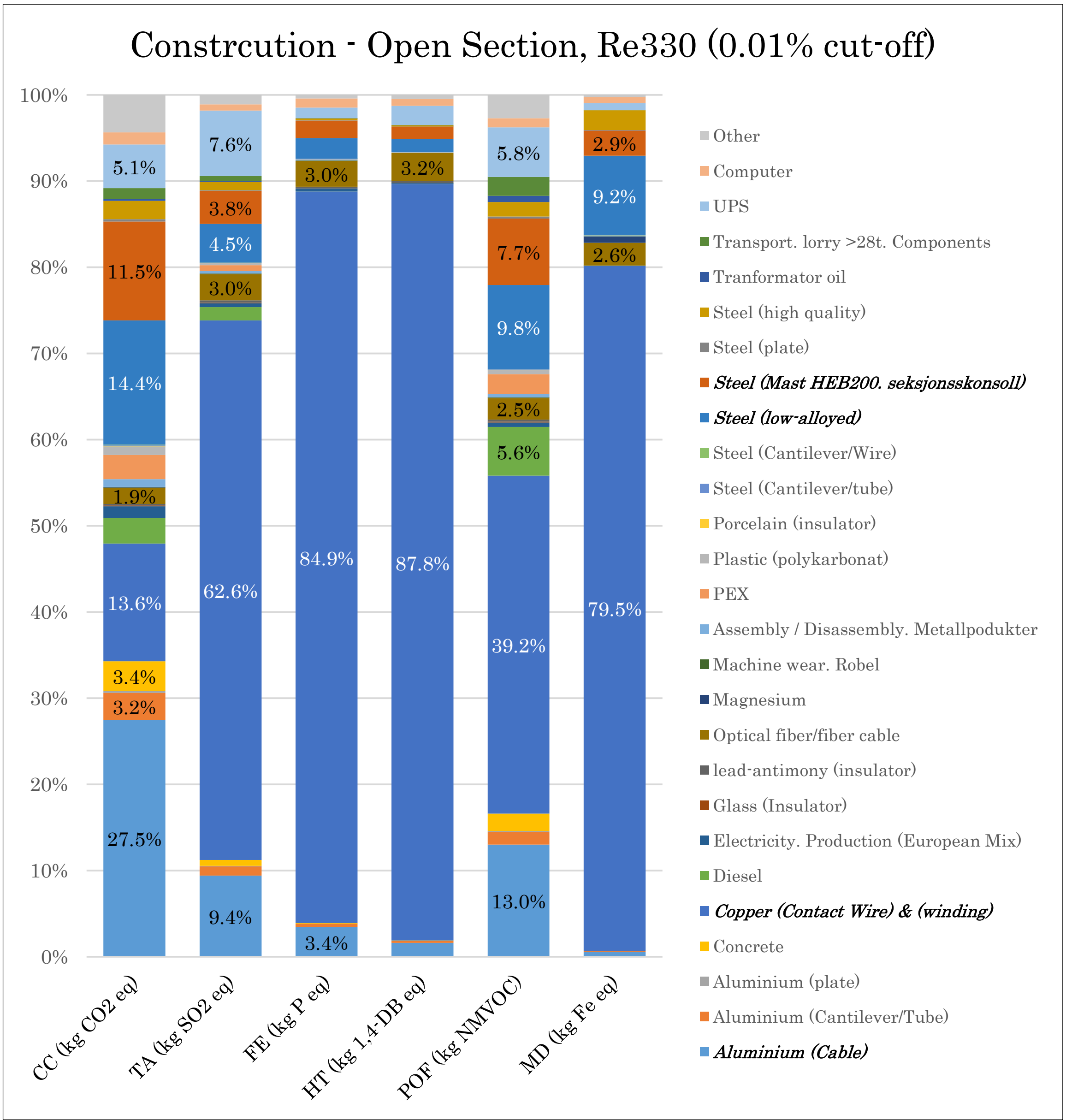


Figure 5.6: Life cycle impact assessment of individual input materials from system Re330 components in open section for the construction phase.

5.1.1.1.2 M&R of individual input materials, Re330 - open section

In maintenance & renewal phase of individual input factors/materials for system Re330 in a kilometer of open section, the results are shifting slightly to other materials (through the 60 years of lifetime) that are shown in figure 5.7. In maintenance & renewal, copper (wire), UPS and diesel perform to be the highest contributors.

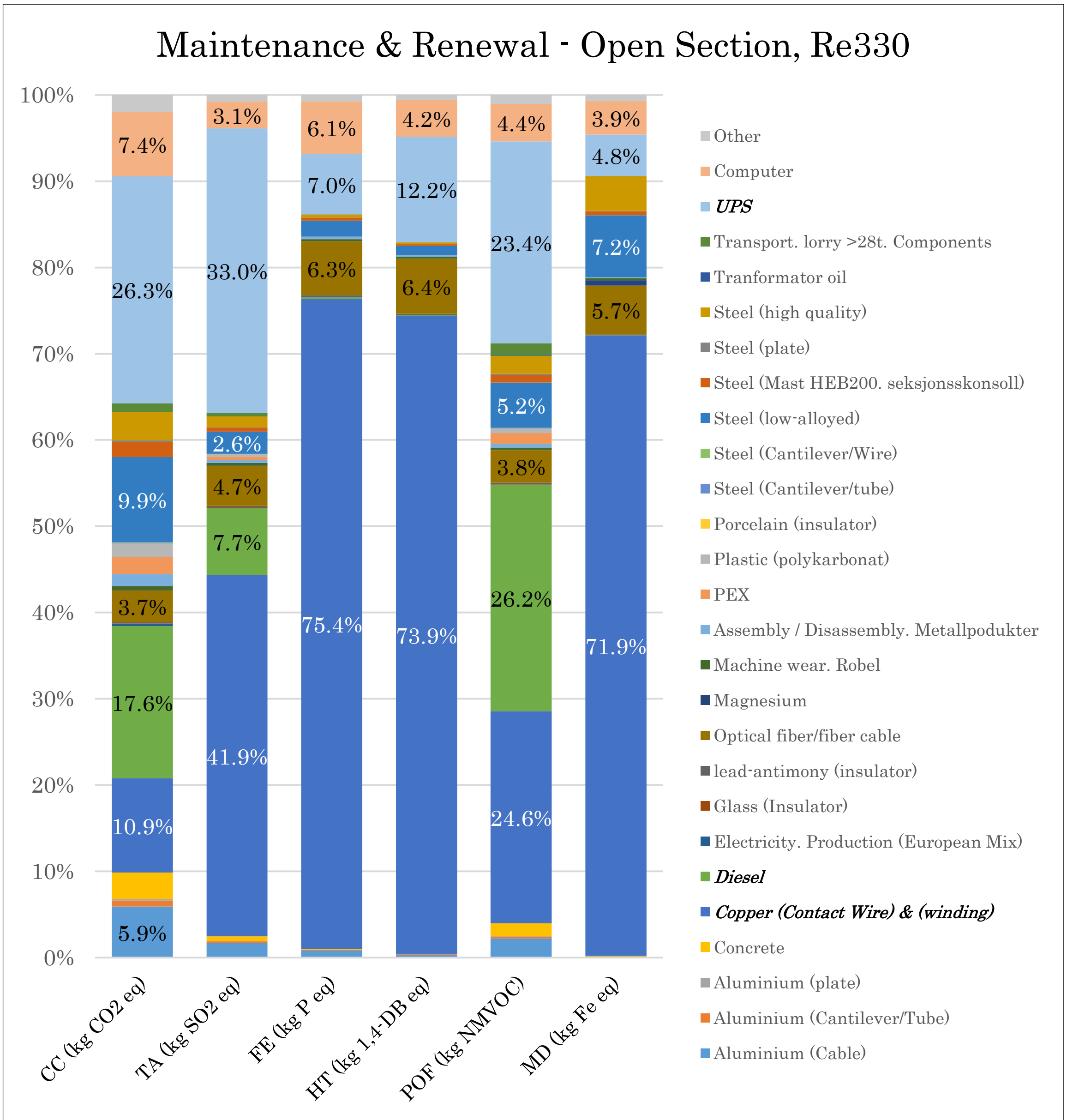


Figure 5.7: Life cycle impact assessment of individual input materials from system Re330 components in open section for the maintenance and renewal phase.

- Clime change still shows the contribution is not dominated by only one material; however, this time UPS[41] and diesel are projected as materials with highest contributions (with 26.3% and 17.6% of impacts, respectively) in climate change impact category.

[41] UPS is a repetitive of batteries in accordance with (AAS-JAKOBSEN 2012, Ovedal et al. 2012, Stripple and Uppenberg 2010).

- It could be seen aluminium (cable) and steel (low-alloyed) do not have a considerable impact in the M&R phase (as they showed in the maintenance phase).
- Copper (wire), UPS and diesel show that they are the main contributors in both TA and POF.
- In spite of various materials involvements in FE, HT and MD, the potential impact of copper is by far more than 71% of total in the mentioned impact categories.

5.1.2 Life cycle phase - tunnel section

As a continuation of life cycle impact assessment, after open section, it is time to start the assessment for a kilometer of tunnel section. The structure of tunnel section will be the same as open section. This means the interpretation starts with life cycle phase of tunnel section, and then goes to components and at the end it finishes with the individual input materials.

Figure 5.8 demonstrates the relative environmental impacts in tunnel section from the two design- speeds for the six impact categories. The same as open section, over

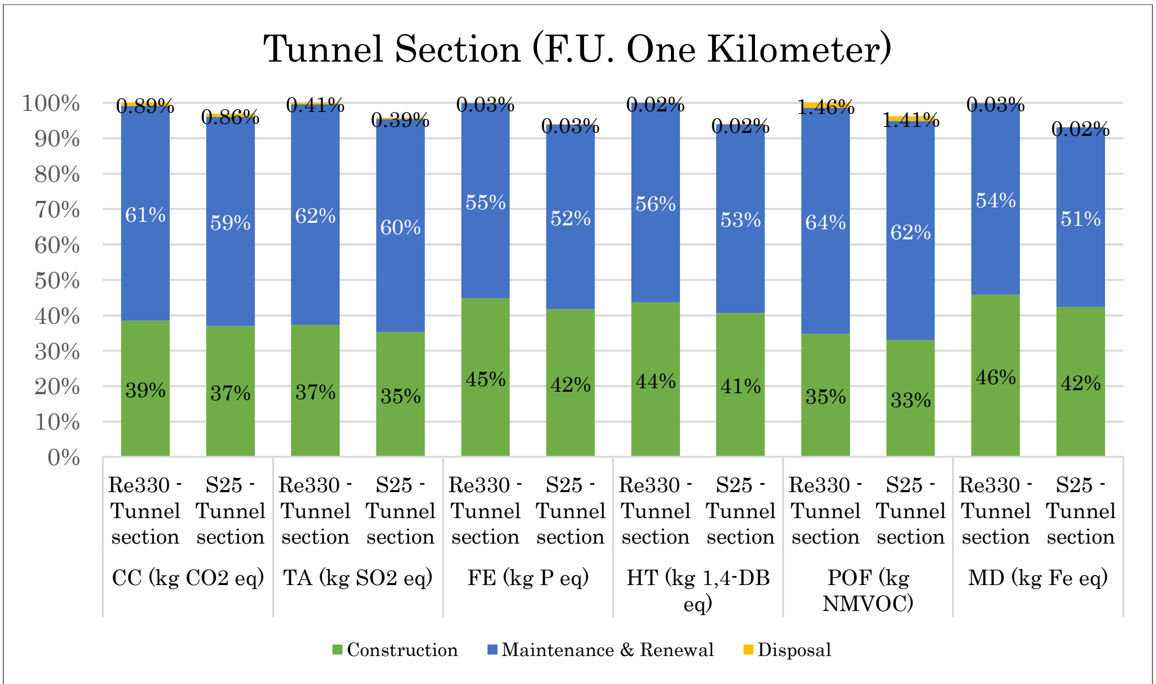


Figure 5.8: Life cycle impact assessment of different life cycle phases for two design-speeds in tunnel section.

90% of impacts are coming from construction, and maintenance & renewal; nevertheless, maintenance & renewal has the highest impacts in the six impact categories. In addition, table 5.4 provides quantitative results of figure 5.8.

- The pattern of two design-speeds is following the same criteria in each impact category; however, Re330 has the highest environmental impacts compare to S25.
- The highest environmental impacts from disposal, and maintenance & renewal is observed coming from impact categories photochemical oxidation formation with a bit over 1% and 64% contributions, respectively (that both are correlated to system Re330).
- The lowest potential impact from construction after POF impact category is corresponded to terrestrial acidification with about 3% of contribution.

Table 5.4: Life cycle impact assessment of different life cycle phases for two design-speeds in tunnel section.

Category	Re330			S25		
	Construction	Maintenance	Disposal	Construction	Maintenance	Disposal
CC (kg CO2 eq)	1.47E+05	2.31E+05	3.41E+03	1.41E+05	2.25E+05	3.29E+03
TA (kg SO2 eq)	1.73E+03	2.88E+03	1.89E+01	1.63E+03	2.78E+03	1.82E+01
FE (kg P eq)	5.14E+02	6.34E+02	3.27E-01	4.79E+02	5.99E+02	3.15E-01
HT (kg 1,4-DB eq)	1.05E+06	1.35E+06	4.33E+02	9.76E+05	1.28E+06	4.17E+02
POF (kg NMVOC)	7.86E+02	1.44E+03	3.29E+01	7.44E+02	1.40E+03	3.17E+01
MD (kg Fe eq)	3.27E+05	3.87E+05	1.85E+02	3.03E+05	3.62E+05	1.78E+02

5.1.2.1 Components of Re330 - tunnel section

Figure 5.9 shows the environmental impacts related to components of system Re330 for a kilometer of tunnel section. As it could be seen, in addition to the six components in open section (overhead contact system, power supply, signaling, telecommunication, diesel and machine wear), lighting and fans[42] are contributing. In addition, table 5.5 provides quantitative environmental impacts information corresponding to figure 5.9.

NB. Machine wear has the lowest impact in construction and maintenance & renewal phases that leads to not be observed in the bar chart.

The results of each life cycle phase are described more in detail as following.

[42] Here, lighting and fans are the representatives of "other installations" that has been mentioned in table 4.5 in chapter 4.

Construction phase

- Overhead contact system has less than 50% of impact in impact categories freshwater eutrophication, human toxicity and metal depletion.
- The second most contributor is power supply by the average contribution of 27% in all impact categories (except in climate change); however, it has the highest impact in global warming potential with 40% of impact.
- Telecommunication is the third contributor with approximately 17% of potential impact. However, the forth-highest considerable impact is coming from signaling (with 10% in HT) or lighting & fans (with 13% in CC) or diesel (with 10% in POF).

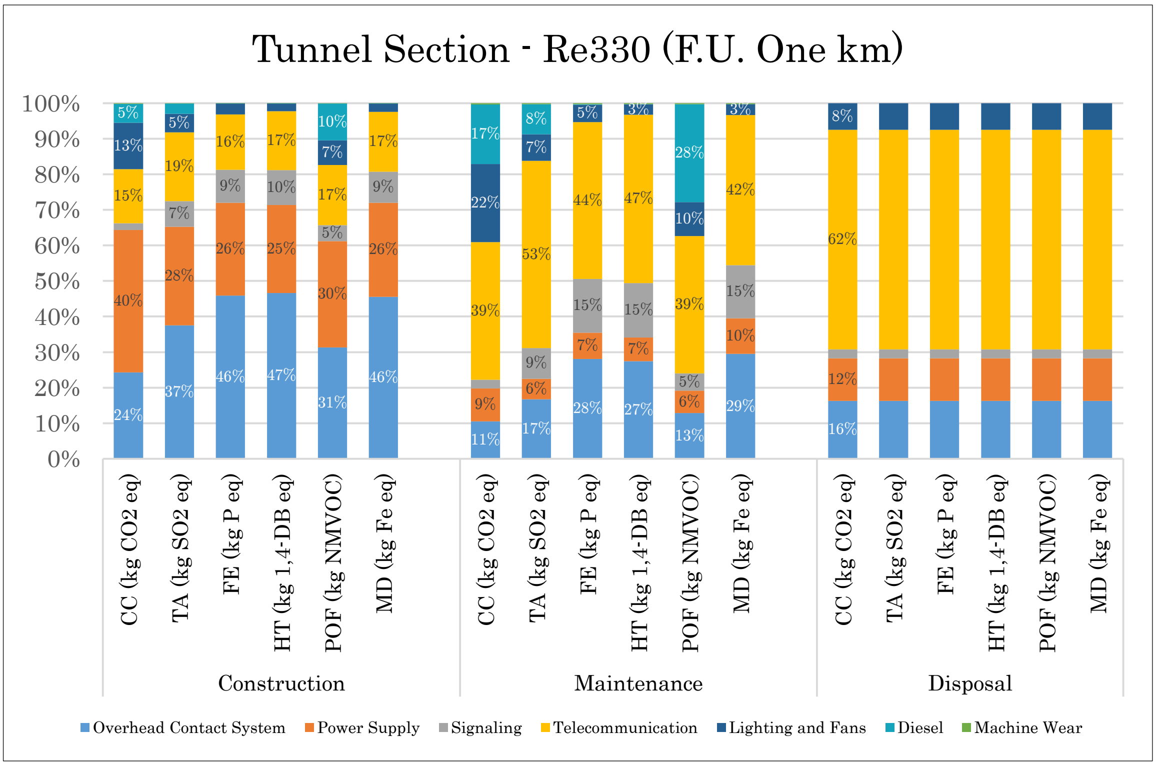


Figure 5.9: Life cycle impact assessment of system Re330 components in tunnel section for different life cycle phases.

Maintenance & renewal phase

- On contrary to construction phase, telecommunication is by far has the highest impact in all impact categories with more than 39% of potential impacts.
- It could be seen; overhead contact system has the second greatest impacts in FE, HT and MD with approx. 28% of contribution.

- However, lighting & fans and diesel showed that they are the second highest contributors in CC (with 22%) and POF (with 28%) of potential impacts, respectively.
- Signaling shows the highest share of potential impacts is coming from MD, HT and FE with 15% of contribution.
- Power supply demonstrates, overall, 7% of contribution in all six-impact categories.

Disposal phase

As it explained in section 5.1.1.1, the environmental effects from transportation is correlated to weight of materials through the entire life cycle (due to this fact that transportation is the only process that represents in the disposal life cycle phase). However, on the contrary to the open section (that OCS has a leading role in the disposal phase), telecommunication is taking a dominant role in the environmental impacts corresponding to disposal phase. This is because of this fact that the masts and concrete are not existing in OCS of tunnel section.

NB. Diesel and machine wear are not contributing in the disposal phase due to this fact that they are excluded from this phase.

Table 5.5: Life cycle impact assessment of system Re330 components in tunnel section for different life cycle phases.

Life Cycle Phase	Category	Overhead Contact System	Power Supply	Signaling	Telecommunication	Lighting & Fans	Diesel	Machine Wear
Construction	CC (kg CO2 eq)	3.58E+04	5.89E+04	2.77E+03	2.23E+04	1.91E+04	7.93E+03	2.15E+02
	TA (kg SO2 eq)	6.47E+02	4.80E+02	1.24E+02	3.33E+02	8.97E+01	5.01E+01	1.97E+00
	FE (kg P eq)	2.36E+02	1.34E+02	4.77E+01	8.03E+01	1.54E+01	2.36E-01	3.77E-01
	HT (kg 1,4-DB eq)	4.89E+05	2.59E+05	1.03E+05	1.74E+05	2.27E+04	3.37E+02	7.94E+02
	POF (kg NMVOC)	2.46E+02	2.35E+02	3.54E+01	1.33E+02	5.46E+01	8.14E+01	9.05E-01
	MD (kg Fe eq)	1.49E+05	8.66E+04	2.87E+04	5.50E+04	7.67E+03	4.93E+01	2.24E+02
Maintenance & Renewal	CC (kg CO2 eq)	2.44E+04	2.14E+04	5.54E+03	8.94E+04	5.09E+04	3.86E+04	8.91E+02
	TA (kg SO2 eq)	4.80E+02	1.67E+02	2.48E+02	1.51E+03	2.15E+02	2.44E+02	8.16E+00
	FE (kg P eq)	1.78E+02	4.73E+01	9.54E+01	2.80E+02	3.07E+01	1.15E+00	1.56E+00
	HT (kg 1,4-DB eq)	3.70E+05	9.08E+04	2.06E+05	6.39E+05	3.84E+04	1.64E+03	3.29E+03
	POF (kg NMVOC)	1.85E+02	9.04E+01	7.08E+01	5.54E+02	1.38E+02	3.96E+02	3.75E+00
	MD (kg Fe eq)	1.14E+05	3.89E+04	5.75E+04	1.63E+05	1.18E+04	2.40E+02	9.28E+02
Disposal	CC (kg CO2 eq)	5.55E+02	4.11E+02	8.36E+01	2.11E+03	2.56E+02	-	-
	TA (kg SO2 eq)	3.08E+00	2.28E+00	4.64E-01	1.17E+01	1.42E+00	-	-
	FE (kg P eq)	5.32E-02	3.94E-02	8.01E-03	2.02E-01	2.46E-02	-	-
	HT (kg 1,4-DB eq)	7.04E+01	5.21E+01	1.06E+01	2.67E+02	3.25E+01	-	-
	POF (kg NMVOC)	5.35E+00	3.96E+00	8.06E-01	2.03E+01	2.47E+00	-	-
	MD (kg Fe eq)	3.00E+01	2.22E+01	4.53E+00	1.14E+02	1.39E+01	-	-

5.1.2.1.1 Construction of individual input materials, Re330 - tunnel section

Figure 5.10 demonstrates the individual input factors and materials for construction of Re330 in a kilometer of tunnel section. As it could be seen like figure 5.6 from open section, the impacts from input materials is well distributed in climate change impact category (and somehow in POF) compare to other impact categories. Due to this fact that only one or two input materials dominate in the other impact categories.

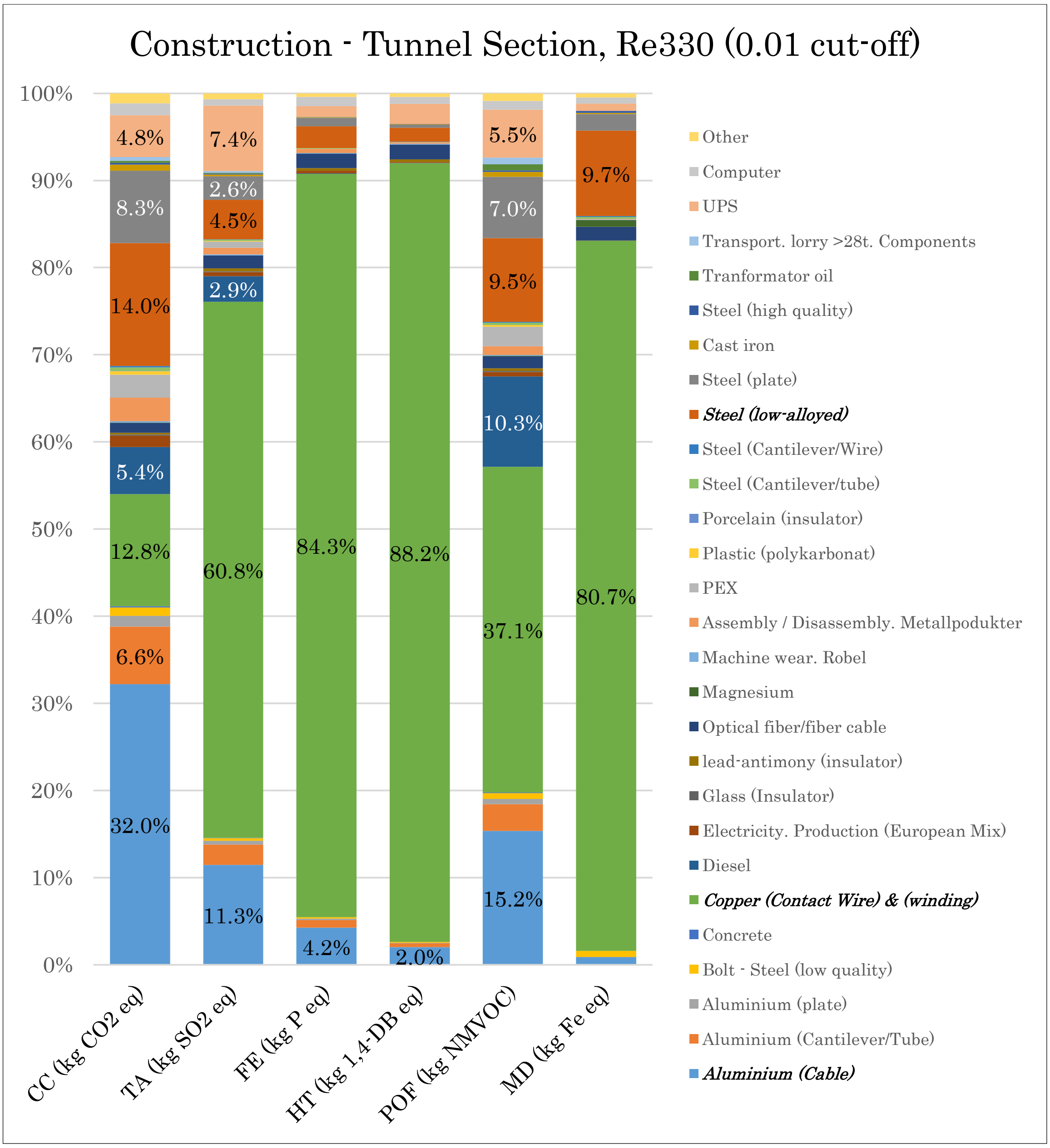


Figure 5.10: Life cycle impact assessment of individual input materials from system Re330 components in tunnel section for the construction phase.

- Aluminium (cable) with 32% of contribution has the highest impact in CC impact category, and it is followed by steel (low-alloyed) and copper (wire) with 14% and 12.8% of contributions, respectively.
- Aluminium (cable) also performs as being the second highest contributor (after copper) in POF and TA by 15.2% and 11.3% impacts, respectively.

- However, copper (wire) has the highest environmental emissions in TA, FE, HT, POF and MD. The highest contribution occurs in human toxicity with 88.2% of impact and the lowest happens in POF with 37.1% of potential impact.
- The other materials that have a bit of potential after the curtail ones (that are noted) are UPS, steel (plate)[43], diesel, and aluminium (cantilever/tube), which most of them show their influences in POF, TA and CC impact categories.

5.1.2.1.2 M&R of individual input materials, Re330 - tunnel section

In maintenance & renewal phase of individual input factors/materials for system Re330 in a kilometer of tunnel section, the results are shifting slightly to other materials that are shown in figure 5.11. In maintenance & renewal, copper (wire), UPS and diesel perform to be the highest contributors (which is the same as M&R of open section in figure 5.7).

- The potential impact corresponding to aluminium (cable) is the greatest in CC impact category (after UPS with 21.3% of contribution) and it has an impact of 6.9% and 5.6% for POF and TA impact categories, respectively.
- Clime change still shows the contribution is not dominated only by one material. UPS and diesel are projected as materials with highest contributions (with 21.3% and 16.6% of impacts, respectively) in CC on contrary to construction phase in tunnel section (that was from steel (low-alloyed) and copper).
- Copper (wire), UPS and diesel show that they are the main contributors in both TA and POF.
- In spite of various materials involvements in FE, HT and MD, the potential impact of copper is by far more than 72% of the total contribution from the rest of input materials.
- The other materials that have a bit of potential after the curtail ones (that are noted) are, steel (plate), computer, and optical fiber/fiber cable, which most of them show their influences in POF, TA and CC impact categories.

[43] Steel (plate) is related to tensioning weights in tunnel section, which in open section the tensioning weights are made of concrete.

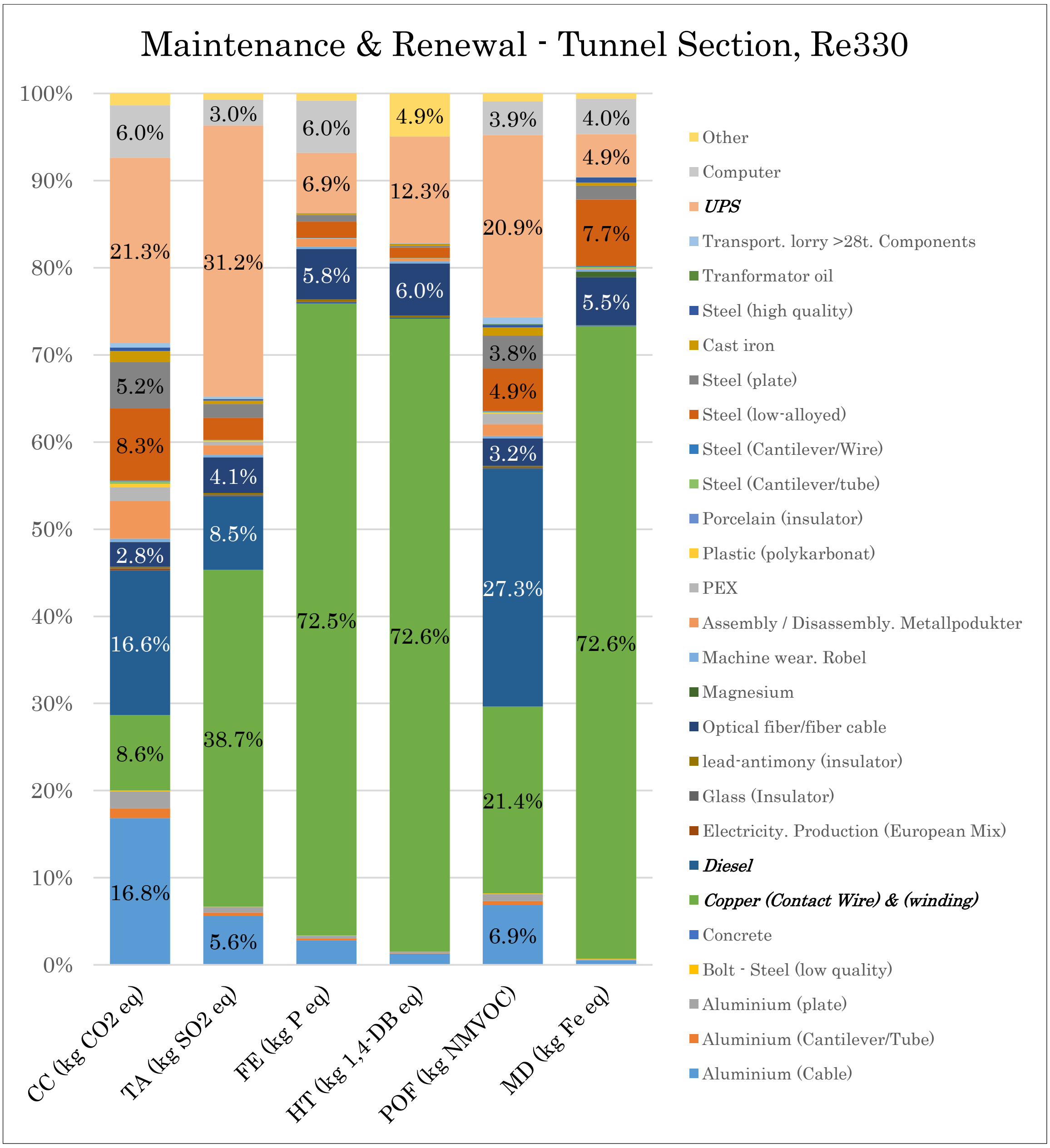


Figure 5.11: Life cycle impact assessment of individual input materials from system Re330 components in tunnel section for the construction phase.

5.2 Corridor planning

After describing the environmental effects of railway electrification for the functional unit of one kilometer, it is time to apply the results from section 5.1 to related corridors. As it mentioned in chapter 4, the calculation procedure that is going to be used is to change the functional unit from one kilometer to the length of corresponding section type and design-speed in corridor planning. For instance, if alignment Ø2:P is considered for the evaluation of environmental impacts of HSR electrification, it will be done as following.

The total length of alignment is 409.49 kilometers of double-track (it also could be seen in table 4.1) that consists of 232.18 km of open section Re330, 6.08 km of open section S25, 150.35 km of tunnel section Re330, and 20.89 km of tunnel section S25. Hence, the calculation of functional unit in SimaPro is adjusted to two times of corresponding lengths of each design-speed of section type. The reason of multiplication of length by two is due to this fact that the calculation that has been driven for section 5.1 is based on the functional unit of one kilometer of single-track.

By applying the same technic for the calculation of LCIA of corridor planning, it could be observed, despite the fact that the compositions of alignments are different (due to different length, section types, and design-speeds); the results of relative potential impacts are following the same pattern. As a consequence, it is decided to show the environmental impact of alignment Ø2:P from the corridor north as an as example of other 11 alignments. In addition, the life cycle impact assessments of all alignments are provided in appendix H.

5.2.1 Main results

After calculation of the potential impacts from HSR electrification, it seems to be a good opportunity to compare the results from this study with the initial study of Norwegian HSR electrification (Bergsdal et al. 2012) to see how much the results have been changed/improved.

Figure 5.12 juxtaposes the results of environmental impacts from this study with the initial study. As it is observed, this thesis, due to higher level of details, improved the results for potential impacts with different resolutions compare to study from (MiSA AS). To have a better picture of how much emissions increased from this study, blue dashed rectangular outlines are added on top of bar charts from the initial study to illustrate how much the results differ in comparison with this thesis (which in the figure it is named as “New electrification”).

NB. Only results with more than 6% are shown inside the dashed rectangular outlines. In addition, As long as the focus of this study is on HSR electrification, it is considered that the emissions from “rest of infrastructure”[44] that is shown as blue bars are the same for both studies.

[44] “Rest of infrastructure” embraces all the processes that are related to HSR electrification such as construction of tunnels, bridges, earthwork etc. that are not related to HSR electrification.

- The figure shows that the emissions from impact categories climate change and photochemical oxidation formation is increased by less than 2%.
- However, the increase in potential impacts in this study (in comparison with the initial one) is greater for the other four six-impact categories. The Highest increase in impact is related to human toxicity with more than 29% and it is followed by freshwater eutrophication with 22.2% of impact (which is mainly due to copper (wire)).
- An interesting observation that can obtain from this graph is that HSR electrification has approx. 47% contribution in HT[45] and 37.51% contribution in FE of total impacts in the LCA of HSR infrastructure.

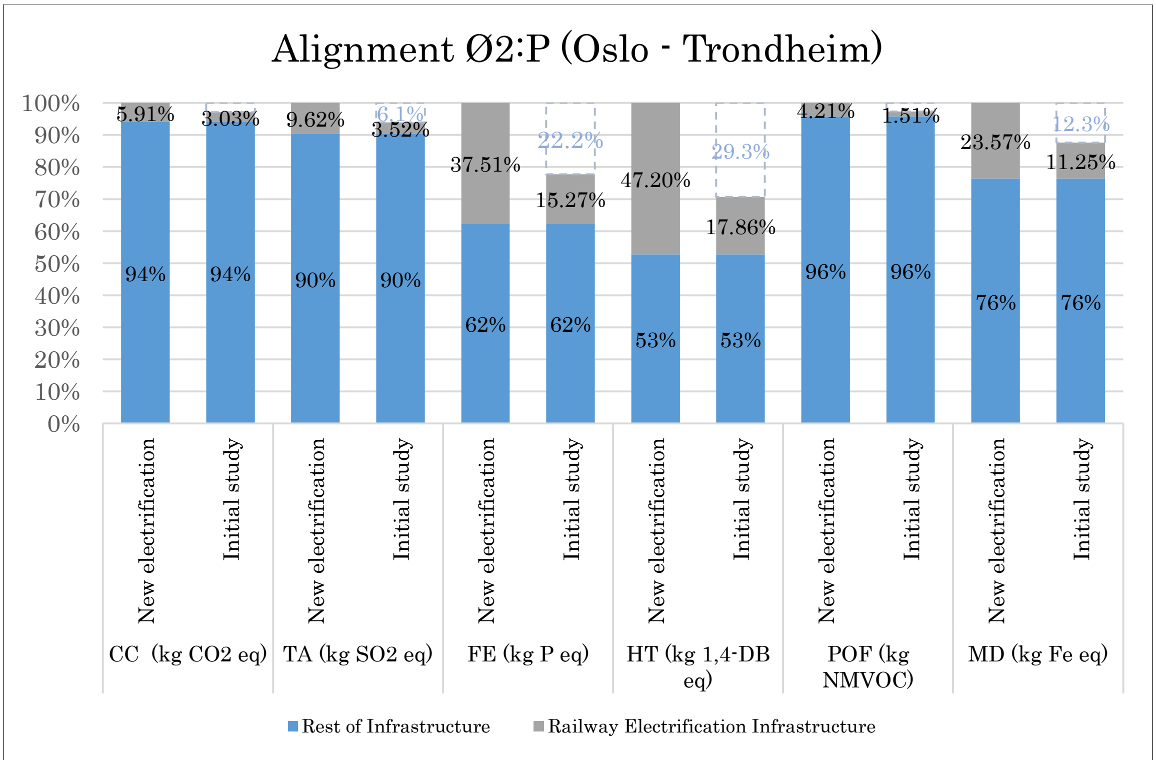


Figure 5.12: The analogy of LCIA of railway electrification between the results from this thesis and study from (MiSA AS).

5.2.1.1 Construction of alignment Ø2:P[46]

Figure 5.13 is the representative of environmental impacts from construction phase of HSR electrification in alignment Ø2:P. As it is shown, figure 5.13 magnifies the potential impact from global warming potential and then illustrates the impacts

[45] In chapter 6 (section 6.4), the uncertainties of HT is discussed.

[46] To eliminate any kinds of imperfection in projection of results, it is decided to take the same procedure as it has been used in section 5.1. Thus, the results are shown in the cascade pattern (like figure 5.2).

from the rest of impact categories underneath it. In addition, it has been attempted to label bars in GWP bar chart with their correlated names to provide a good flow of information for the readers; however, it could not be possible to do the same for the other impact categories. As a result, it is decided to show the corresponding bars with same colors in the all six impact categories. This tactic was the only solution that could facilitate the issue of not having enough space.

By having a look at the graph, it could be seen that the far left bar chart represents the potential impacts from railway electrification and rest of infrastructure. Rest of infrastructure is comprised of all equipment that are needed to contracture a line like earthwork, construction of tunnels, bridges, track bed, electricity for operation of electrical equipment and so forth that are not dealing with electrification of a high-speed rail infrastructure (that is the concern of this thesis).

The second bar chart from the left side demonstrates the spectrum of life cycle phases that consist of construction, maintenance & renewal, and disposal.

The next bar chart after the life cycle phases expands the construction phase from the life cycle phase bar chart, by showing the compositions of alignment Ø2:P that is comprised of two section types (tunnel section and open section) for design-speeds S25 and Re330. The results that are obtained from the composition of construction phase might show a contrary to the results from figure 5.3.The reason of having higher contribution from the open section – Re330 compare to the tunnel section – Re330 is due to length variation. As it mentioned in the introduction of this section (5.2), more open section of system Re330 are involving than tunnel section of the same design-speed.

Finally, the far right bar chart in the graph illustrates the environmental impacts of individual input material from the construction of entire alignment Ø2:P. The information that is provided helped to give a holistic view of figures 5.13, and 5.14. Owing to the fact that the structure of figures is having the same basis. Now, it is time for going to the details of figure 5.13 and try to show how the environmental performances are varying in corridor planning. It is decided to concentrate each time on one bar (i.e. input material) and then endeavor to compare it with all impact categories. However, LCIA of Ø2:P bar (in figure 5.13) is not going to be explained due to the discussion that has been made in section 5.2.1 (figure 5.12).

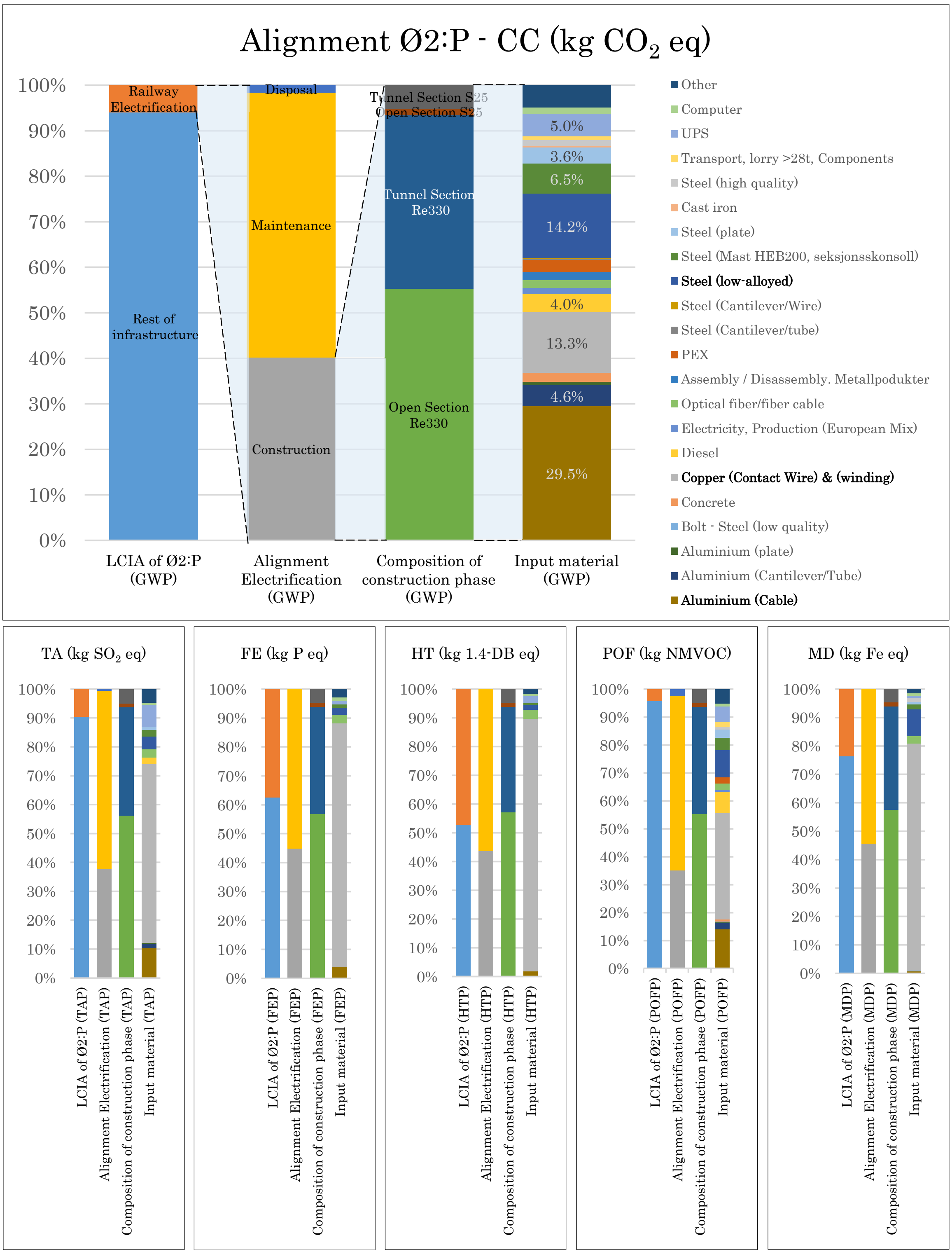


Figure 5.13: Breakdown of construction phase of alignment Ø2:P for all the six-impact categories.

Alignment electrification

As it could be seen, still maintenance & renewal is the dominant life cycle phase and has the highest impacts in all six-impact categories, and it is chased by construction phase that has in average 40% of environmental impacts. Despite of great contribution from construction and maintenance & renewal, the emissions from disposal phase is still limited to a small fraction in the LCIA of HSR electrification in alignment Ø2:P.

Composition of construction phase

Composition of construction phase for all impact categories show approximately the same environmental performance, which open section - Re330 with more than 50% of contribution is placed as the highest contributor and followed by tunnel section - Re330 with about 40% of impacts.

Input material

Although the variation in composition of an alignment leads to changes in associated impacts related to section types and design-speeds, the results from input material points out nearly the same results from section 5.1 for individual design-speeds in different section types.

The reason of having such performance is because of having relatively some similar inputs (with slightly differences). As it described in chapter 4 of this thesis, it is assumed that all systems of design-speeds in both section types are having the same description of input material for power supply and telecommunication; and lighting & fans are the same for tunnel section of Re330 and S25. However, the dissimilarities are coming from signaling and overhead contact systems. Signaling is divided into signaling for open section and tunnel section, which are not differing for different design-speeds. On contrary, overhead contact systems are specific for different design-speeds and different section types.

Some of important input materials that can be observed from figure 5.13 are explained below.

- Aluminium (cable) with 29.5% and steel (low-alloyed) with 14.2% of impacts are projected as materials with the highest contributions in CC impact category. However, in POF, copper (wire) with 38% of potential impact has higher impact, and it is followed by aluminium (cable) with 14% of contribution.
- Copper (wire) shows that it is the main contributor in impact categories TA, FE, HT and MD by far more than 60% of potential impact in the mentioned impact categories.

- Steel (low-alloyed), UPS, steel (mast HEB200), and optical fiber/fiber cable are other materials that demonstrate having impacts after copper and aluminium (cable) in the construction phase.

5.2.1.2 Maintenance & renewal of alignment Ø2:P

Figure 5.14 is the representative of environmental impacts from the maintenance & renewal phase of HSR electrification in alignment Ø2:P. The same as construction phase in figure 5.13; figure 5.14 magnifies the potential impact in climate change and then illustrates the impacts from the rest of impact categories underneath it. Because of avoiding impracticality of repetition of same explanation that has been done for section 5.2.1.1, it is tried to only highlight changes in maintenance & renewal of HSR electrification in alignment Ø2:P with respect to the construction phase.

The Structures of bar charts in this section is the same as construction phase. The same as construction phase the focus is only on one bar each time and then try to compare it with all impact categories. Moreover, no time is planned to be spent on describing LCIA of Ø2:P and alignment electrification bars due to consisting of the same information as the construction phase in section 5.2.1.1.

Composition of maintenance & renewal phase

The structure of composition of M&R phase follows the same basis for all impact categories. Open section - Re330 with more than half of contribution has the highest impact and tunnel section - Re330 with approx. 40% of impacts is shown as the second largest contributor. This performance is because of length variation in section types for different design-speeds (e.g. larger distance is dedicated to open section - Re330 than the other in alignment Ø2:P).

Input material

Input material for maintenance & renewal phase is by some means, is the same as M&R of HSR for the functional unit of one kilometer. The reason of such performance is due to the same rationale description for construction phase of alignment Ø2:P (section 5.2.1.1).

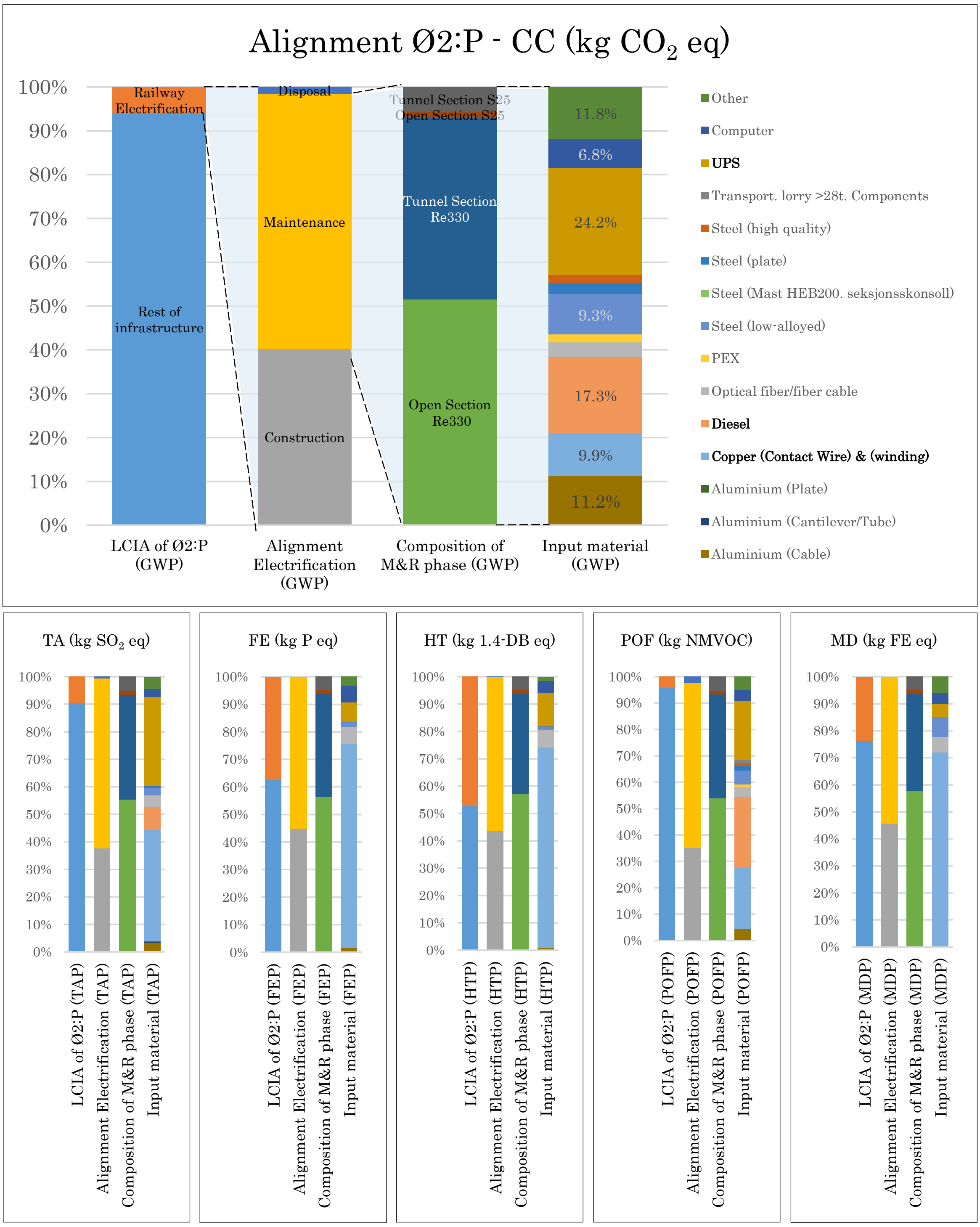


Figure 5.14: Breakdown of maintenance & renewal phase of alignment Ø2:P for all the six-impact categories.

Some of important input materials that can be observed from figure 5.14 are explained below.

- UPS with 24.2% and diesel with 17.3% of impacts are projected as materials with highest contributions in GWP. However, in POF, diesel with 26.8% of potential impact has higher impact than UPS with 22.3% of contribution.

- Copper (wire), UPS and diesel show that they are the main contributors in both TA and POF.
- In spite of various materials involvements in FE, HT and MD, the potential impact of copper is by far more than 70% of total.
- Steel (low-alloyed), computer, and optical fiber/fiber cable are other materials that demonstrate having impacts after copper, UPS, and diesel in the M&R phase.

5.2.1.3 Disposal of alignment Ø2:P

As long as the disposal phase is only corresponding to the transportation and it is only corresponding to a small fraction of contribution (below 3%), it is not practical to mention the results corresponding to this phase (due to avoiding impracticality). However, the results of it could be easily calculated (by means of the same technic that is explained at the beginning of this section) from the result in appendix F that is related to LCA of HSR electrification based on the F.U. of one kilometer.

5.3 Sensitivity Analysis

In respect of the result that is shown from the first two sections (5.1 and 5.2) in this chapter, it becomes clear that copper, diesel, aluminium (cable), steel (low-alloyed) and UPS have significant environmental impacts. Thus, it is planned to run some sets of sensitivity analyses for each of corresponding materials to illustrate how much of the results from section 5.1 will alter by changing the amount of respective input materials. In addition to the mentioned input materials, in this section a sensitivity analysis will be run based on the results from the Swedish tool “klimatkalkyl˙2.0” for ERTMS Level2 to observe how emissions from signaling and telecommunication will change, compare to the results from section 5.1.

It is also decided, based on the results that was obtained in semester project (E. Ebrahimi 2014), to run some extra sensitivity analyses like changing the mast type to H6 and B3, and changing the model and types of transport of materials.

NB. In this section, due to similarity of results from Re330 and S25 it is decided to only show the outcomes from system Re330 and presents the results from the both systems (Re330 and S25) in Appendix I.

NB. Y-axis in the graphs of this section is shown in percentages. A 100% line corresponds to the results from environmental assessments that have been obtained from section 5.1, and either increase or decrease from the 100% line shows how much emission from different scenarios changes relatively to the base study. For instance, if a result shows 103% increase in CC impact category, it means 3% of emission from CC is raised up compare to the base result in section 5.1.

5.3.1 Copper

According to the results in section 5.1 and 5.2, they revealed that copper has a high potential impact in MD, HT, and FE impact categories. Therefore, it is determined to alter the input from copper in this thesis to project the responsive magnitude of emissions for different copper input in the system.

Three sensitivity analyses are chosen for copper that are: increasing in amount of copper by 5%, 10% and 20% in overhead contact system, increasing in total amount of copper in the HSR electrification study by 5%, 10% and 20%, and change the share of primary and secondary copper in the background process. The outcomes of sensitivities are as following.

5.3.1.1 Copper increase in overhead contact system

In the calculation of input materials in overhead contact system, it has been endeavored to have high level of details. However, due to variation in weather condition, pollution and atmospheric air the lifetime of overhead contact system could differ. In addition, in a study of comparing of two types of contact wires, one with CuMg and the other with CuAg, showed CuMg has four-times of lifespan compare to CuAg contact wire. (Goossens 2010) Hence, it is decided to increase the amount of copper input for OCS by 5%, 10% and 20% to see how much emissions will increase if the lifetime reduces from 30 years.

Figure 5.15 shows the effect of raise in amount of copper input in overhead contact system. As it could be seen tunnel section and open section of system Re330 are projecting the same performance, but with slightly differences that is really hard to notice. Climate change shows of not much changes by increase in amount of copper and it demonstrates of less than 1% increase by additional 20% of copper.

However, as it is mentioned, MD, HT, and FE are the main impact categories that copper performs a high contribution and with respect with that by increasing copper from 5% to 20%, the emissions from these impact categories raise from 1% to a bit over 4%, respectively.

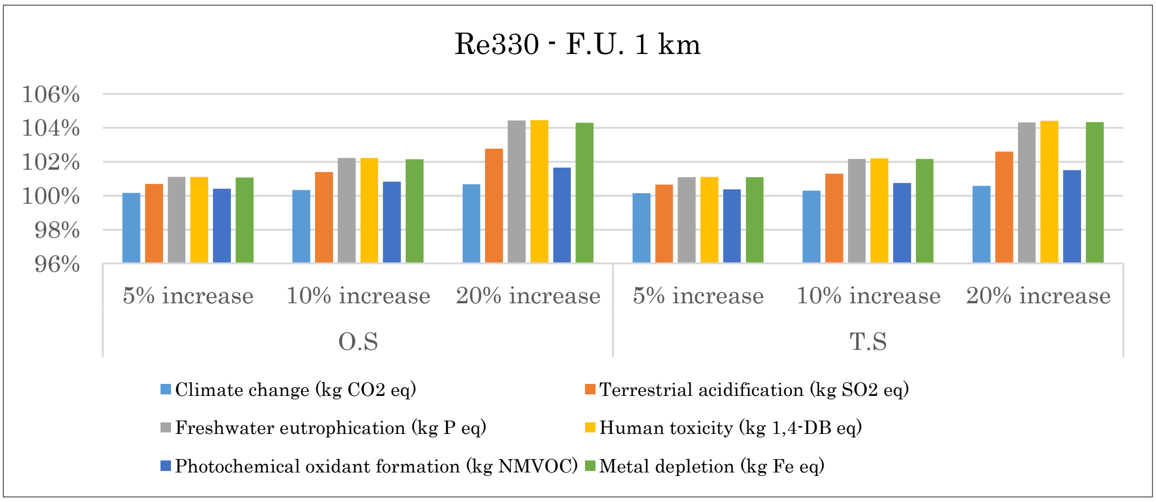


Figure 5.15: LCIA of sensitivity analysis of increase in amount of copper in overhead contact system (OCS) for system Re330.

5.3.1.2 Copper increase in entire HSR electrification system

After increasing the amount of copper in OCS in previous section (5.3.1.2), it is determined in this section (5.3.1.2) to add up the total amount of copper input by 5%, 10% and 20%. Figure Below shows that still tunnel section and open section have the same pattern in demonstration of increase in the total amount of copper.

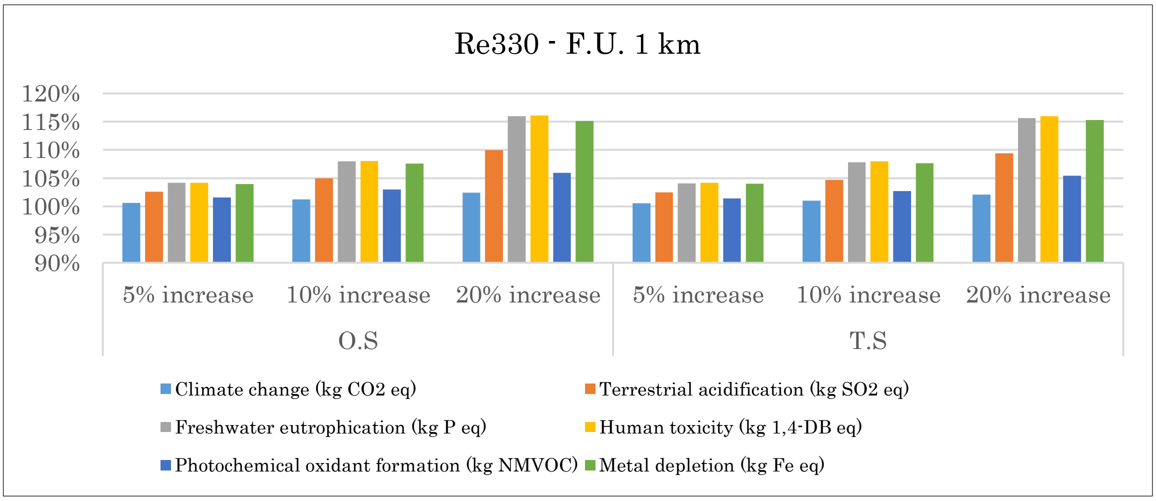


Figure 5.16: LCIA of sensitivity analysis of increase in total amount of copper for system Re330.

- The same as increase in amount of copper in OCS; MD, HT, and FE are the main impact categories that copper plays a leading role at.

- By 20% increase in total copper input, the emission increases by; ca. 15% in MD, HT, and FE impact categories; ca. 10% in TA; and ca. 5% in POF.
- Climate change still illustrates of the lowest contribution corresponding to copper increase. After CC, POF is the second impact category that shows the lowest response to increase of copper.

5.3.1.3 Changing the share of primary and secondary copper

The last attempt in performing a sensitivity analysis for copper is to change the share of primary and scarp copper. To do so, it is planned to use the same process of copper from ecoinvent. Process "Copper, at regional storage/RER U" consists of different types of copper; however, it is tries to modify the share of primary and secondary in the European regions (RER). This means only sub-processes "Copper, primary, at refinery/RER U" and "Copper, secondary, at refinery/RER U" are modified. The modification is driven by reduction of primary copper by 40%, 70% and 100%, and at the same increase in the amount of secondary copper by 40%, 70% and 100%, respectively.

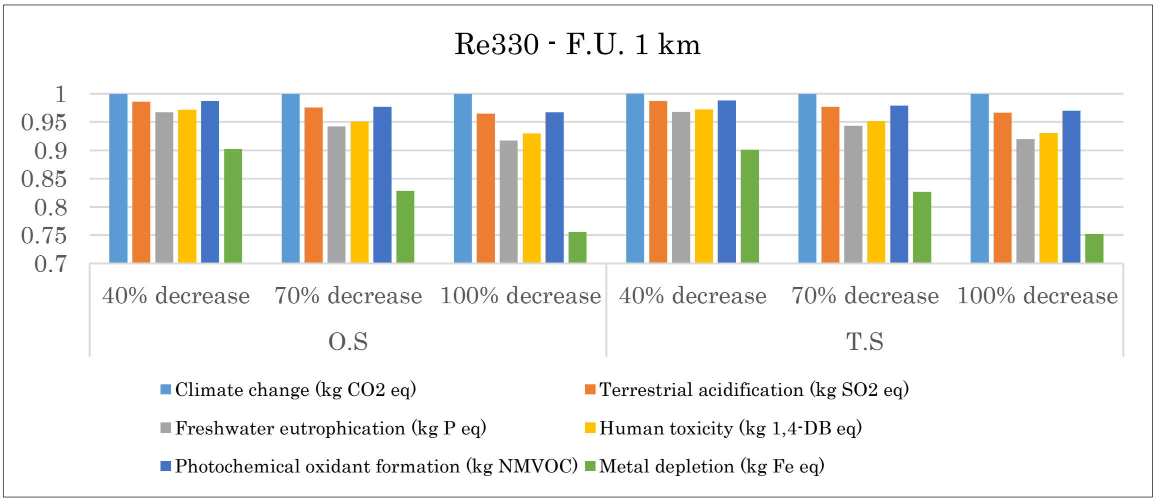


Figure 5.17: LCIA of sensitivity analysis in altering the share of primary and secondary copper for system Re330.

Figure 5.17 shows metal depletion potential is sensitive to replacement of primary with secondary. As it could be seen, MD reduces by 10%, 15%, and 25% when the share of primary copper in the process decreases by 40%, 70% and 100%, respectively. Open section and tunnel section still present the same way of projection in impact assessment.

However, climate change shows no change in potential impact corresponding to altering in share of copper. After MD, freshwater eutrophication and human toxicity are the second and third impact categories, respectively, that show how emissions are reduced by altering the share.

NB. In fact, the reason of having the same pattern of increase in copper in both open section and tunnel section is due to this fact that both section types are increasing copper with relatively the same input of copper, but in signaling of open section more copper are included than tunnel section.

5.3.2 Diesel

The structure of sensitivity analysis for diesel is based on two scenarios. The first on is related to underestimation of diesel requirement through the entire lifetime of HSR electrification. The second one considers that if the amount of diesel consumption is overestimated or due to technology improvement less diesel is consumed through the 60-year of life cycle. Therefore, it is considered to increase and decrease the amount of diesel by 10%, 20% and 30% for underestimated and overestimated scenarios, respectively.

5.3.2.1 Elevation of diesel consumption

Figure 5.18 illustrates the results related to increase in amount of diesel use in both

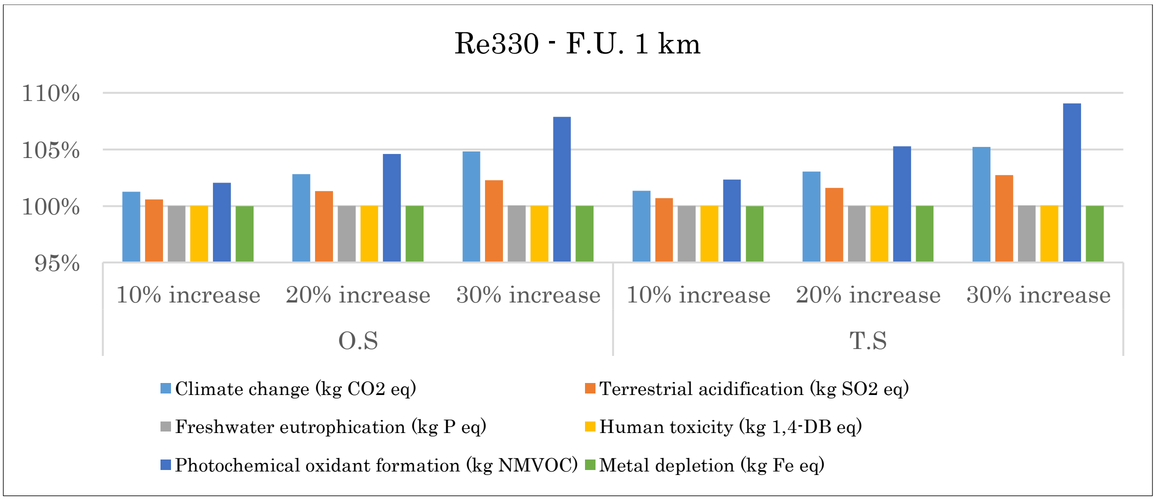


Figure 5.18: LCIA of sensitivity analysis of increase in total amount of diesel consumption for system Re330.

open section and tunnel section. As it could be seen, the results from tunnel section is a bit higher than open section (; however, they are still following the same pattern) due to extra requirement for diesel in lighting and fans in the tunnel section.

Based on the results, POF is the most sensitive to increase in diesel and after that climate change and terrestrial acidification potential are the second and third impact categories that are sensitive to increase in amount of diesel. Nevertheless, FE, HT and MD are not responsive to changes in diesel consumption.

5.3.2.2 Reduction of diesel consumption

The same as increase in diesel use, POF has the highest marginal response to decrease of consumption of diesel, moreover, CC and TA are at the second and third places. On contrary to increase in amount of diesel in figure 5.18, decrease of it does not have the same performance. For instance, if 30% increase and decrease are considered for POF impact category, it could be seen that increase in amount of diesel consumption leads to ca. 8% increase, but decrease in amount of diesel leads to ca. 5% reduction. In addition to differences in performance of two figures, FE, HT and MD are not sensitive to changes in diesel use.

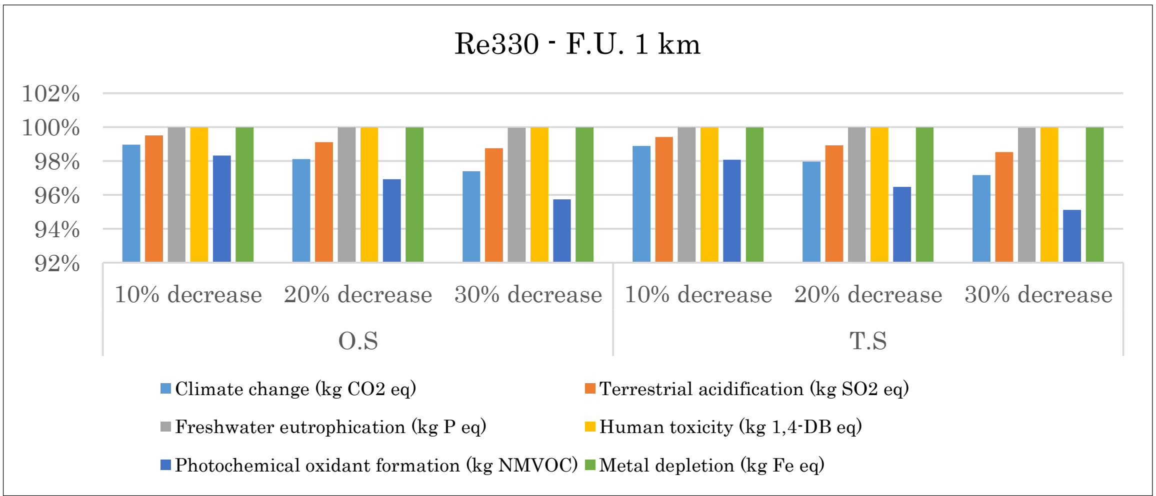


Figure 5.19: LCIA of sensitivity analysis of reduction in total amount of diesel consumption for system Re330.

The reason of having this performance in increase or decrease of diesel is due to variation in impacts related to the mass of diesel and consequently changes in amount of transport. This means, the increase in amount of diesel consequence to the increase in environmental impact associated to transportation. However, decrease in amount of diesel leads to decrease in environmental performance related to transportation.

5.3.3 Aluminium

Aluminium (cable) is the other input material that projected a considerable impact in GWP (in the construction phase). Here, two types of sensitivity analyses will be perform for aluminium (cable) input. The first one is based on increase in amount of aluminium (cable) input by 5%, 10% and 20%, and the other one is related to reducing the share of primary aluminium in the background process in ecoinvent by 40%, 70% and 100%.

5.3.3.1 Aluminium (cable) increase

Figure below shows how emission will increase by adding 5%, 10% and 20% more

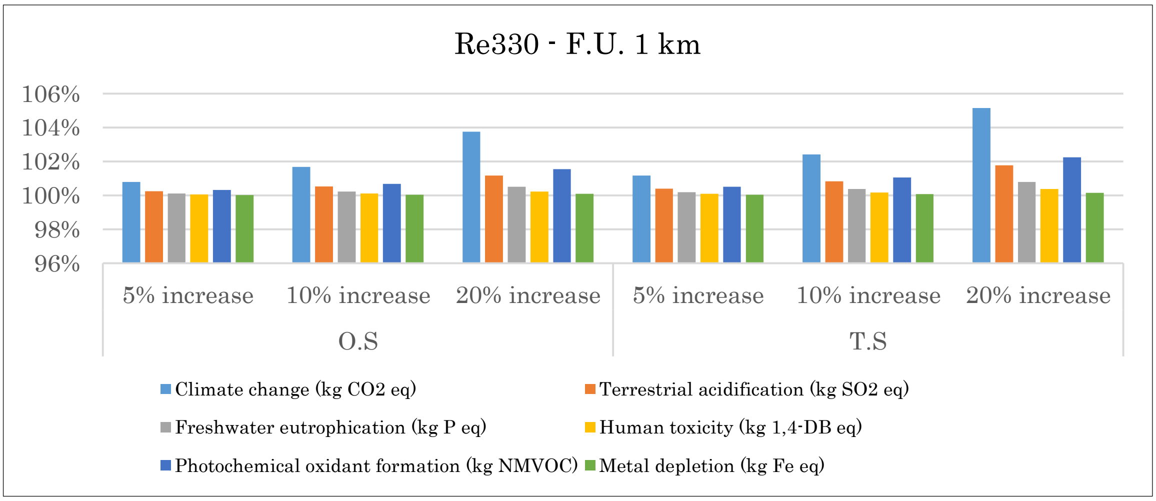


Figure 5.20: LCIA of sensitivity analysis of increase in amount of aluminium (cable) for system Re330.

aluminium (cable) input into the system. As it was expecting, climate change shows the highest sensitivity to increase in aluminium input. After GWP, POF and TA are the two other impact categories that show increase in emissions. However, MD and HT illustrate not much response to aluminium (cable) increase.

5.3.3.2 Changing the share of primary and secondary aluminium

The same as copper in section 5.3.1, the last attempt in performing a sensitivity analysis for aluminium (cable) is to change the share of primary and scarp aluminium (cable). To do so, it is planned to use the same process of aluminium from ecoinvent. Process "*Alumini-um, production mix, at plant/RER U*" consists of different types of aluminiums. This means sub-processes "*Aluminium, primary, at plant/RER U*", "Aluminium, secondary, from new scrap, at plant/RER U" and "*Aluminium, secondary, from old scrap, at plant/RER U*" are modified. The modification is driven by reduction of primary copper by 40%, 70% and 100%, and at the same time increases in the amount of secondary copper by 40%, 70% and 100%, respectively.

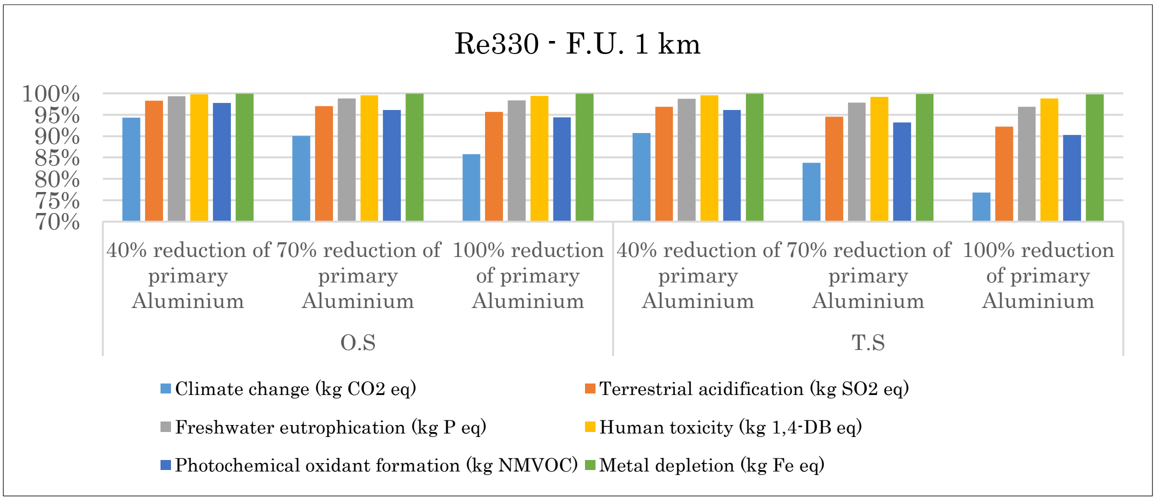


Figure 5.21: LCIA of sensitivity analysis in altering the share of primary and secondary aluminium for system Re330.

Figure 5.21 shows climate change and photochemical depletion potentials are sensitive to replacement of primary with secondary aluminium. As it could be seen, CC is reduced by approx. 5%, 10%, and 15% when the share of primary aluminium in the process decreases by 40%, 70% and 100%, respectively, in open section. Nevertheless, tunnel section presents more impact corresponding to CC (due to use of aluminium (cable) for lighting & fans) impact is reduced by ca. 10%, 15%, and 25% when the share of primary aluminium in the process decreases by 40%, 70% and 100%, respectively.

However, metal depletion potential shows no change in potential impact corresponding to altering in share of aluminium. After impact categories CC and POF; terrestrial acidification and freshwater eutrophication are the third and fourth impact categories, respectively, that show how emissions are reduced by altering the share.

5.3.4 Steel (low-alloyed)

Based on the results from section 5.1, steel (low-alloyed) projected that its highest potential impacts happen in impact categories CC, POF and MD. The sensitivity analysis in this section will be based on increase in amount of steel (low-alloyed) input in the entire system by 5%, 10% and 20%.

5.3.4.1 Steel (low-alloyed) increase

As it was expecting, CC, POF and MD are the three impact categories that show the highest responses to increase in amount of steel (low-alloyed) input. The results perform the same pattern in open section and tunnel section, but with very small differences that is because of utilization of steel (low-alloyed) in mast for signaling in open section.

By increasing in the amount of steel (low-alloyed) input with 20%, the emission increases by lower than 3% in tunnel section for CC impact category compare to the open section. The same as CC, less than 2% and a bit less than 2% increase for impact categories MD and POF, respectively, happens for tunnel section (in comparison with the open section).

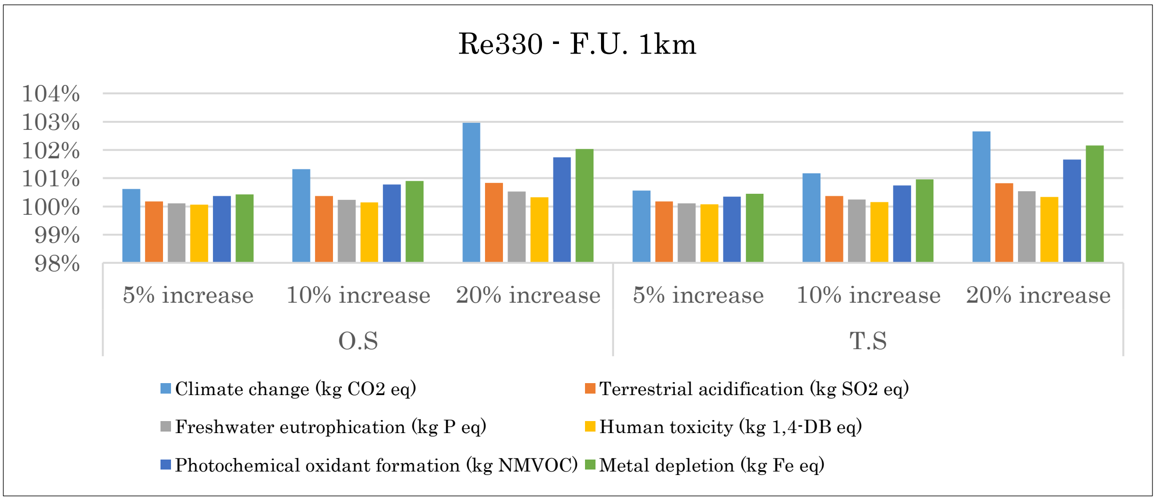


Figure 5.22: LCIA of sensitivity analysis of increase in amount of steel (low-alloyed) for system Re330.

5.3.5 UPS (batteries)

Batteries from telecommunication performed considerable impacts in TA, POF and CC impact categories in the maintenance & renewal phase. The structure of sensitivity analysis for UPS is based on three scenarios. The first on is related to underestimation of UPS requirement through the entire lifetime of HSR electrification. The second one considers that if the number of UPSs is overestimated or due to technology improvement fewer number of UPSs through the 60-year of life cycle are required that might be because of longer lifetime of batteries compare to the estimated lifetime that has been done by (AAS-JAKOBSEN 2012, Ovedal et al. 2012). Therefore, it is assumed to increase and decrease the number from the base analysis by 10%, 20% and 30% for underestimated and overestimated scenarios, respectively. Moreover, a scenario based on changing the share of lead is considered.

5.3.5.1 Increase in the amount of UPS

The figure 5.23 shows how emission grows by increase in the number of UPS. As it could be expected, TA has the highest increase in amount of UPS and followed by POF and CC impact categories. Both open section and tunnel section are showing the same performance, but the emissions relative to open section are slightly higher. The reason is because of this fact in open section the relative performance from aluminium (cable), copper and diesel is higher than the tunnel section.

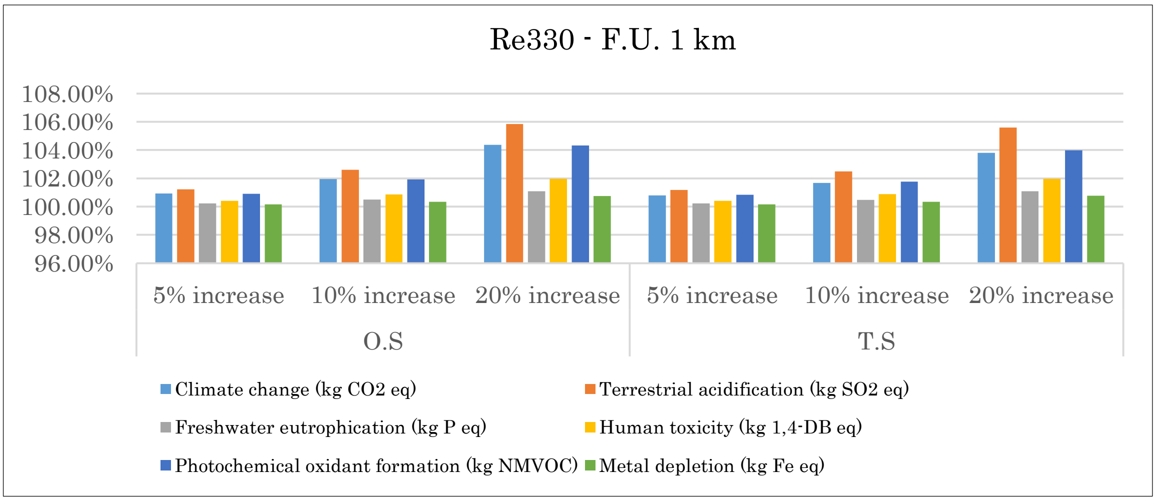


Figure 5.23: LCIA of sensitivity analysis of increase in amount of UPS for system Re330.

5.3.5.2 Reduction of UPS

The same as increase in number of UPSs, TA has the highest marginal responses to decrease the number of UPSs, and POF and CC are at the second and third places of response. On contrary to increase in number of UPSs in figure 5.23,

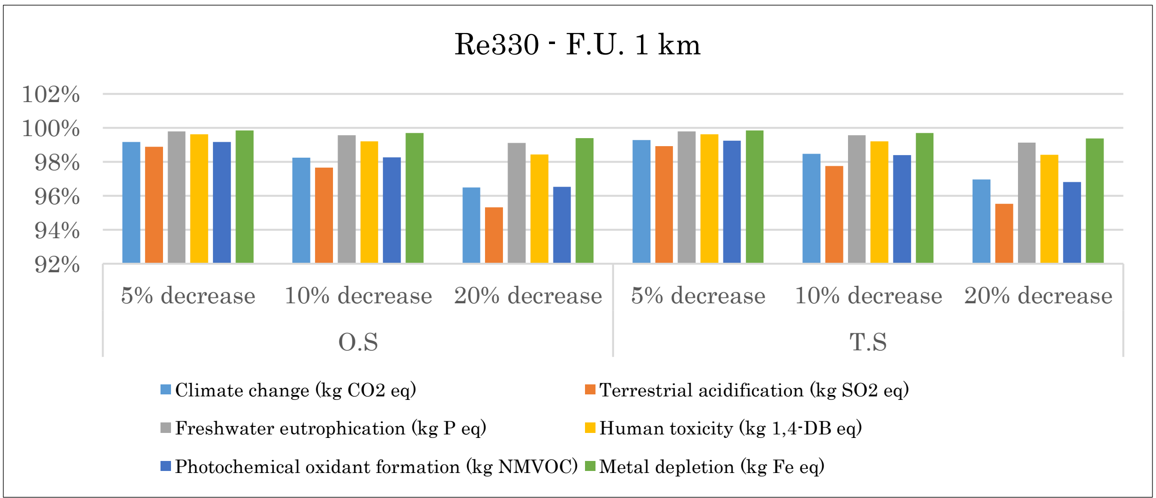


Figure 5.24: LCIA of sensitivity analysis of increase in amount of UPS for system Re330.

decrease of UPSs does not have the same performance. For instance, if 20% increase and decrease are considered for TA impact category, it could be seen that increase in UPS leads to ca. 6% increase, but decrease in amount of it leads to ca. 5% reduction. The reason of having such a behavior is because of the same explanation that has been done in section 5.3.2 that explains alteration in transport of goods is the reason of these variations. This means, the increase in amount of UPS leads consequence to the increase in environmental impact associated to transportation. However, decrease in amount of mass leads to decrease in environmental performance related to transport of the mass.

5.3.5.3 Change the share of primary and secondary lead

As it could be seen in appendix D that describes the quantities of material flows, lead is the by far a dominant material input for UPS. In addition, in emissions related to one piece of UPS, it is shown that lead does have the main impacts. Therefore, it is planned to change the share of primary lead with secondary lead.

Same as copper in section 5.3.1 and aluminium (cable) in section 5.3.3, the last attempt in performing a sensitivity analysis for UPS is to change the share of primary and scarp lead. By observing ecoinvent process of "Lead, at regional storage/RER U", it demonstrates lead has a share of 75% secondary lead and 25% of primary lead. Hence, the sensitivity will only consider a scenario that if 100% of lead is secondary.

Figure 5.25, shows how the emissions will vary by having 100% secondary lead. The

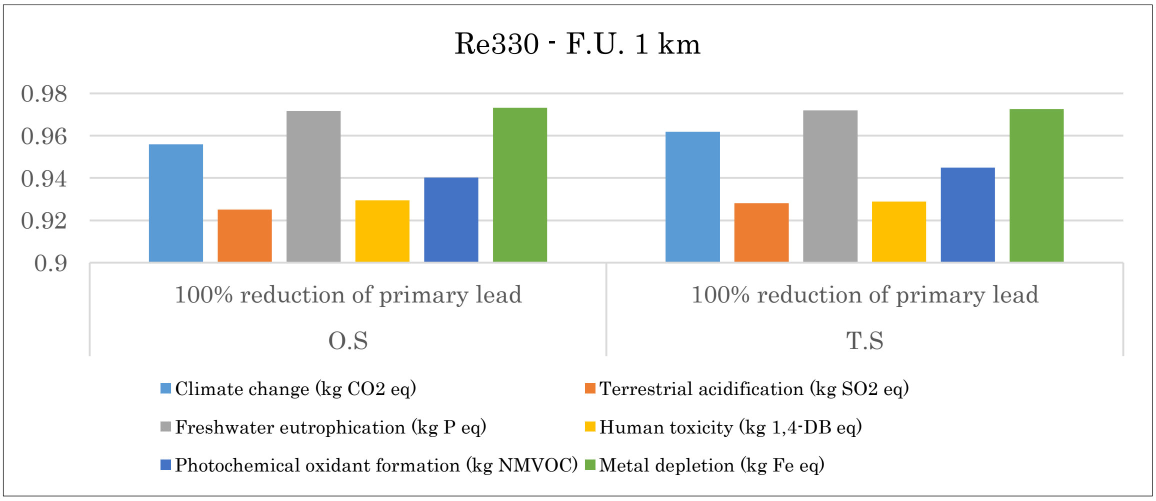


Figure 5.25: LCIA of sensitivity analysis in altering the share of primary and secondary lead for system Re330.

same as increase or decrease in number of UPS, TA has the highest marginal response to altering the share of lead. However, this time HT and POF are at the second and third places of response (on contrary to POF and CC as second and third impact categories in UPS increase or decrease).

5.3.6 Signaling and telecommunication

Based on an email communication with Mr. Stefan Uppenberg for having an internal environmental product declaration (EPD) of signaling and telecom systems of the Bothnia Line (due to utilization of system ERTMS Level2), (Botniabanan AB 2010a) he provided data related to the request by referring to "Klimatkalkul". (Uppenberg 2014)

The Swedish tool of "Klimatkalkul˙2.0" is an excel sheet software program that calculates energy use and carbon footprint from construction and maintenance of roads and railroads. It is decided to use the results from the Swedish tool for the signaling and telecommunication to compare how much emission from GWP will differ compare to the results from this thesis. Calculation that is done for the sensitivity analysis of signaling and telecommunication is presented in appendix B for more information.

Figure 5.26 illustrates how the emissions of GWP change by replacing the results of signaling and telecommunication. Figure shows that impacts from open section and tunnel section reduce by 40% and 30%, respectively.

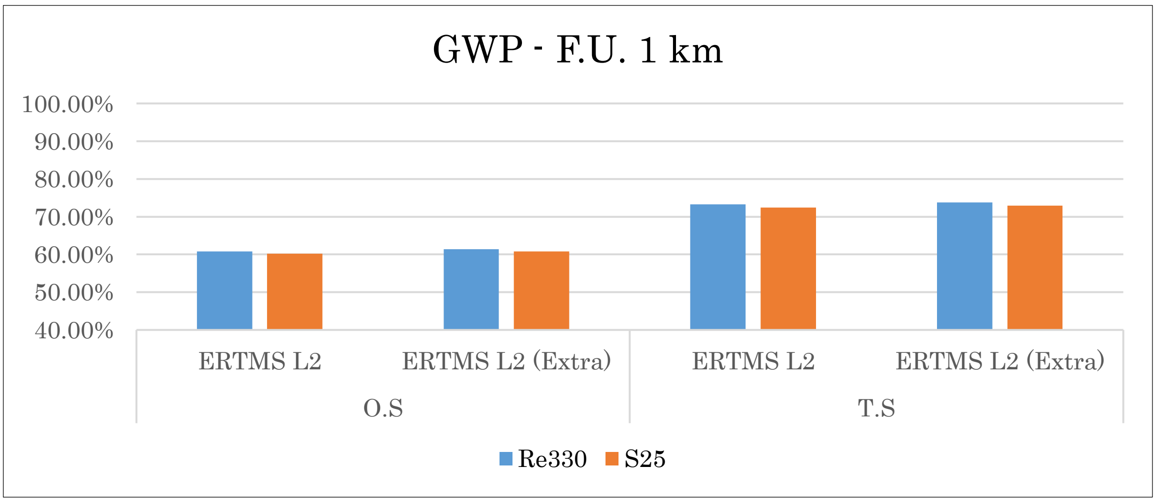


Figure 5.26: LCIA of sensitivity analysis of signaling and telecommunication.

By observing the calculation part of this section (provided in appendix B), it could be seen that batteries (, which here is named based on (Ovedal et al. 2012, Stripple and Uppenberg 2010) as UPS) are excluded. However, in the report from (Stripple and Uppenberg 2010), it is mentioned that UPS are included in the calculation in the Bothnia Line.

In addition, based on environmental performance from signaling and telecommunication it became clear that batteries due to high level of requirement for replacement in the 60-year lifetime of HSR electrification led to considerable impacts.

5.3.7 Transportation

As it mentioned in chapter 4, transportation is a crucial and inseparable process in an LCA study. Hence, two types of sensitivities are done for transport of materials; which, one of them illustrates the effect of increase in total amount of transport by 20%, 30% and 50%, and the second one shows the effect of changing in types of process of transport.

5.3.7.1 Transportation increase

Figure 5.27 shows how much emission will increase by raising the amount of total transportation. As it is illustrated, the highest increase of impact (that is related to impact category POF - 50% increase) is 0.24%. This means, by adding 50% more transport of goods, the results rise for less than 1%.

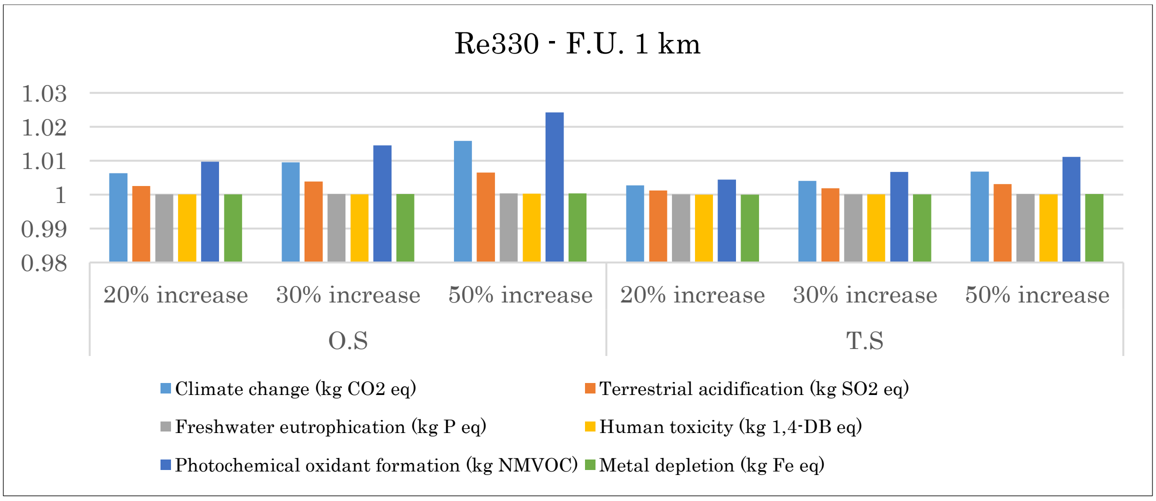


Figure 5.27: LCIA of sensitivity analysis of increase in amount of total materials transport for system Re330.

In addition, the results show that adding extra transportation has more effect on open section than tunnel section. The reason is relying to this fact that more mass (weight) is corresponding to open section. The crucial materials that lead to such alteration in results are steel in masts, and concrete in fundaments and tensioning weights in open section.

Moreover, additional transport leads to increase in amount of emissions in POF, CC and TA impact categories, respectively. However, increase in transport models does not cause to any changes in impact categories FE, HT and MD.

5.3.7.2 Different transportation types

In this part two types of transport are considered to check the sensitivity of LCA of HSR electrification. Here, processes "*Transport, lorry >16t, fleet average/RER U*" and "*Transport, lorry 16-32t, EURO5/RER U*" are the two transport processes in ecoinvent that are assumed. Figure 5.28 shows the effect of alteration in transport process. As it is shown, transport >16 does not show changes in transport with respect to the original process in this thesis that is "*Transport, lorry >28t, fleet average/CH U*".

However, the emissions reduce by altering the transport process in this thesis to transport Euro5. The same as the results from transport increase, only impact categories POF, CC and TA show the changes. The highest reduction happens for POF impact categories. In addition, the results show that the transport in open section is more sensitive than tunnel section due to more mass (weight) corresponding to open section.

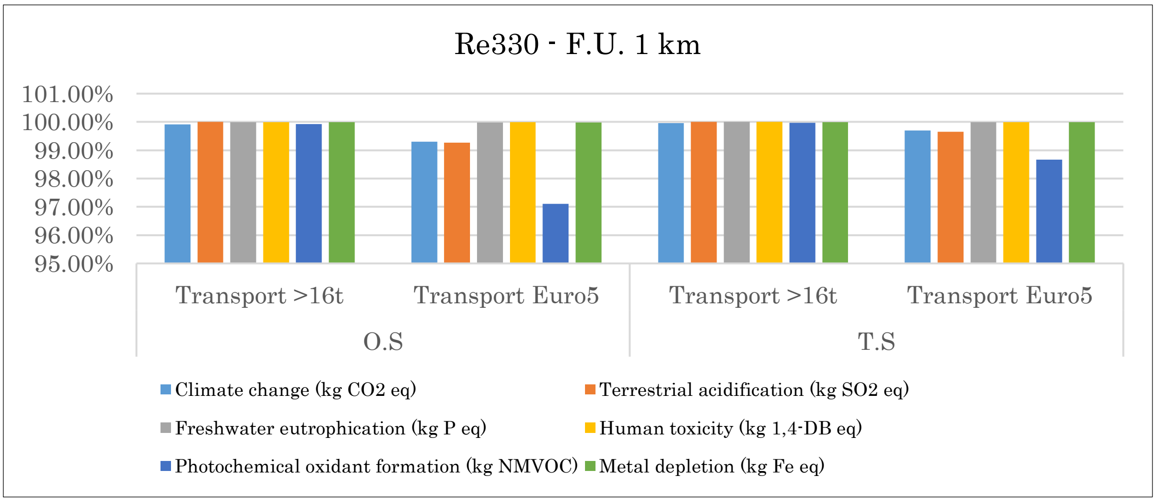


Figure 5.28: LCIA of sensitivity analysis of altering process of materials transport for system Re330.

5.3.8 Mast Type

As it is mentioned in the introduction to the sensitivity analysis, it is determined to use two types of mast (H6 and B3)[47] to show how the emissions alter. Figure 5.29 demonstrates the outcome of changing mast type from HEB200 that is assumed in the calculation in section 5.1 and 5.2.

It presents by altering the type of mast to H6 the emissions change mainly in CC and POF by more than 1%. The figure also projects how emission is decreased by shifting to mast B3. The same as mast type H6, CC and POF have the most responses by about 1% reduction in their emission (compare to mast type HEB200).

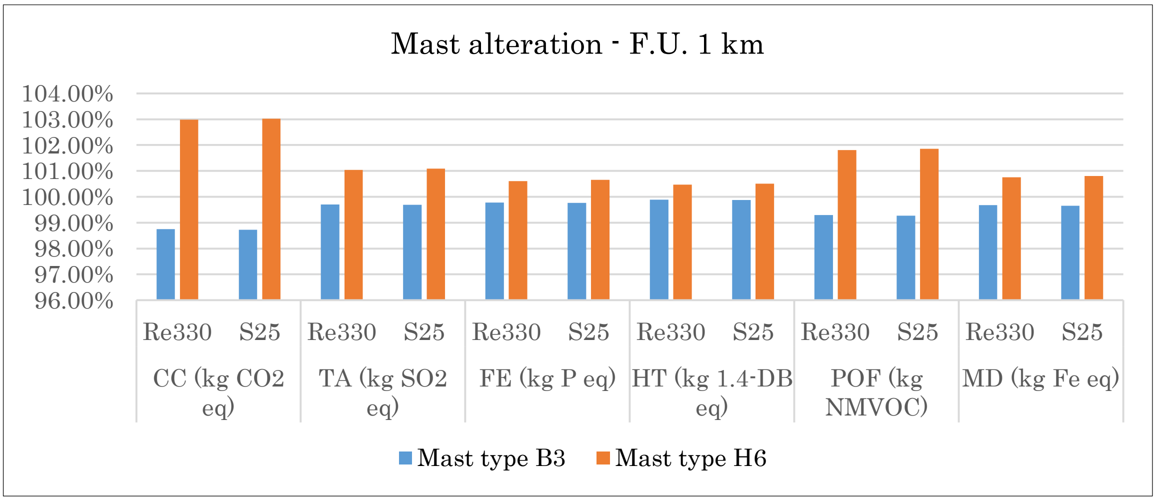


Figure 5.29: LCIA of changing in mast types

[47] The results from semester project (E. Ebrahimi 2014) showed H6 has the highest and B3 has the lowest potential impacts compare to mast type HEB200.

NB. The sensitivity is done based on this assumption that all masts have the height of 9.5 meters.

Chapter 6

Discussion

Chapter 5, in this thesis, projected emissions corresponding to HSR electrification. The results mainly focused on system of design-speed Re330. The reason of such action was due to both similarity of two systems of design-speeds and avoiding repetition of saying the same concept repeatedly. However, the results for all stages of study that have been for system Re330 (in chapter 5) is presented in appendix E for system S25 as well.

In this chapter, it is tried to create a good overview of the results by highlighting important main findings. In section 6.1, the main finding of HSR electrification for the functional unit of 1 kilometer and effect on corridor planning are discussed. Section 6.2 shows if the results having the same voice in comparison with the literatures in chapter 2. Then, section 6.3 tells the quality of data, and in addition, explains the related emissions processes/sources for the main input materials. After that, in section 6.4 and 6.5 uncertainties and future work related to this study are discussed, respectively.

6.1 Main findings

6.1.1 HSR Electrification (F.U. 1 km)

The overall results (in section 5.1, figure 5.3) show that section types for a kilometer of tunnel section are contributing to higher emissions than open section in impact categories CC, TA and POF. However, for the other three impact categories the performance is different. FEP showed Re330 in tunnel section and open section are the first high contributors, respectively, and Re330 in open section has the highest impacts in both MDP and HTP. The reason of performing such variation in environmental emissions is due to changes in the input of materials and related emissions.

Due to various material inputs with different impact intensities, various effects could be observed as it mentioned. In tables (in appendix G), detail information about such variation in environmental impacts from open section and tunnel section of system Re330 is shown to deliver a better perspective. According to the table, the highest impacts of system Re330 in tunnel section are coming from aluminiunm (cable), aluminium (cantilever/tube), aluminium (plate), diesel, assembly/disassembly, steel (plate), steel (cantilever/tube), and cast iron. However, system Re330 in open section shows high emissions are conducted by concrete, copper (wire), optic cable, plastic (polycarbonate), steel (mast HEB200), steel (high quality) and transport, lorry >28t that leads to have variations in figure 5.3. In addition to the tables (in appendix G), extra information in table (in appendix D) is provided to address the logic behind these behaviors from mentioned material inputs.

In addition to the potential impacts, the cumulative energy demand (CED) for each system of design-speed in the two section types is projected. The overall energy consumption showed that tunnel section is contributing to higher energy demand than open section, and in each section type, Re330 has higher energy demand than S25.

Contribution of different life cycle phases (in section 5.1.1.2 for open section and section 5.1.1.3 for tunnel section) demonstrated relatively even distribution in all impact categories, which maintenance & renewal with more than 50% potential impact was the dominant life cycle phase and followed by construction phase with an average contribution of 40% impact in all six-impact categories. However, the disposal phase of life cycle showed the lowest contribution due to the assumption of having only transport of materials.

6.1.2 Corridor planning

As it explained in section 5.2, emissions corresponding to HSR electrification are following the same pattern in corridor planning as it was in section 5.1, but with slightly differences due to variation in compositions of alignments. This means, despite the fact that in corridor planning different lengths of various design-speeds and section types are contribution, the final impact associated to the six-impact categories still corresponded by the nearly same input material[48] with relatively the same impacts.

As a result, the outcome of life cycle impact assessment for corridor planning showed that all alignments[49] have nearly the same relative emission bar charts as alignment Ø2:P.

6.2 Agreement with literatures

In the introduction and in the chapter 2 (literature review) of this study, it was pointed out that few studies have been so far attempted to address the environmental impacts related to HSR electrification by having different perspective and aims.

This study by having the aim of showing higher resolution of HSR electrification started its LCA work and showed (on contrary to the mentioned studies) how the concept of design-speed could be effective in the variation of section types. In addition, it illustrates that higher resolutions of HSR electrification shows more impacts are corresponding to electrification of high-speed rail in comparison with the initial study of Norwegian HSR (Bergsdal et al. 2012).

The main findings from this study projected some similarities with some of the literatures in chapter 2 due to utilization of some parts of their data[50] (that is shown in table 4.3). However, it is decided to evaluate the variation of their potential impacts in climate change for the mentioned studies (due to having GWP as a common characterization factor in their environmental assessment of HSR) to compare the variations in their results. This study (as it shown in table 5.1) demonstrates emissions are from 3.25E+05 to 3.3E+05 (kg CO_2 eq.) in a kilometer

[48] Because, for instance, in tunnel section no mast type HEB200 and concrete weights are utilized, but on contrary, no steel and aluminium plates are used in overhead contact system of open section.

[49] The quantitative data are provided in appendix H.

[50] Nonetheless, in the summary of assumptions (section 4.5) had been mentioned that steel (high quality) is replaced in some processes by steel (low-alloyed) that could lead to lower result of emission in some impact categories (especially in climate change and photochemical oxidation formation). This means if the result of GWP from COWI report (Ovedal et al. 2012) is considered the emission of electrification is 7.48E+05 that is 7 times higher than the lowest value for the HSR electrification in this study.

of open section, and from 3.7E+05 to 3.82E+05 (kg CO_2 eq.) in a kilometer of tunnel section.

To begin with, UIC study (Baron, Martinetti, and Pépion 2011) mentioned that electrification has a potential of 3.5 tons of CO_2 eq., which in a 60-year of lifetime it has an impact of 2.1E+05 (kg CO_2 eq.) that is approximately 1E+05 (kg CO_2 eq) lower than the lowest value (in open section for system S25) in this thesis. Moreover, the California's study (Chang and Kendall 2011) show that the construction of HSR electrification for 725 km of the line has the potential impact of 69610 tons of CO_2 eq. in CC. By scaling up the results of this study (from the construction of S25 in an open section) the result shows the 97875 tons of CO_2 eq. impact that is 28265 tons of CO_2 eq. is greater than the California's study. However, the Bothnia Line results (Stripple and Uppenberg 2010) from the electrification of line entitled as "Railway electric power and control system model" showed the total (in accordance with PCR guideline) is 2.55E+06 (kg CO_2 eq.) that is approx. 7 times bigger than the results from this study of HSR electrification. The outcome from the Bothnia Line brings this hypothesis that the study had either so much data or overestimated data. Nonetheless, it is beyond the capacity of this thesis to find the reason of it due having neither access to the Bothnia line data nor enough time.

6.3 Data quality and related emissions

Based on the outcome of chapter 5 for the material input, it showed that (regardless of performing the assessment for the functional unit of 1 km or corridor planning) a vast number of materials are leading in emissions related to HSR electrification. This section mentions and discusses the main input materials that have performed their significance in this thesis.

Table below is inspired from the Follo Line project (Ovedal et al. 2012, Bergsdal, Graarud, and Holen 2011, AAS-JAKOBSEN 2012) as a good way of illustration of data quality to present the robustness of analysis.

NB. The results in the table present the input material in each responsive components (that are coming from 0.1% cut-off from the network tool in SimaPro).

Table 6.1: Data quality for overhead contact system components.

Input Material	Quality	Contribution	Comments
Aluminium (cantilever/tube)	High	Negligible/very low	The main impact happens in GWP and POFP
Aluminium (plate) (T.S)	High	Negligible	
Bolts (Tunnel section)	High	Negligible	
Concrete	High	Negligible/very low	The main impact happens in GWP and POFP
Copper wire	High	Medium/high	Medium contribution in GWP, high contribution in other six impact categories
Electricity (European Mix)	High	Negligible	Used in production of cables
Glass (insulator)	Medium	Negligible	Used in production of insulators
Lead-antimony (insulator)	Medium	Negligible	Used in production of insulators
Magnesium	High	Very low	Used in production of cables
PEX	High	Negligible	Used in grounding cables
Silver	High	Negligible	Used in production of cables
Steel (cantilever/tube)	High	Negligible	Used in production of tensioning components
Steel (wire)	High	Negligible	Used in production of cantilever & tensioning components
Steel (mast HEB200)	Medium	Low/very low	Low contribution in GWP and POFP, very low impacts in the rest of impact categories
Steel (plate) (T.S)	High	Medium	Due to in tensioning system

Table 6.2: Data quality for power supply components

Input Material	Quality	Contribution	Comments
Aluminium (cable)	Medium/High	Very low/medium	Medium contribution in GWP and POFP, very low impacts in the rest of impact categories
Aluminium (plate)	Medium	Negligible	Used in switchgear - SF6 breaker
Concrete	Medium	Negligible	Used as autotransformer foundation
Copper wire	Medium	Low	Used in low voltage cables, high voltage cable and transformer (small and without oil) mostly
Electricity (European Mix)	Medium/High	Negligible	Used in production of cables
Lead-antimony (insulator)	Medium	Negligible	Used in production of insulators
PEX	Medium	Very low	Used in production of cables and the main impact comes from high voltage cable
Porcelain	Low	Negligible	Used in production of insulators

Steel (low-alloyed)	Medium	Very low/medium	Medium contribution in GWP and MDP, very low impacts in the rest of impact categories
Steel (plate)	Medium	Negligible	Used in switchgear - SF6 breaker
Transformer oil	Low	Negligible	Used in autotransformer
Others	Medium	Negligible	Such as epoxy, zinc, HDPE etc.

Table 6.3: Data quality for telecommunication components.

Input Material	Quality	Contribution	Comments
Aluminium (cable)	Medium	Negligible	Used in cables
Copper (wire)	Medium	Low	Used in cables
Optical fiber/fiber cable	Medium	Very low	Used in cables
PEX	Medium	Negligible	Used in cables
Steel (low-alloyed)	Medium	Very low/low	Low contribution in GWP and MDP, very low impacts in the rest of impact categories
Steel (high quality)	Low/Medium	Negligible	Used in Repeater
UPS	Medium	Medium	Main impact in TAP, GWP and POFP
Computer	Medium	Low	Low contribution in all impact categories
Plastic (polycarbonate)	Medium	Negligible	Used in El-tavle, repeater
Others	Medium	Negligible	Router, data cable, mouse device etc.

Table 6.4: Data quality for signaling components in open section.

Input Material	Quality	Contribution	Comments
Aluminium (cable)	Medium	Very low/Medium	Used in ATC, axle counter, computers etc.
Assembly / Disassembly	Low	Very low	Used in ATC, axle counter, computers etc.
Plastic (polycarbonate)	Medium	Very low	Used in ATC, axle counter, computers etc.
Steel (low-alloyed)	Medium	Low	Main contribution from construction of Mast in GWP and POFP
Steel (high quality)	Medium	Low	The main impact happens in GWP and MDP
Concrete	Medium	Negligible	Used in cables casing
Copper (wire)	Medium	Low/medium	Low contribution in GWP, medium contribution in other six impact categories
Optical fiber/fiber cable	Medium	Very low	
Others	Medium	Negligible	LED lams, data cable etc.

Table 6.5: Data quality for signaling components in tunnel section.

Input Material	Quality	Contribution	Comments
Aluminium (cable)	Medium	Negligible	Used in ATC, axle counter, computers etc.
Assembly / Disassembly	Low	Negligible	Used in ATC, axle counter, computers etc.
Plastic (polycarbonate)	Medium	Negligible	Used in ATC, axle counter, computers etc.
Steel (low-alloyed)	Medium	Negligible	Main contribution from construction of Mast in GWP and POFP
Steel (high quality)	Medium	Negligible	The main impact happens in GWP and MDP
Concrete	Medium	Negligible	Used in cables casing
Copper (wire)	Medium	Low/medium	Low contribution in GWP, medium contribution in other six impact categories
Optical fiber/fiber cable	Medium	Very low	
Others	Medium	Negligible	LED lams, data cable etc.

Table 6.6: Data quality for other installations components (lighting & fans) in tunnel section.

Input Material	Quality	Contribution	Comments
Aluminium (cable)	Medium	Low/medium	The main impact happens in GWP and POFP
Steel (plate)	Medium	Very low	Used in fans
Cast iron	Medium	Very low	Used in fans & lighting
Steel (low-alloyed)	Medium	Negligible	Used in fans
Copper (wire)	Medium	Negligible	Used in fans & lighting
Assembly / Disassembly	Low	Negligible	Used in fans & lighting
Others	Medium	Negligible	LED lamps and plastic (polycarbonate)

Based on the results from chapter 5, the important input materials are as following.

- Copper (wire)
- Aluminium (cable)
- Diesel
- Steel (low-alloyed)
- UPS

6.3.1 Copper (wire)

In accordance with the Sankey diagram in figure 5.1, it demonstrates copper (wire) has relatively a small fraction of total mass (in a kilogram) compare to the other material inputs. However, copper (wire) by far has the highest impact intensity in terrestrial acidification, freshwater eutrophication, human toxicity, and metal depletion impact categories. The processes that are corresponding to this performance are mainly: "copper, primary, at refinery" for terrestrial acidification potential; "disposal, sulfidic tailing, off-site" for FEP and HTP; and "copper concentrate, at beneficiation" for metal depletion potential.

The main emission source from exploitation of copper is due to dust from mining that comes from metals and sulphur and beneficiation that comes from metals and PM10. (Classen et al. 2007) Nevertheless, different processes are associated with production of one kilogram of copper in addition to exploitation. In table 6.7, the main emissions associated with production of one kilogram of copper (wire) according to the results from the modeling on SimaPro are shown.

Table 6.7: Emissions corresponding to production of copper (wire) for selective impact categories.

Category	Contribution (%)	Emission
TA (kg SO2 eq)	>80%	Air/sulfur dioxide
FE (kg P eq)	>99%	Water/Phosphate
HT (kg 1,4-DB eq)	>50%	Water/manganese
	~20%	Water/arsenic
	~20%	Air/arsenic
MD (kg Fe eq)	~40%	Raw/copper, 1.18% in sulfide, cu 0.39% and Mo 8.2E-3% in crude ore
	~30%	Raw/copper, 2.19% in sulfide, cu 1.83% and Mo 8.2E-3% in crude ore

6.3.2 Diesel

According to the outcome of LCIA for the lifetime of 60 years, diesel projected its influential potential in climate change and photochemical oxidation formation impact categories. The main process associated to this result is coming from "transport, lorry 20-28t" due to transport of diesel to the railway sites. Moreover, table 6.8 shows the emissions sources in CC and POF impact categories.

Table 6.8: Emissions corresponding to diesel for selective impact categories.

Category	Contribution (%)	Emission
CC (kg CO2 eq)	>90%	Air/carbon dioxide, fossil
POF (kg NMVOC)	>75%	Air/nitrogen oxides
	>20%	Air/NMVOC, non-methane volatile organic compounds, unspecified origin

6.3.3 Aluminium (cable)

On an average, one-third of impact from GWP is related to aluminium (cable). Photochemical oxidation formation also shows impact associated with aluminium (cable); however, the contribution is not as great as GWP. The main processes that are corresponding to such performances are due to so many processes, which the two main ones are: “aluminium, primary, liquid at plant”, and “hard coal, burned in power plant”. In addition to the processes, it is practical to know what the main sources of emissions are from production on aluminum (cable). Table below demonstrates the emissions associated with production of aluminium (cable).

Table 6.9: Emissions corresponding to production of aluminium (cable) for selective impact categories.

Category	Contribution (%)	Emission
CC (kg CO2 eq)	>75%	Air/cabon dioxide, fossil
POF (kg NMVOC)	>55%	Air/nitrogen oxides
	>20%	Air/carbon monoxide, fossil

6.3.4 Steel (low-alloyed)

After utilization of steel (low-alloyed) in various processes and replacement of some material inputs, especially steel (high-quality), with steel (low-alloyed), it could be expected to see the emissions from steel (low-alloyed) show higher contributions. Steel (low-alloyed) presents to be an input material that can have potential impacts in impact categories CC, MD and POF.

The processes that are corresponding to emissions in these three impact categories are as following. “Pig iron”, “natural gas” and “hard coal” show to be the primarily processes for GWP. “Magnesium”, “iron ore”, “chromite”, and “ferronickel” are main processes that lead to MDP. Last, “sinster iron”, “blasting”, “hard coal”, “diesel”, “shipping” and so forth are the other main processes that cause high contribution in impact category photochemical oxidation formation.

The same as the other input material, table 6.10 presents the emission sources coming from production of steel (low-alloyed) in this thesis.

Table 6.10: Emissions corresponding to production of steel (low-alloyed) for selective impact categories.

Category	Contribution (%)	Emission
CC (kg CO2 eq)	>90%	Air/carbon dioxide, fossil
POF (kg NMVOC)	>50%	Air/nitrogen oxides
	~20%	Air/NMVOC, non-methane volatile organic compounds, unspecified origin
MD (kg Fe eq)	>25%	Raw/manganese
	>25%	Raw/iron
	~20%	Raw/nickel, 1.98% in silicates, 1.04% in crude ore
	~20%	Raw/chromium

6.3.5 UPS (batteries)

Due to utilization of large amount of UPS batteries in the lifetime of LCA study, UPS batteries present their potential emissions in impact categories terrestrial acidification, photochemical oxidation formation, and climate change. It is primarily "production of lead secondary and primary at plant", and "polypropylene, granulate" are responsible processes for emission in mentioned impact categories.

In addition to the process, the main emission sources are highlighted in table 6.11.

Table 6.11: Emissions corresponding to production of UPS for selective impact categories.

Category	Contribution (%)	Emission
CC (kg CO2 eq)	>90%	Air/carbon dioxide, fossil
TA (kg SO2 eq)	>80%	Air/sulfur dioxide
POF (kg NMVOC)	>55%	Air/nitrogen oxides
	>20%	Air/sulfur dioxide

6.4 Uncertainties

In addition to the tables that discuses the data quality of this thesis, in section 5.3 a set of sensitivity analyses were performed to address if there are inputs that are sensitive to changes. As it described, the sensitivities were focused on the five crucial inputs (mentioned in bullet-points in section 6.3) and furthermore, three extra sensitivity analyses related to transportation, signaling & telecommunication, and altering mast types in open section.

The study of sensitivity focuses on increase, decrease of corresponding inputs; and in addition, checks how positive/negative feedbacks can be gained by switching from primary to secondary inputs. Suprisingly, the results show that the study is not much sensitive (except for few cases) to variation in changes.

However, the data for the signaling & telecommunication is completely replaced by data from "Klimatkalkul" that showed a tremendous reduction in greenhouse gases emissions that brought this hypothesis that maybe the input data from

"Klimatkalkul" are not accurate enough or the data for signaling and telecommunication from this study are not applicable for HSR electrification.

In addition to the sensitivity there is a bit of concern about the accuracy of HT. Figure 5.12 shows that HSR electrification has approximately 50% potential impact. However, human toxicity is still subjected as an impact category with high uncertainty (due to the normalization factors for toxicity) that is fully dominated by heavy metals (which here copper is the only reason of it in accordance with the results in figures 5.13 and 5.14). (Sleeswijk et al. 2008, Fuglseth 2013)

Furthermore, the transportation model and type is the other type of uncertainty that this study tried to model it as good as it could; however, the trasportation requires accurate model and type selection due to various factors such as location of regional storages, railway sites etc. that can vary from a corridor to corridor.

6.5 Future work

As a part of implication for development and progression of having an even more clear understanding of LCA of HSR electrification, it is required to spend time on some areas of this study. The main an important part that needs to be focused on is signaling and telecommunication. In accordance with the results that have been obtained in the sensitivity section (5.3.6), it became obvious that emission is less for the new signaling and telecommunication systems. However, due to being uncertain in the resolution of data (because of lacking i.e. batteries) in KilmatKalkul, there was a pressing question that what the correct emissions from the system are.

LCA is a data intensive study, and consequently, it requires valid and accurate level of information to perform a comprehensive level of impact assessment. Hence, it is highly recommended for the future development of this study to improve the data quality by selection of correct background processes and better modeling of foreground processes. For instance, an average European mix is considered for aluminium production that might seems a bit inaccurate due to production of aluminium in Norway with low emissions (especially in GWP).

Moreover, it is needed to make the LCA study of HSR electrification even more transparent by means of **process codes** (that are developed by JBV) to make the structure of inventory and results based on JBV's classification. Utilization of process codes will provide advantage such as:

- First, process codes are structured in accordance with JBV that can facilitate documentation of results,
- Second, makes the modeling easier for different decision stages of a project due to using the same structure of components/materials,
- Third, structure skeleton can be later on utilized for life cycle cost assessment and because although its assessment has different analysis, but it shares same components/materials with LCIA.

In addition, it is highly recommended to upgrade the foreground system by correct suppliers' EPDs. Some items, in this thesis, are only structured based on material inputs that do not consider how much and what kinds of energy sources are utilized in the manufacturing and assembly of them.

Moreover, a better transportation model is needed for the future study. In this thesis, a generic model of transportation is assumed for the transportation of items, which is not a good way to illustrate because different alignments have different locations and different transportation requirements. Therefore, it will be great for the future work to consider the correct length and types of transportation (lorry transport, rail transport etc.).

As it is shown in figure 5.12 due to having more details, emissions from HSR electrification increased in impact categories FE, MD, and HT compare to initial study from (Bergsdal et al. 2012) that was many due to contribution of more copper (wire) and lead (in batteries). So, it is suggested that the future study goes more in detail in copper and lead utilization due to having great potential impacts in mentioned impact categories.

Maintenance showed high contribution (more than 50% share) in all six-impact categories. It brings this issue that how the emission will be corresponded to maintenance in the future if due to technology development more secondary components and items with longer lifetime use. As a result, it is needed to consider some scenarios with shorter lifetime (in addition to the 60-year lifetime by PCR guideline) to be able to have a better environmental assessment of HSR electrification.

This study did not distinguished between open section and tunnel section of telecommunication and power supply components. However, the performance would differ due to variation in requirements in section types. This means the future LCA of HSR electrification should also make the assessment in section types more comprehensive.

Chapter 7

Conclusion

This thesis with the aim of environmental assessment of HSR electrification (by means of PCR guideline) and effect of its results on corridor planning showed how emissions could vary due to variation in the section types and consequently in the design-speeds. The main focus of assessment was based on LCA of HSR electrification in Norway and it has been attempted to create a correct model of HSR electrification.

Based on the PCR framework, the results for three life cycle phases (construction, maintenance & renewal, and disposal) are demonstrated that more than 90% of potential impact for six-impact categories is associated with construction and maintenance & renewal phases. In addition, the six-impact categories corresponding to this LCA study are: climate change, terrestrial acidification, freshwater eutrophication, human toxicity, photochemical oxidation formation, and metal depletion.

In consonance with the results in the mentioned six-impact categories, it becomes clear that five input materials in the analysis have significant impacts that are:

- Copper
- Diesel
- Aluminium (cable)
- Steel (low-alloyed)

- UPS (batteries)

The study of HSR electrification could be the interest of the Norwegian National Rail administration (Jernbaneverket, JBV) and other consulting companies working directly or indirectly with railroads. Based on the outcome of the study and with an outlook on the white paper entitled "National Transport Plan 2014-2023" by The Norwegian Ministry of Transport and Communications, it is highly recommended to have more focus on five input materials. In accordance to the results, aluminium (in cables, soffit posts, and cantilever), steel (in casing, tensioning weight, and masts), diesel, copper (catenary and cables) and UPS (batteries in telecom) show to be the main components in CC impact category. Hence, these four input materials should be taken into consideration and for the reduction of their potential impacts in CC, use of secondary material types should be considered.

However, this LCA study shows that climate change is not the only impact category that needs to be focused on. In fact, based on the outcome from the comparison of the LCA result of HSR electrification by rest of HSR infrastructure, it becomes clear that HSR electrification has more impact in other impact category (due to having more resolution HSR electrification than previous study of NHSR).

Bibliography

(c) PRe Consultants, Radboud University Nijmegen, Leiden University, and RIVM. 2013. ReCiPe 2008. In *ReCiPe 2008*, edited by Mark Goedkoop, Reinout Heijungs, Mark Huijbregts, A. D. Schryver, J. Struijs and R. V. Zelm.

AAS-JAKOBSEN. 2012. Nytt dobbeltspor Oslo – Ski - Innføring Oslo S. Norway: AAS-JAKOBSEN.

Åkerman, Jonas. 2011. "The role of high-speed rail in mitigating climate change – The Swedish case Europabanan from a life cycle perspective." *Transportation Research Part D: Transport and Environment* no. 16 (3):208-217. doi: http://dx.doi.org/10.1016/j.trd.2010.12.004.

Alstom. 2006. Environmental Product Declaration - CORADIA LIREX Commuter Train for Stockholm/Sweden. Germany.

AREMA. 2003. *Practical guide to railway engineering*. Landover, Md.: American Railway Engineering and Maintenance of Way Association.

Atkins. 2012. *Norway high speed rail assessment study: phase III : journey time analysis : marked, demand & revenue analysi s : estimation & assessment of investment costs : economic & financial analysis : summary report*. [Oslo]: Atkins.

Baron, T., G. Martinetti, and D. Pépion. 2011. Carbon Footprint of High Speed Rail. edited by M. Tuchschmid. Paris.

Barton, K., R. Carlson, M. Fracchia, G. Ghilardi, P. Hård, U. Kral, N. Leitao, A. Oberhauser, P. Steckler, and Stefan Uppenberg. 2010. D14 Suggestions for a process model for chosen components. InfraGuidER.

Bergsdal, H. 2014. Master thesis entitled "LCA of HSR electrification and effect on corridor planning". edited by Babak E. Ebrahimi. Trondheim, Norway: E. Ebrahimi, B.

Bergsdal, H., E. Graarud, and Å. Holen. 2011. Life Cycle Assessment of the Follo Line – Infrastructure. Norway: Asplan Viak AS,.

Bergsdal, H., J. Pettersen, C. Solli, C. Hung, C. Grossrieder, and J. Hammervold. 2012. Norwegian High-Speed Rail Assessment – Climate. Norway.

Bergsdal, Håvard. 2009. *Dynamic modeling and analysis of stocks and flows in building systems*. Vol. 2009:257. Trondheim: Norges teknisk-naturvitenskapelige universitet.

BOMBARDIER. 2012. REGINA Intercity X55 - Environmental Product Declaration. Sweden: EPD.

Botniabanan AB. 2010a. Environmental Product Declaration for power, signalling and telecom systems on the Bothnia Line. edited by Bureau Veritas Certification. Sweden: EPD.

Botniabanan AB. 2010b. Environmental Product Declaration for railway bridges on the Bothnia Line. edited by Bureau Veritas Certification. Sweden: EPD.

Botniabanan AB. 2010c. Environmental Product Declaration for railway track on the Bothnia Line. edited by Bureau Veritas Certification. Sweden: EPD.

Botniabanan AB. 2010d. Environmental Product Declaration for railway tunnels on the Bothnia Line. edited by Bureau Veritas Certification. Sweden: EPD.

Brattebø, Helge. 2011. Chapter 12: Life cycle assessment. In *Textbook in Industrial Ecology*. Unpublished.

Campos, Javier, and Ginés de Rus. 2009. "Some stylized facts about high-speed rail: A review of HSR experiences around the world." *Transport Policy* no. 16 (1):19-28. doi: http://dx.doi.org/10.1016/j.tranpol.2009.02.008.

Chang, Brenda, and Alissa Kendall. 2011. "Life cycle greenhouse gas assessment of infrastructure construction for California's high-speed rail system." *Transportation Research Part D: Transport and Environment* no. 16 (6):429-434. doi: http://dx.doi.org/10.1016/j.trd.2011.04.004.

Chester, Mikhail V., and Megan S. Ryerson. 2014. "Grand challenges for high-speed rail environmental assessment in the United States." *Transportation Research Part A: Policy and Practice* no. 61 (0):15-26. doi: http://dx.doi.org/10.1016/j.tra.2013.12.007.

Christopher, A. Bolin, and T. Smith Stephen. 2013. "Life Cycle Assessment of Creosote-Treated Wooden Railroad Crossties in the US with Comparisons to Concrete and Plastic Composite Railroad Crossties." *Transportation Technologies*:149-161.

Clark, M. S. S. 2009. LEAD-ANTIMONY, LEAD-CALCIUM, LEAD-SELENIUM, VRLA, NI-CD. . Knoxville, TN.

Classen, Mischa, H. J. Althaus, Silvio Blaser, Wolfram Scharnhorst, M. Tuchschmid, Niels Jungbluth, and Mireille F. Emmenegger. 2007. Life Cycle Inventories of Metals. In *Life Cycle Inventories of Metals*. Dubendorf: Swiss Centre for Life Cycle Inventories.

Community of European, Railway and infrastructure companies, and International Union of Railways. 2008. *Rail Transport and the environment: Facts and Figures*. Bruxelles: CER & UIC.

Dr. Fockenberg, K. 2013. Anchor Bolts attach innovative Overhead Contact Lines to Segments. In *Internet*, edited by Neue Produkte — New Products. Germany: http://www.tunnel-online.info/.

E. Ebrahimi, Babak. 2014. Life cycle assessment of railway electrification. Unpublished: NTNU, Industrial Ecology.

ELEKTRO. 2013. *Glassisolator*. EB Elektro AS, 2013 [cited 15.11 2013]. Available from http://www.eb-elektro.no/glassisolatorer/cms/73.

European Commission. 2010. ILCD Handbook, General guide for Life Cycle Assessment - Detailed guide. edited by First edition. Luxembourg: Institute for Environment and Sustainability.

European Commission. 2014. *Transport 2050: Commission outlines ambitious plan to increase mobility and reduce emissions*. Europa 2011 [cited 4th of July 2014]. Available from http://europa.eu/rapid/press-release˙IP-11-372˙en.htm.

Fuglseth, Mie Sparby. 2013. *Livsløpsvurdering av utbygging og utvidelse av 2-felts motorveg til 4-felts moderne motorvei*, Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim.

Gidlund, Jan-Olof, and LAKfGn. 2009. Power supply installations: Autotransformers with a rated output of 3 and 5 MVA. BV group.

Goedkoop, M., R. Heijungs, M. Huijbregts, A. D. Schryver, J. Struijs, and R. V. Zelm. 2013. ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level Netherlands: Ministry of Housing, Spatial Planning and Environment.

Goedkoop, M., M. Oele, M. Vieira, J. Leijting, T. Ponsioen, and E. Meijer. 2014. SimaPro Tutorial. PRé.

Goossens, Hugo. 2010. *Maintenance of high speed lines: report*. Paris: International Union of Railways.

Grant, H. Roger. 2005. *The railroad: the life story of a technology*. Westport, Conn.: Greenwood Press.

Grossrieder, Carine. 2011. *Life-cycle assessment of future high-speed rail in Norway*. [Trondheim]: C. Grossrieder.

Haugnes, Erling. 2011. The Follo Line - Double track Oslo-Ski. Norway: Jernbaneverket.

Holter, Kjell. 2013. “Green” signalling for the future. Norway: Jernbaneverket.

Houk, Randy. 2014. *Railroad History* 2008 [cited 10.04 2014]. Available from http://www.sdrm.org/history/timeline/.

ISO. 2006a. *Miljøstyring, livsløpsvurdering, krav og retningslinjer (ISO 14044:2006)*. Oslo: Standard Norge.

ISO. 2006b. *Miljøstyring, livsløpsvurdering, prinsipper og rammeverk (ISO 14040:2006)*. Lysaker: Standard Norge.

Iversen, P. 2012. Approach (connection) Oslo S. Norway: Jernbaneverket.

Jain, M. K. *Overhead Equipment - Overlaps*. RailElectrica 2014. Available from http://www.railelectrica.com/traction-distribution/overhead-equipment-overlaps/.

Jernbaneverket. 1998. *Kontaktledning: regler for prosjektering*. [Oslo]: JBV.

Jernbaneverket. 2002. KONTAKTLEDNINGSANLEGG. In *3.1*, edited by Jernbaneverket. Norway: Jernbaneverket.

Jernbaneverket. 2009. *ERTMS implementation plan*. [Oslo]: Jernbaneverket.

Jernbaneverket. 2010a. edited by JD540 05D fig001.png: Jernbaneverket.

Jernbaneverket. 2010b. Kontaktledningsanlegg med AT-system med seksjonert kontaktledning. Norway.

Jernbaneverket. 2011. *Slik fungerer jernbanen: en presentasjon av trafikksystemets infrastruktur*. Oslo: Jernbaneverket.

Jernbaneverket. 2013. Contact line: Design. Autotransformer system with segmented overhead contact line. Norway.

Jernbaneverket. 2014. *Felles elektro/Prosjektering og bygging/Jording*. Jernbaneverket, 20.02.2014 2014 [cited 13.05 2014]. Available from https://trv.jbv.no/wiki/Felles˙elektro/Prosjektering˙og˙bygging/Jording.

Kato, H., N. Shibahara, M. Osada, and Y. Hayashi. 2005. "A LIFE CYCLE ASSESSMENT FOR EVALUATING ENVIRONMENTAL IMPACTS OF INTER-REGIONAL HIGH-SPEED MASS TRANSIT PROJECTS." *the Eastern Asia Society for Transportation Studies* no. 6:13.

Kiani, Mohamad, Tony Parry, and Heather Ceney. 2008. "Environmental life-cycle assessment of railway track beds." *Engineering Sustainability* no. 161 (ES2):135-142.

Kichenside, Geoffrey. 2008. *Two centuries of railway signaling*. Hersham: Ian Allan Publishing.

Kiessling, Friedrich. 2009. *Contact lines for electric railways: planning, design, implementation, maintenance*. Munich: Publicis.

Kießling, Friedrich, Rainer Puschmann, and Axel Schmieder. 2001. *Contact lines for electric railways: planning, design, implementation*. Munich: Publicis.

Kjerkol, H., J. Amlie, and G. Dahl. 2012. Veileder for utarbeidelse av Miljøbudsjett for jernbaneinfrastruktur - Pilot Follobanen. Norway: Asplan Viak.

Lee, Cheul-Kyu, Yong-Ki Kim, Phirada Pruitichaiwiboon, Jung-Suk Kim, Kun-Mo Lee, and Chang-Sik Ju. 2010. "Assessing environmentally friendly recycling methods for composite bodies of railway rolling stock using life-cycle analysis." *Transportation Research Part D: Transport and Environment* no. 15 (4):197-203. doi: http://dx.doi.org/10.1016/j.trd.2010.02.001.

MARTÍN, LOREA GARCÍA SAN. 2011. *Life Cycle Assessment of Railway Bridges* Structural Design and Bridges, KTH, Sweden.

Meunier, J. 2002. *On the Fast Track: French Railway Modernization and the Origins of the TGV, 1944-1983*: Praeger.

Mikhail, C., and H. Arpad. 2010. "Life-cycle assessment of high-speed rail: the case of California." *Environmental Research Letters* no. 5 (1):014003.

MiSA AS. 2008-2014. MiSA er norsk forhandler for SimaPro, verdens mest brukte LCA-verktøy. In *SimaPro*, edited by An example of a screenshot from SimaPro. Norway: MiSA AS,.

Morita, Y., K. Shimizu, H. Kato, N. Shibahara, and T. Yamasaki. 2011. A STUDY FOR THE MEASUREMENT OF ENVIRONMENTAL IMPACT RESULTING FROM RAILWAY CONSTRUCTION. In *the ASME/ASCE/IEEE 2011 Joint Rail Conference*. Colorado, USA

Nes, Rasmus Nikolai. 2012. *Life cycle assessment of an offshore electricity grid interconnecting Northern Europe*. Masteroppgave, Department of Energy and Process Engineering, Norwegian University of Science and Technology, trondheim.

NICHIGOH COMMUNICATION ELECTRIC WIRE CO. 2009. Environmental Product Declaration For wire and cable World Wide Standard Cableff ECO-FLEX series In *Environmental Product Declaration*.

Norge, Samferdselsdepartementet. 2013. *National transport plan 2014-2023*. Oslo: Norwegian Ministry of Transport and Communications.

Ovedal, A., A. Brekke, L. Marie, and H. Kjerkol. 2012. Nytt Dobbeltspor Oslo – Ski (Follobanen. Tunnelstrekning). Norway: COWI AS,.

PRé Consultants. 2013. *Licenses and Features*. PRé Consultants, 2013a [cited 20.12 2013]. Available from http://www.pre-sustainability.com/licenses-features.

Pré Consultants. 2013. *SimaPro Databases and Methods*. Pré Consultants, 2013b [cited 20.12 2013]. Available from http://www.pre-sustainability.com/databases.

Profillidis, V. A. 2006. *Railway management and engineering*. Aldershot, Hampshire: Ashgate.

Pupke, Dr.-Ing. Frank. 2010. Installation of Contact Wire (CW) for High Speed Lines - Recommendations. Houstnon: Product Development Metal and Railways, IEEE meeting.

RMweb. 2014. *British Railways OLE*. RMweb 2013 [cited 13.04 2014]. Available from http://www.rmweb.co.uk/community/index.php?/topic/80403-british-railways-ole-part-four-overlap/.

Rodrigue, Jean-Paul, Claude Comtois, and Brian Slack. 2009. *The geography of transport systems*. London: Routledge.

Siemens AG. 2010. "Product Catalog 2010." In *Contact line equipment for mass transit and main line railways*: Siemens AG,. https://w3.usa.siemens.com/mobility/us/Documents/en/rail-solutions/railway-electrification/contact-line/product-catalog-mass-transit-2010-en.pdf.

Sleeswijk, Anneke Wegener, Lauran F. C. M. van Oers, Jeroen B. Guinée, Jaap Struijs, and Mark A. J. Huijbregts. 2008. "Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000." *Science of The Total Environment* no. 390 (1):227-240. doi: http://dx.doi.org/10.1016/j.scitotenv.2007.09.040.

Solli, C. 2004. *Fission or Fossil: A Comparative Hybrid Life Cycle Assessment of two Different Hydrogen Production Methods*, Dept. Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim.

Stripple, Håkan, and Stefan Uppenberg. 2010. *Life cycle assessment of railways and rail transports: application in environmental product declarations (EPDs) for the Bothnia Line*. Göteborg: IVL Swedish Environmental Research Institute.

Svensson, Niclas. 2006. *Life-cycle considerations for environmental management of the Swedish Railway infrastructure*. Vol. no. 1064. Linköping: Universitetet.

Svingheim, N. 2014. *High-speed rail services can be run on a commercially viable basis*. Jernbaneverket 2012 [cited 10th of May 2014]. Available from http://www.jernbaneverket.no/en/startpage1/Projects/High-speed-rail-services-can-be-run-on-a-commercially-viable-basis/.

The International EPDff System. COMMUNICATING ENVIRONMENTAL PRODUCT DECLARATIONS (EPDff). edited by The Swedish Environmental Management Council. Stockholm: The International EPDff System,.

The International EPDff System. 2014. *What Is An EPDff?* The International EPDff System, 2014 [cited 10.05 2014]. Available from http://www.environdec.com/en/What-is-an-EPD/#.U7mcAPmSy6F.

Thor Egil, T. 2013a. Are Systems 35 and 35 MS used for electrification or they are replaced gradually with the other Threes (S20 A, S20 B or S25)? Trondheim, 13.12.

Thor Egil, T. 2013b. Description and characterization of all overhead contact systems in JBV. Trondheim, 28.10.

Thor Egil, T. 2013c. Kontaktledningsanlegg med AT-system med seksjonert kontaktledning. Trondheim, 7.11.

Tingos, I. C., and F. L. Raposa. 1996. Safety considerations with railroad electrification: A preliminary review and assessment. U.S.: U.S. Department of Transportation.

Uic. 2009. *High speed rail: fast track to sustainable mobility*. Paris: UIC.

Uppenberg, Stefan. 2014. ERTMS Level 2 & GSM-R. In *Outlook* edited by Babak E. Ebrahimi.

Werner, F., and R. Schrägle. 2008. Life cycle assessment (LCA) of railway sleeper. http://www.vhn.org/pdf/LCA-biels-samenv.pdf.

Wolf, M. A., R. Pant, K. Chomkhamsri, S. Sala, and D. Pennington. 2012. ILCD Handbook, International Reference Life Cycle Data System. Luxembourg: Institute for Environment and Sustainability.

WSP, and (the Swedish Transport Administration) Trafikverket. 2013. Railways.

Yue, Y. 2013. *LIFE CYCLE ASSESSMENT OF CHINA'S HIGH SPEED RAIL SYSTEMS*, Natural Resources and Environment, the University of Michigan, USA.

Appendix A

Towards High-Speed Rail

Growth of railways was significantly affected by the industrial revolution that led to a massive modification in transportation system. (Rodrigue, Comtois, and Slack 2009, Profillidis 2006) 19th century was the age of development of railways by introduction of steam traction locomotives and they were incompatible for decades. Faster connection due to higher speeds led to a decisive development of railways that could be seen in increase in the size and consequently power of steam locomotives. In 1890, speeds up to 144 km/h could achieve in test runs, but operation speeds were much lower. (Profillidis 2006, Grant 2005)

Electric and internal combustion tractions locomotives found their way to steam-powered engines in the late 19th century and represented practicality of them. (AREMA 2003, Grant 2005, Houk 2008) In addition, they showed some points that steam locomotives were lacking from, such as reduction in operation cost, fuel, crew and maintenance, and eliminating delays for water and coal. After World War II, no other transportation systems were capable to recover the economics of war-torn countries. Consequently, this made national states to replace steam with diesel or electric locomotives or diesel-electric locomotives. (Houk 2008) However, due to entrance of a new competitor (air transport) in the area of transportation a pressure was given to railways to reevaluate the current situation to find better solutions to modernize the condition. (Meunier 2002)

Parallel with conventional railways, in the mid-1950s, France began the direct origin of fast trains. (Grant 2005) This was the start of a new era in the rail transportation system that proceeded to other countries in some years after.

Among the experimental developments, Japan introduced a new high-speed rail between Tokyo and Osaka that brought a new concept of rail transport. The new technology did not need the connection of vehicle wheels to track infrastructure (metal-to-metal) and instead utilized magnetic levitation concept.

HSR has been defined in many standpoints. However, the definition of it according to European Union Directive 96/48/EC, Annex 1 is made of three elements. (Profillidis 2006)

- Infrastructure
- Rolling stock
- Combination of infrastructure and rolling stock

The directive mentions either a line must be built specifically for high speed (which in this case the speed is above 250 km/h) or upgraded for high speed (which in this case the speed in working order of 200 km/h) to be able to call a line an HSR.

Appendix B

Calculations

Transport of HSR electrification goods (construction and maintenance & renewal)

NB. Bellow, the schematic way of calculation (from sites to depots and from depots to the track) is explained in details.

After transport of goods to the sites, the materials are transported for the second time either to depots or for installation on the line. It is assumed that depots are storage rooms that are along the rail tracks and distributed with a distance of 100 km.

Assumptions

Based on the length of different alignments that are presented on table 4.1, a length of 400 kilometers is presumed as an average length for an HSR in Norway. As it mentioned, materials directly for the sites are transported either to the depots or for installation along the track.

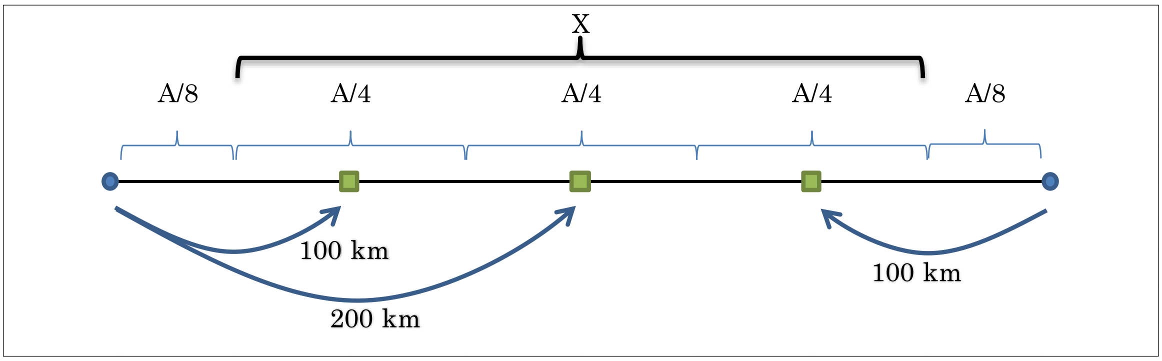
Transport to depots and installation from depots

It is assumed each depot is distributed in every 100 kilometers. Therefore, materials are transported from sites to the depots with the distance that are shown in figure bellow (100 km and 200 km). Nevertheless, depots only cover an area that is shown as A/4[51] (that is a length of 100 kilometers with respect to the total length of alignment, that is 400 km). This means, if transport of goods is going to be happen

[51] A is a representative of total amount of material required for the alignment.

from one depot, the depot covers 100 kilometer which is equivalent of a quarter of amount of material that are going to be installed on the area A/4 (figure 4.3). Depots only cover area X as it is shown in figure 4.3.

Moreover, it is assumed that materials are delivered directly from each site at both end of alignment. This means that components are distributed along the two areas A/8 from sites. Depots do not cover the two remaining areas (A/8, with length of 50 kilometers each).



Transportation along the line

By the defined hypothesis about the transport, the mathematical solution of transport of goods for the functional unit of 1 kilometer on the theoretical 400 km of track is as following.

$$Req.Transport = \left[\left(\overbrace{(100+200+100)\,km}^{L1} + \overbrace{300\,km}^{L2}\right)\cdot\frac{3\cdot A}{4}\right] + \left[\overbrace{100\,km}^{L3}\cdot\frac{A}{4}\right] \tag{1}$$

$$Req.Transport = 525\,(km)\cdot A\,(ton)$$

Description of three elements in equation (1) for the construction and M&R phases.

Element	Definitions
L1	is the total transport from the sites to the depots
L2	is the area X that is the transport of goods from the depots to instalation along the track
L3	is the the total transport from the sites to installations along the track

Based on the result, the total requirement of transport is 525 kilometers. However, an additional 75-kilometer is assumed due to uncertainty of having a low estimation. Thus, the total length of transport for 400 kilometers of a rail is 625 kilometers. To find out how much of transport per kilometer is required, the total value should be divided by 400 kilometers. Therefore, the result will be ***1.563 km*** of transport per one kilometer of a line.

Transport of HSR electrification goods (disposal)

To do so, it is assumed the same procedure as construction and maintenance & renewal (in the previous section) for the disposal phase is taken, but with slightly differences. In the method of transport, the same distance length as construction and M&R is assumed from dismantling and sending to the sites. This includes the complexity of process that has been explained in the previous section. This means if the same formula as equation (1) is considered, the description table is changed as following in table below.

Description of three elements in equation (1) for the disposal phase.

Element	Definitions
L1	is the total transport of dismantled materials from the depots to the sites
L2	is the area X that is the transport of goods from the dismantling along the track and sending to the depots
L3	is the the total transport from the dismantling along the track and sending to the sites

After all the transportation of goods from the track and sending to the sites, it is time for the final transport that is about sending dismantled materials to a waste treatment plant. On contrary to construction and M&R phases, a 200-kilometer of transport is presumed as an average transport

Tensioning section (open section)

S25 and Re 330 have a five-span overlap (240 meters). The calculations are the same. For auto-flexible tensioning, the number of auto-flexible tensioning in a kilometer is 1.59, and the calculation is as following;

$$\frac{[(100 * 1500) - (100 * 240)]\ (m)}{1000\ (m)} = \frac{200\ (auto\ flexible\ tensioings)}{x}$$

<u>*For mid-point anchor*</u> (the number of mid-point anchor in a kilometer is 0.79)

$$\frac{[(100 * 1500) - (100 * 240)]\ (m)}{1000\ (m)} = \frac{100\ (auto\ flexible\ tensioings)}{x}$$

Three-span overlap (the number of overlap in a kilometer is 0.78)

$$\frac{[(100 * 1500) - (100 * 240)]\ (m)}{1000\ (m)} = \frac{(100 - 1)\ (overlap)}{x}$$

Tensioning section (tunnel section)

Auto-Flexible tensioning (the number of auto-flexible tensioning in a kilometer is 2.7)

$$\frac{[(30 * 900) - (30 * 160)]\ (m)}{1000\ (m)} = \frac{60\ (auto\ flexible\ tensioings)}{x}$$

For mid-point anchor (the number of mid-point anchor in a kilometer is 1.35)

$$\frac{[(30 * 900) - (30 * 160)]\ (m)}{1000\ (m)} = \frac{30\ (mid - point\ anchors)}{x}$$

Three-span overlap (the number of overlap in a kilometer is 1.3)

$$\frac{[(30 * 900) - (30 * 160)]\ (m)}{1000\ (m)} = \frac{(30 - 1)\ (overlap)}{x}$$

Signaling and telecommunication

This part of calculation provides tables of data that in this LCA study considered for the sensitivity analysis related to signaling and telecommunication. The data as it was mentioned came from “KlimatKalkul” tool.

ERTMS Level 2

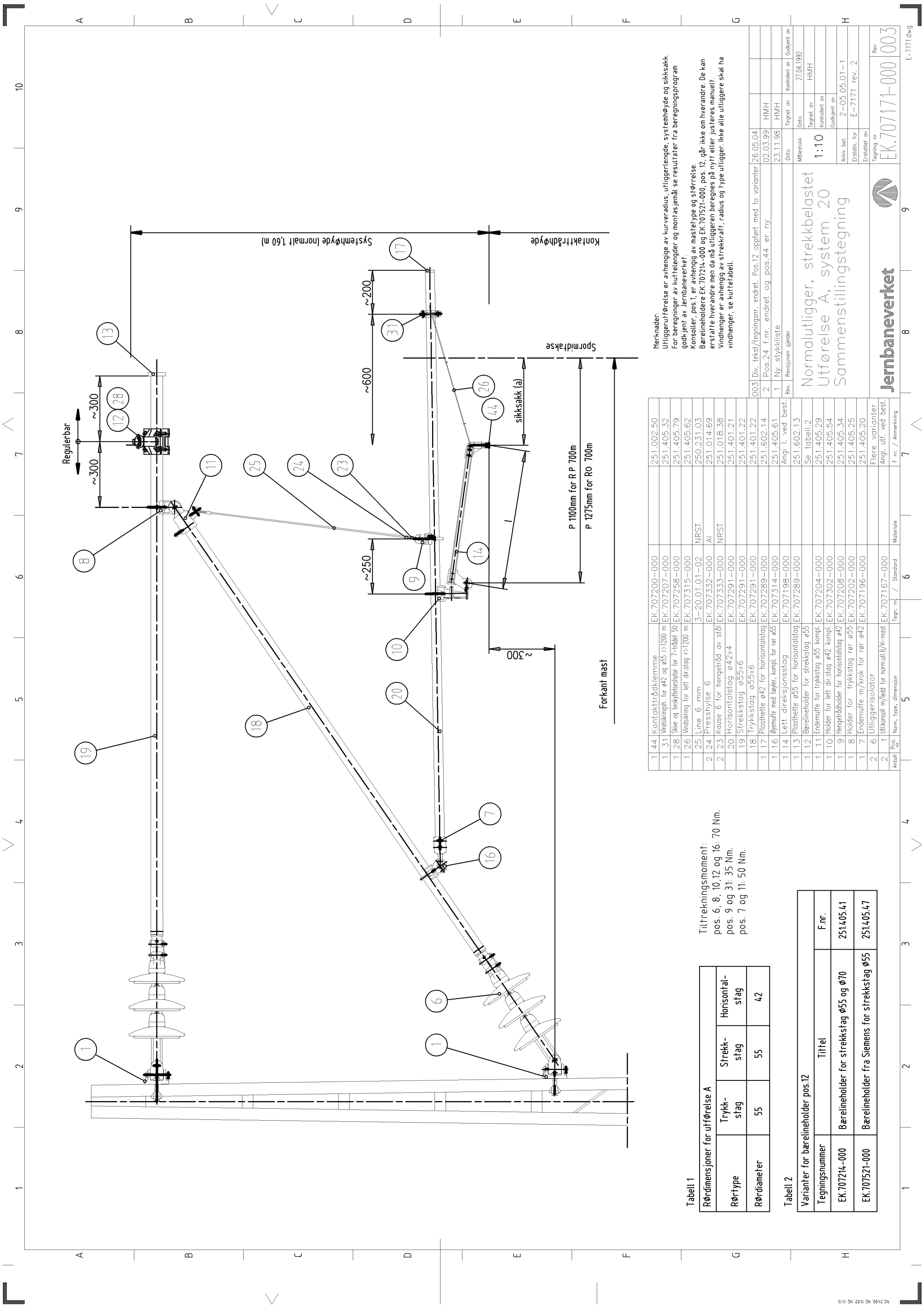
Items	Unit	Lifetime	climate impact (kg CO2-ekv./km/år)	Construciton	Maintenance
Baliser (EBI Link 2000)	stk	30	3.81E+00	1.14E+02	1.14E+02
cabel, signal	m	40	1.04E+02	4.16E+03	2.08E+03
ERTMS (EBI Lock 950)	stk	20	1.09E+01	2.18E+02	4.35E+02
EST	m	40	7.71E+01	3.09E+03	1.54E+03
Kabel, telecom	m	40	2.93E+01	1.17E+03	5.85E+02
SIR-mast	m	40	1.28E+01	5.10E+02	2.55E+02

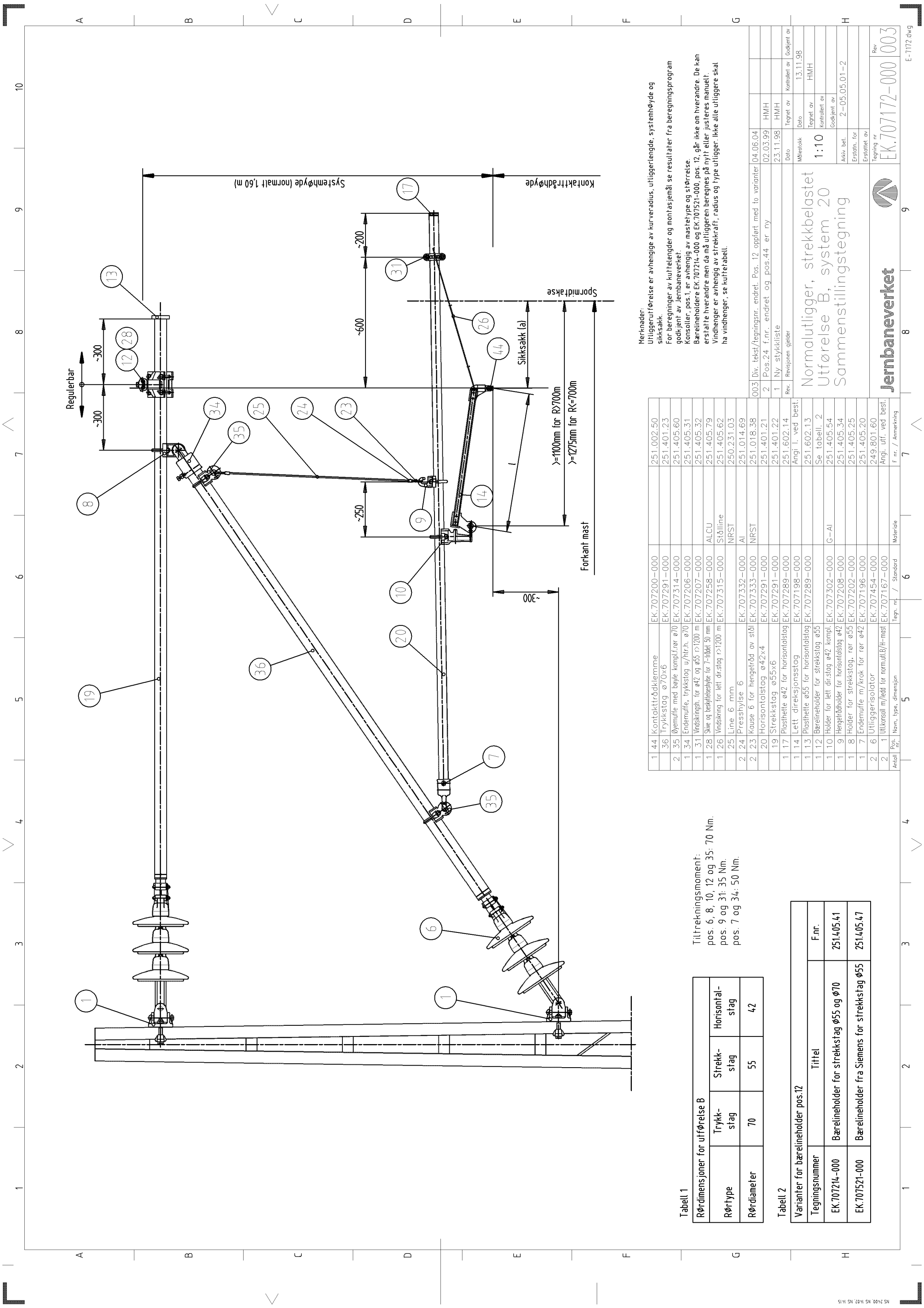
ERTMS Level 2 (with extra information)

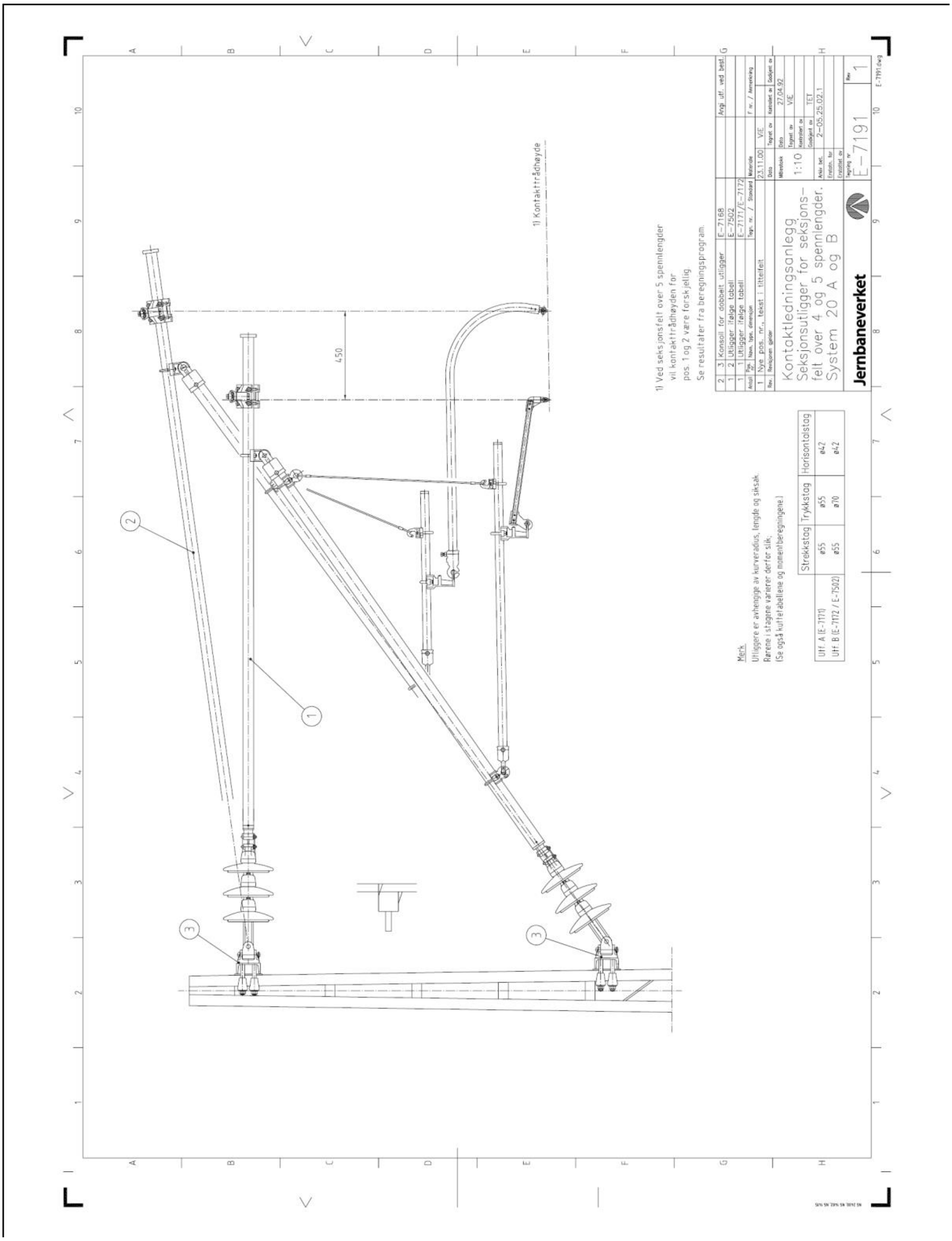
Items	Unit	Lifetime	climate impact (kg CO2-ekv./km/år)	Construciton	Maintenance
Baliser (EBI Link 2000)	stk	30	4.35E+00	1.31E+02	1.31E+02
cabel, signal	m	40	1.19E+02	4.75E+03	2.38E+03
ERTMS (EBI Lock 950)	stk	20	1.24E+01	2.49E+02	4.97E+02
EST	m	40	8.81E+01	3.52E+03	1.76E+03
Kabel, telecom	m	40	3.34E+01	1.34E+03	6.68E+02
SIR-mast	m	40	1.46E+01	5.83E+02	2.91E+02

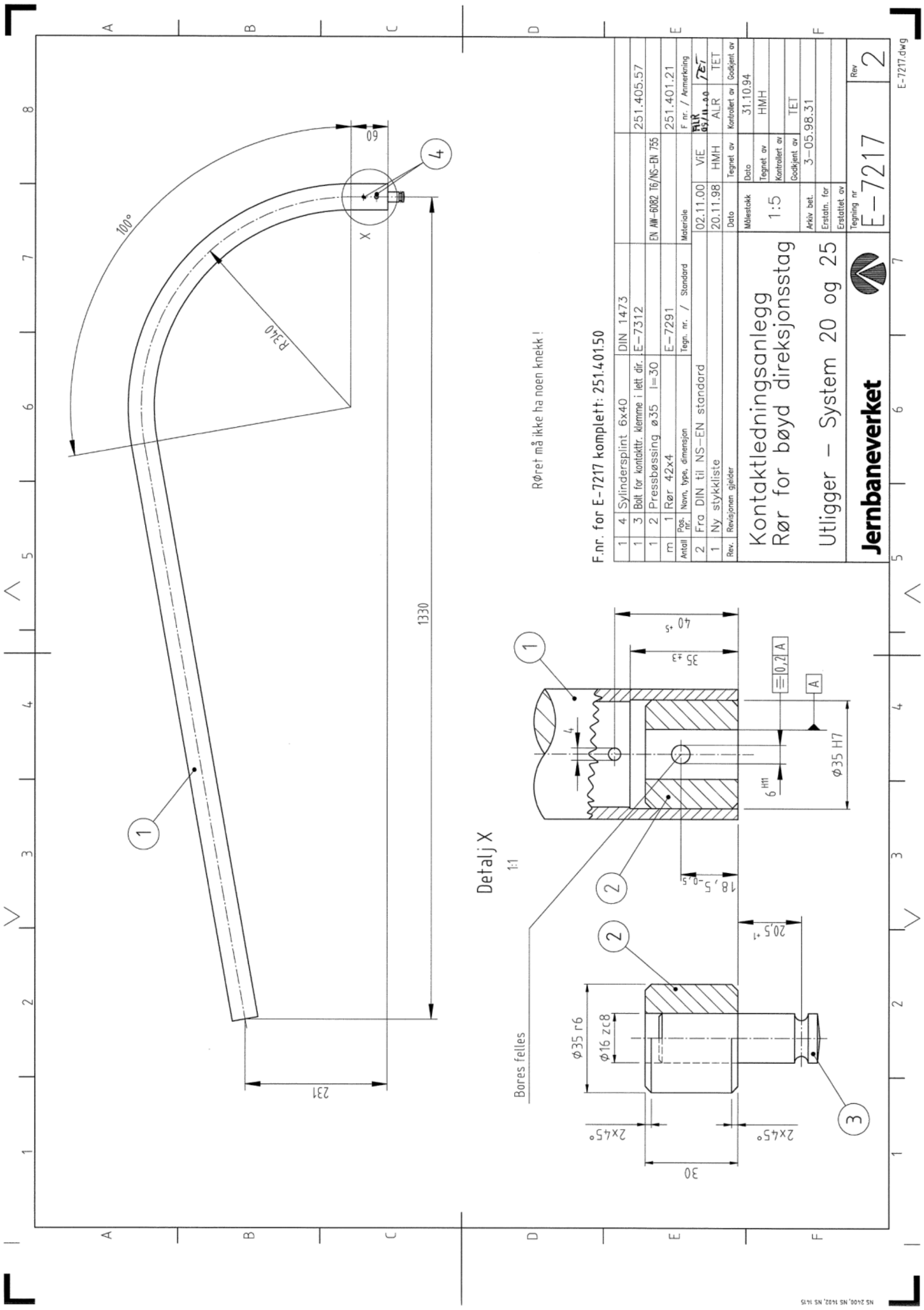
Appendix C

Layouts

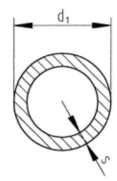

Systemhøyde (normalt 1,60 m)
Kontakttrådhøyde
Spormidtakse
Forkant mast
sikksakk (a)
P 1100mm for R P 700m
P 1275mm for RO 700m
Regulerbar
~300
~300
~600
~200
~250
~300
Merknader:
Utliggerutførelse er avhengige av kurveradius, utliggerlengde, systemhøyde og sikksakk.
For beregninger av kuttelengder og montasjemål se resultater fra beregningsprogram godkjent av Jernbaneverket.
Konsoller, pos.1, er avhengig av mastetype og størrelse.
Bærelineholdere EK.707214-000 og EK.707521-000, pos. 12, går ikke om hverandre. De kan erstatte hverandre men da må utliggeren beregnes på nytt eller justeres manuelt.
Vindhenger er avhengig av strekkraft, radius og type utligger. Ikke alle utliggere skal ha vindhenger, se kuttetabell.
Tiltrekningsmoment:
pos. 6, 8, 10,12 og 16: 70 Nm.
pos. 9 og 31: 35 Nm.
pos. 7 og 11: 50 Nm.
Tabell 1
Rørdimensjoner for utførelse A
Rørtype | Trykk-stag | Strekk-stag | Horisontal-stag
Rørdiameter | 55 | 55 | 42
Tabell 2
Varianter for bærelineholder pos.12
Tegningsnummer | Tittel | F.nr.
EK.707214-000 | Bærelineholder for strekkstag ø55 og ø70 | 251405.41
EK.707521-000 | Bærelineholder fra Siemens for strekkstag ø55 | 251405.47
Antall | Pos. nr. | Navn, type, dimensjon | Tegn. nr. / Standard | Materiale | F. nr. / Anmerkning
1 | 44 | Kontakttrådklemme | EK.707200-000 | | 251.002.50
1 | 31 | Vindsikringsh. for ø42 og ø55 r>1200 m | EK.707207-000 | | 251.405.32
1 | 28 | Skive og beskyttelseshylse for 7-tråds ø50 | EK.707258-000 | | 251.405.79
1 | 26 | Vindsikring for lett dir.stag r>1200 m | EK.707315-000 | | 251.405.62
 | 25 | Line 6 mm | 3-20.01.01-02 | NRST | 250.231.03
2 | 24 | Presshylse 6 | EK.707332-000 | Al | 251.014.69
2 | 23 | Kause 6 for hengetråd av stål | EK.707333-000 | NRST | 251.018.38
 | 20 | Horisontalstag ø42x4 | EK.707291-000 | | 251.401.21
 | 19 | Strekkstag ø55x6 | EK.707291-000 | | 251.401.22
 | 18 | Trykkstag ø55x6 | EK.707291-000 | | 251.401.22
1 | 17 | Plasthette ø42 for horisontalstag | EK.707289-000 | | 251.602.14
1 | 16 | Øyemuffe med bøyler, kompl. for rør ø55 | EK.707314-000 | | 251.405.61
1 | 14 | Lett direksjonsstag | EK.707198-000 | | Angi l. ved best.
1 | 13 | Plasthette ø55 for horisontalstag | EK.707289-000 | | 251.602.13
1 | 12 | Bærelineholder | | | Se tabell 2
1 | 11 | Endemuffe for trykkstag ø55 kompl. | EK.707204-000 | | 251.405.29
1 | 10 | Holder for lett dir.stag ø42 kompl. | EK.707302-000 | | 251.405.54
1 | 9 | Hengetrådholder for horisontalstag ø42 | EK.707208-000 | | 251.405.34
1 | 8 | Holder for trykkstag rør ø55 | EK.707202-000 | | 251.405.25
1 | 7 | Endemuffe m/krok for rør ø42 | EK.707196-000 | | 251.405.20
2 | 6 | Utliggerisolator | | | Flere varianter
2 | 1 | Utl.konsoll m/ledd for normalutl.B/H-mast | EK.707167-000 | | Angi. utf. ved best.
003 | Div. tekst/tegningsnr. endret. Pos.12 oppført med to varianter | 26.05.04
2 | Pos.24 f.nr. endret og pos.44 er ny | 02.03.99 | HMH
1 | Ny stykkliste | 23.11.98 | HMH
Normalutligger, strekkbelastet
Utførelse A, system 20
Sammenstillingstegning
Jernbaneverket
1:10
27.04.1992
HMH
2-05.05.01-1
E-7171 rev. 2
EK.707171-000 003
E-7171.dwg




1) Ved seksjonsfelt over 5 spennlengder
vil kontakttrådhøyden for
pos. 1 og 2 være forskjellig.
Se resultater fra beregningsprogram.
1) Kontakttrådhøyde
450
Merk
Strekkstag
Trykkstag
Horisontalstag
Kontaktledningsanlegg
Seksjonsutligger for seksjons-
felt over 4 og 5 spennlengder.
System 20 A og B
Jernbaneverket
E-7191


F.nr. for E-7217 komplett: 251.401.50
Røret må ikke ha noen knekk !
Detalj X
1:1
Bores felles
Kontaktledningsanlegg
Rør for bøyd direksjonsstag
Utligger – System 20 og 25
Jernbaneverket
E-7217
1:5
Sylindersplint 6x40
DIN 1473
Bolt for kontaktr. klemme i lett dir.
E-7312
Pressbøssing ø35 l=30
Rør 42x4
E-7291
Fra DIN til NS-EN standard
Ny stykkliste
251.405.57
251.401.21
R340
1330
231
100°
60

Pos	Rør d/xs	Toleranser f.d. $\Delta\bar{d}$ mm	Toleranser f.d. Δd_1 mm	A mm²	J cm⁴	W cm³	Vekt kg\m	Nyttes som
1	26x3,5	+0,6 -0,1 x)	+1,5 -0,1 x)	247,40	1,603	1,233	0,668	Direksjonsstag, bryterstang, strekkstag, stag.
2	42x4	+0,7 -0,35 x)	+1,8 -0,9 x)	477,52	8,715	4,150	1,289	Horisontalstag, strekkstag, Loddføringsrør.
3	55x6	±0,8	+1 -2	923,63	28,136	10,231	2,494	Trykkstag, strekkstag, horisontalstag.
4	70x6	±0,8	±2	1206,37	62,309	17,803	3,257	Trykkstag
5	80x6	±0,8	±2	1394,87	96,106	24.027	3,766	Trykkstag
6	100x10	±0,9	±2,3	2827,43	289,812	57.962	7,634	Hengemast
7	120x12	±0,9	±2,3	4071,50	600,954	100,159	10,993	Hengemast



Materiale: EN AW-6082 T6, fasthetsegenskaper etter NS-EN 755-2.
Tekniske leveringsbetingelser: NS-EN 755-1.
Mål og tillatte avvik: NS-EN 755-7.
Unntatt verdier som er merket med x):
$\Delta\bar{d}$ =tillatt avvikfra gj. snitt. utvendig diameter.
Δd_1 =tillatt avvik og urundhet.

Antall	Pos. nr.	Navn, type, dimensjon	Tegn. nr. / Standard	Materiale	F nr. / Anmerkning
m.	7	Aluminiumsrør 120x12		EN AW-6082 T6	251.401.26
m.	6	Aluminiumsrør 100x10		EN AW-6082 T6	251.401.25
m.	5	Aluminiumsrør 80x6		EN AW-6082 T6	251.401.24
m.	4	Aluminiumsrør 70x6		EN AW-6082 T6	251.401.23
m.	3	Aluminiumsrør 55x6		EN AW-6082 T6	251.401.22
m.	2	Aluminiumsrør 42x4		EN AW-6082 T6	251.401.21
m.	1	Aluminiumsrør 26x3,5		EN AW-6082 T6	251.401.20

Rev.	Revisjonen gjelder	Dato	Tegnet av	Kontrollert av	Godkjent av
2	Fra DIN til NS-EN standard	09.10.00	ViE	ALR 10/11.00	TET
1	Ny stykkliste	11.11.98	HMH	ALR	TET

Kontaktledningsanlegg
Ekstruderte aluminiumsrør

Utligger – System 20 og 25

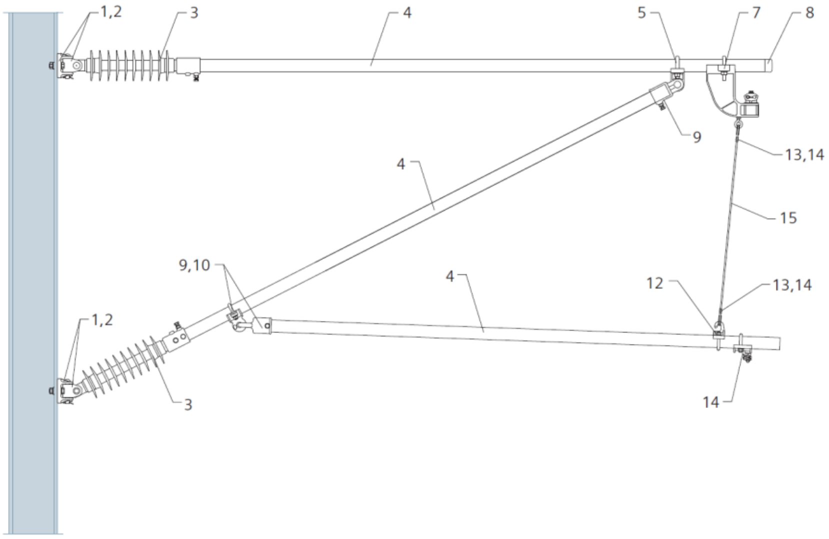
Målestokk	1:1
Dato	02.11.92
Tegnet av	HMH
Kontrollert av	
Godkjent av	TET
Arkiv bet.	4-20.20.16
Erstatn. for	
Erstattet av	
Tegning nr	E-7291
Rev	2

Jernbaneverket

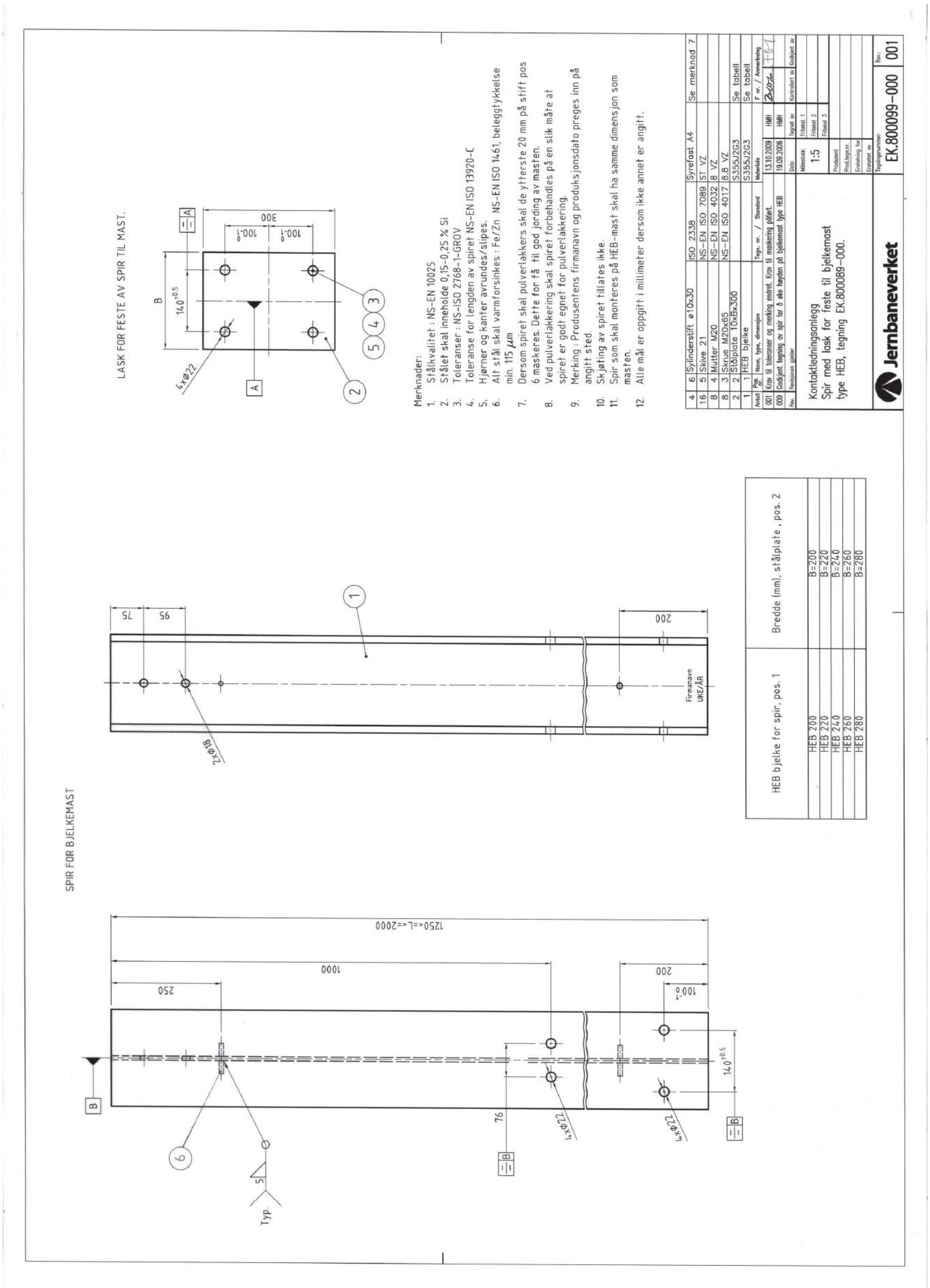
E-7291.dwg

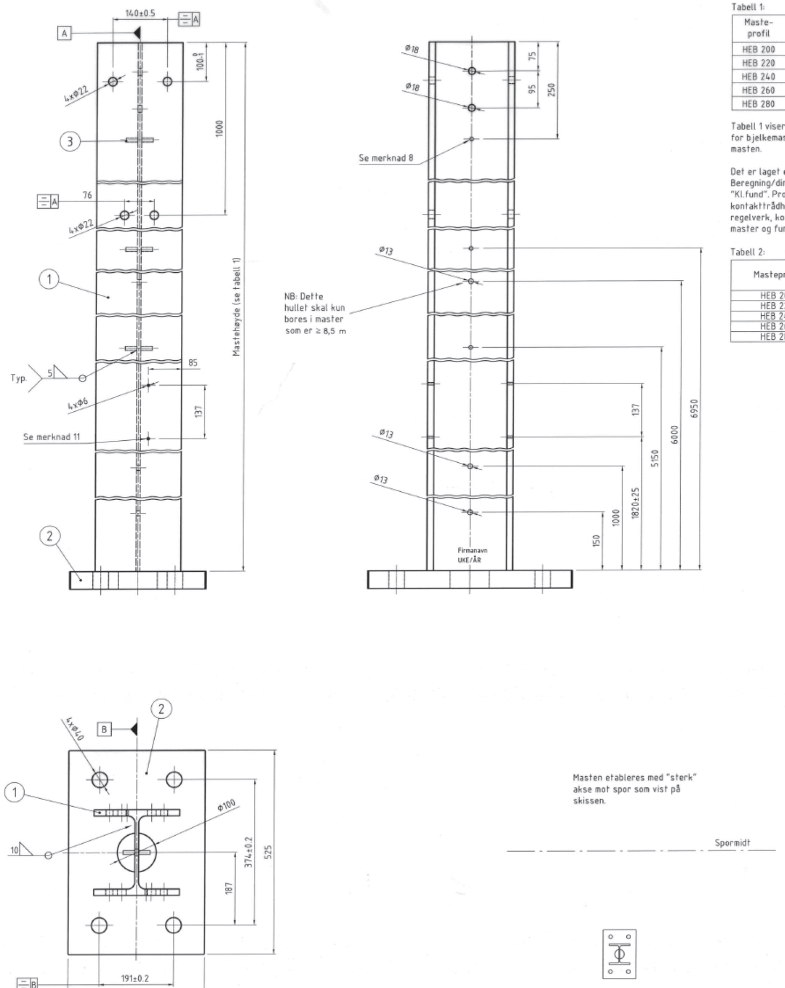
NS 2400, NS 1402, NS 1415

Cantilever, lifted for low system heights on steel pole in main-line railways



Position	Designation	Order no.
1	Cantilever swivel bracket	8WL2124-4
2	Swivel with clevis	8WL2126-1
3	Composite insulator 25 kV AC	8WL3078-2A
4	Aluminium tube 55x6 (length as needed)	8WL2167-0
5	Eye clamp 55	8WL2115-1
6	Catenary wire support clamp 55/14 with hook	8WL2027-0C
7	End cap 55	8WL2184-3
8	Clevis end fitting 55	8WL2121-5
9	Eye clamp 55	8WL2114-1
10	Hook end fitting 55	8WL2104-2
11	Hook clip 55	8WL2148-6
12	Thimble 35	8WL1501-1
13	Compression joint	8WL1553-0
14	Wire rope 6 (length as needed)	8WL7093-2


SPIR FOR BJELKEMAST
LASK FOR FESTE AV SPIR TIL MAST.
Typ.
2xØ18
4xØ22
Firmanavn
UKE/ÅR
1250<=L<=2000
1000
250
200
75
95
76
300
140±0.5
HEB bjelke for spir, pos. 1
Bredde (mm), stålplate , pos. 2
HEB 200 B=200
HEB 220 B=220
HEB 240 B=240
HEB 260 B=260
HEB 280 B=280
Merknader:
1. Stålkvalitet : NS-EN 10025
2. Stålet skal inneholde 0,15-0,25 % Si
3. Toleranser : NS-ISO 2768-1-GROV
4. Toleranse for lengden av spiret NS-EN ISO 13920-C
5. Hjørner og kanter avrundes/slipes.
6. Alt stål skal varmforsinkes : Fe/Zn NS-EN ISO 1461, beleggtykkelse min. 115 μm
7. Dersom spiret skal pulverlakkers skal de ytterste 20 mm på stift pos 6 maskeres. Dette for få til god jording av masten.
8. Ved pulverlakkering skal spiret forbehandles på en slik måte at spiret er godt egnet for pulverlakkering.
9. Merking : Produsentens firmanavn og produksjonsdato preges inn på angitt sted.
10. Skjøting av spiret tillates ikke.
11. Spir som skal monteres på HEB-mast skal ha samme dimensjon som masten.
12. Alle mål er oppgitt i millimeter dersom ikke annet er angitt.
4 6 Sylinderstift ø10x30 ISO 2338 Syrefast A4 Se merknad 7
16 5 Skive 21 NS-EN ISO 7089 ST VZ
8 4 Mutter M20 NS-EN ISO 4032 8 VZ
8 3 Skrue M20x65 NS-EN ISO 4017 8.8 VZ
2 2 Stålplate 10xBx300 S355J2G3 Se tabell
1 1 HEB bjelke S355J2G3 Se tabell
Antall Pos. nr. Navn, type, dimensjon Tegn. nr. / Standard Materiale F. nr. / Anmerkning
001 Krav til toleranser og merking endret. Krav til maskering påført. 13.10.2009 HMH
000 Godkjent tegning av spir for å øke høyden på bjelkemast type HEB 19.09.2006 HMH
Rev. Revisjonen gjelder Dato Tegnet av Kontrollert av Godkjent av
Kontaktledningsanlegg
Spir med lask for feste til bjelkemast
type HEB, tegning EK.800089-000.
Målestokk: 1:5
Jernbaneverket
EK.800099-000
Rev.: 001



Tabell 1:

Maste-profil	Mastehøyde (m) 6,0	6,5	7,0	7,5	8,0	8,5	9,0	9,5	10,0	10,5	11,0	11,5	12,0	12,5	13,0
HEB 200	249018010	249018020	249018030	249018040	249018050	249018060	249018070	249018080	–	–	–	–	–	–	–
HEB 220	249018090	249018100	249018110	249018120	249018130	249018140	249018150	249018160	249018170	249018180	249018190	–	–	–	–
HEB 240	249018200	249018210	249018220	249018230	249018240	249018250	249018260	249018270	249018280	249018290	249018300	249018310	249018320	–	–
HEB 260	249018330	249018340	249018350	249018360	249018370	249018380	249018390	249018400	249018410	249018420	249018430	249018440	249018450	249018460	249018470
HEB 280	249018480	249018490	249018500	249018510	249018520	249018530	249018540	249018550	249018560	249018570	249018580	249018590	249018600	249018610	249018620

Tabell 1 viser Jernbaneverkets artikkelnummer (F.nr.), masteprofiler og mastehøyder for bjelkemastene. Tabell 2 viser de ulike profilers maksimale moment i foten av masten.

Det er laget et dataprogram for valg av bjelkemaster ved ulike belastninger. Beregning/dimensjonering av bjelkemastene kan utføres ved hjelp av programmet "Kl.fund". Programmet oppgir kreftene i forskjellige grensetilstander og forskyvning i kontakttrådhøyde, samt utnyttelsesgrad. For mer informasjon henvises det til Teknisk regelverk, kontaktledning, prosjektering, kap. 7, vedlegg, "Konstruksjon, beregning av master og fundamenter".

Tabell 2:

Masteprofil	Maksimalt moment i bruddgrense i mastefot (kNm)
HEB 200	120
HEB 220	140
HEB 240	160
HEB 260	180
HEB 280	190

Merknader:

1. Stålkvalitet : NS-EN 10025
2. Stålet skal inneholde 0,15-0,25 % Si
3. Toleranser : NS-ISO 2768-1-GROV
4. Toleranse for mastehøyde NS-EN ISO 13920-C
5. Sveising : NS 470 KLASSE B, NS-EN 288 og NS-EN 287
6. Hjørner og kanter avrundes/slipes.
7. Alt stål skal varmforsinkes : Fe/Zn NS-EN ISO 1461, beleggtykkelse min 115 μm.
8. Dersom mastene skal pulverlakkers skal alle hull med Ø13 mm maskeres med Ø35 mm maskering før mastene lakkeres. Jordingspunkt pos. 3 stiftens ytterste i 20 mm skal maskeres. Dette for få til god jording av masten.
9. Ved pulverlakkering skal masten forbehandles på en slik måte at masten er godt egnet for pulverlakkering.
10. Merking : Produsentens firmanavn/UKE/ÅR preges inn på angitt sted.
11. Skjøting av masten tillates ikke.
12. Hull for skilt kan erstattes med at hullene markeres med gul lakk eller maling.
13. Minimum 10 % av sveisene skal kontrolleres med MPI.
14. Alle mål er oppgitt i millimeter dersom ikke annet er angitt.

Antall	Pos. nr.	Navn, type, dimensjon	Tegn. nr. / Standard	Materiale	F. nr. / Anmerkning
6	3	Sylinderstift ø10x30	ISO 2338	Syrefast A4	Se merknad 8
1	2	Stålplate 45x350x525	NS-EN 10029	S355J2G3	
1	1	HEB		S355J2G3	Se tabell 1

Rev.	Revisjonen gjelder	Dato	Tegnet av	Kontrollert av	Godkjent av
001	Krav til maskering påført. Toleranser er endret/presisert.	23.10.09	HMH	Blok	FH
000	Ny godkjent tegning av bjelkemast type HEB, lengde 6,0 – 13,0 m	20.09.06	HMH		

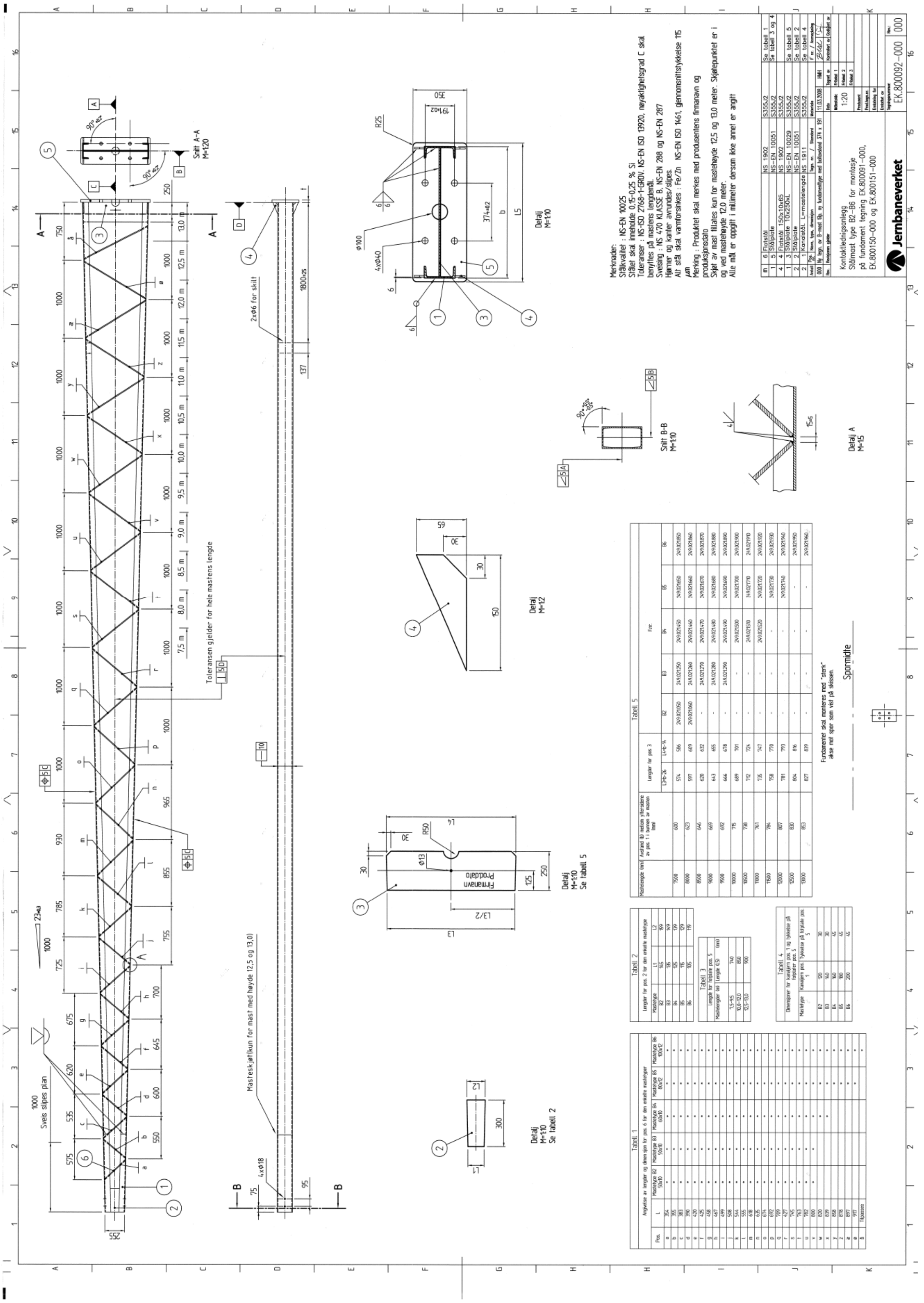
Kontaktledningsanlegg. Bjelkemast, type HEB med fotplate. For fundamenter med avstand R, fra senter fundamenttopp til senter bolt, lik 210 mm. Høyde 6,0 – 13,0 m

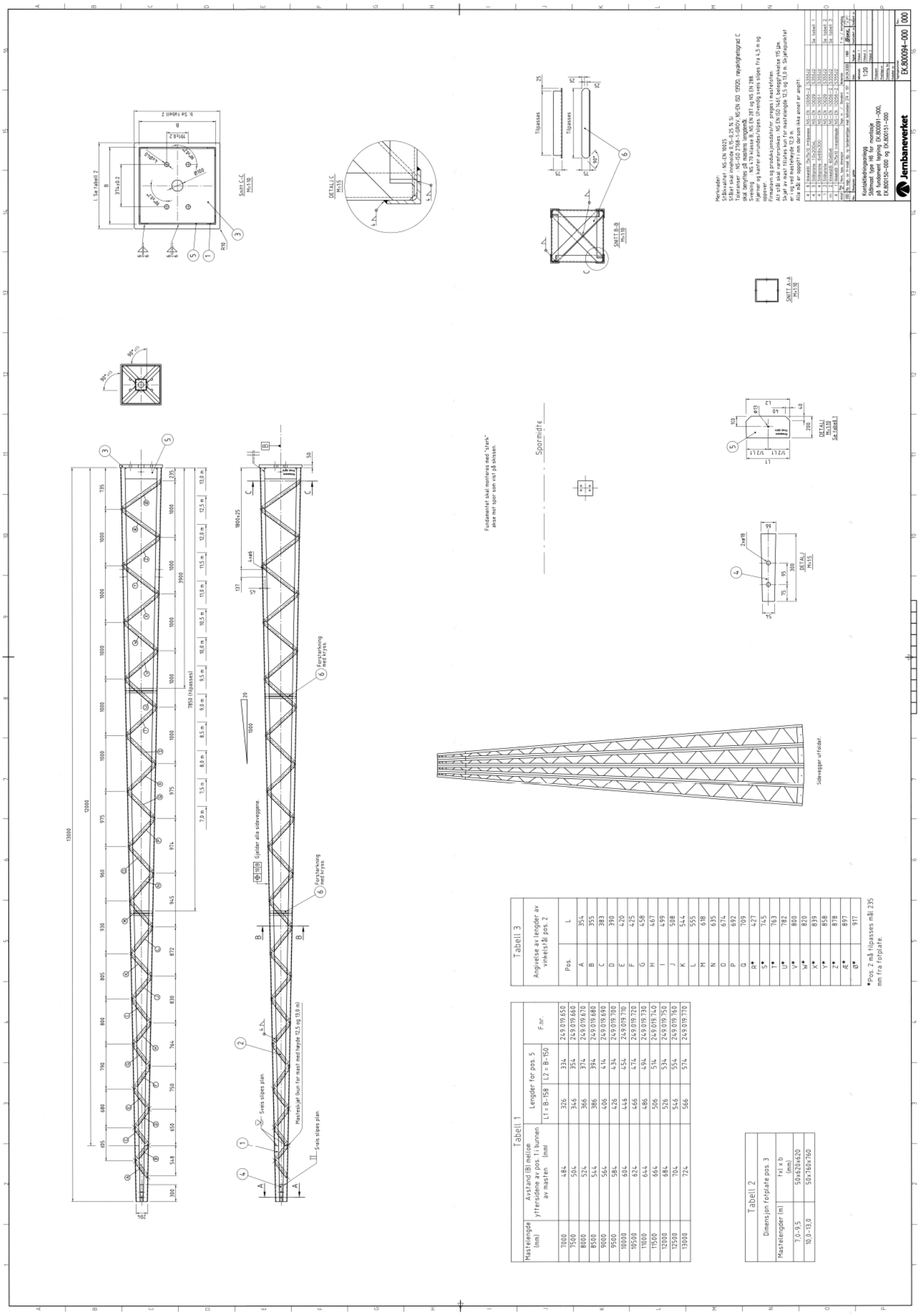
Målestokk: 1:5

Fritekst 1
Fritekst 2
Fritekst 3
Produsent
Prod.tegn.nr.
Erstatning for
Erstattet av

Jernbaneverket

Tegningsnummer: EK.800089-000 Rev.: 001


Jernbaneverket
EK.800092-000



Tabell 1

Mastelengde (mm)	Avstand (B) mellom yttersidene av pos. 1 i bunnen av masten (mm)	Lengder for pos. 5 L1 = B-158	Lengder for pos. 5 L2 = B-150	F.nr.
7000	484	326	334	249.019.650
7500	504	346	354	249.019.660
8000	524	366	374	249.019.670
8500	544	386	394	249.019.680
9000	564	406	414	249.019.690
9500	584	426	434	249.019.700
10000	604	446	454	249.019.710
10500	624	466	474	249.019.720
11000	644	486	494	249.019.730
11500	664	506	514	249.019.740
12000	684	526	534	249.019.750
12500	704	546	554	249.019.760
13000	724	566	574	249.019.770

Tabell 2

Dimensjon fotplate pos. 3

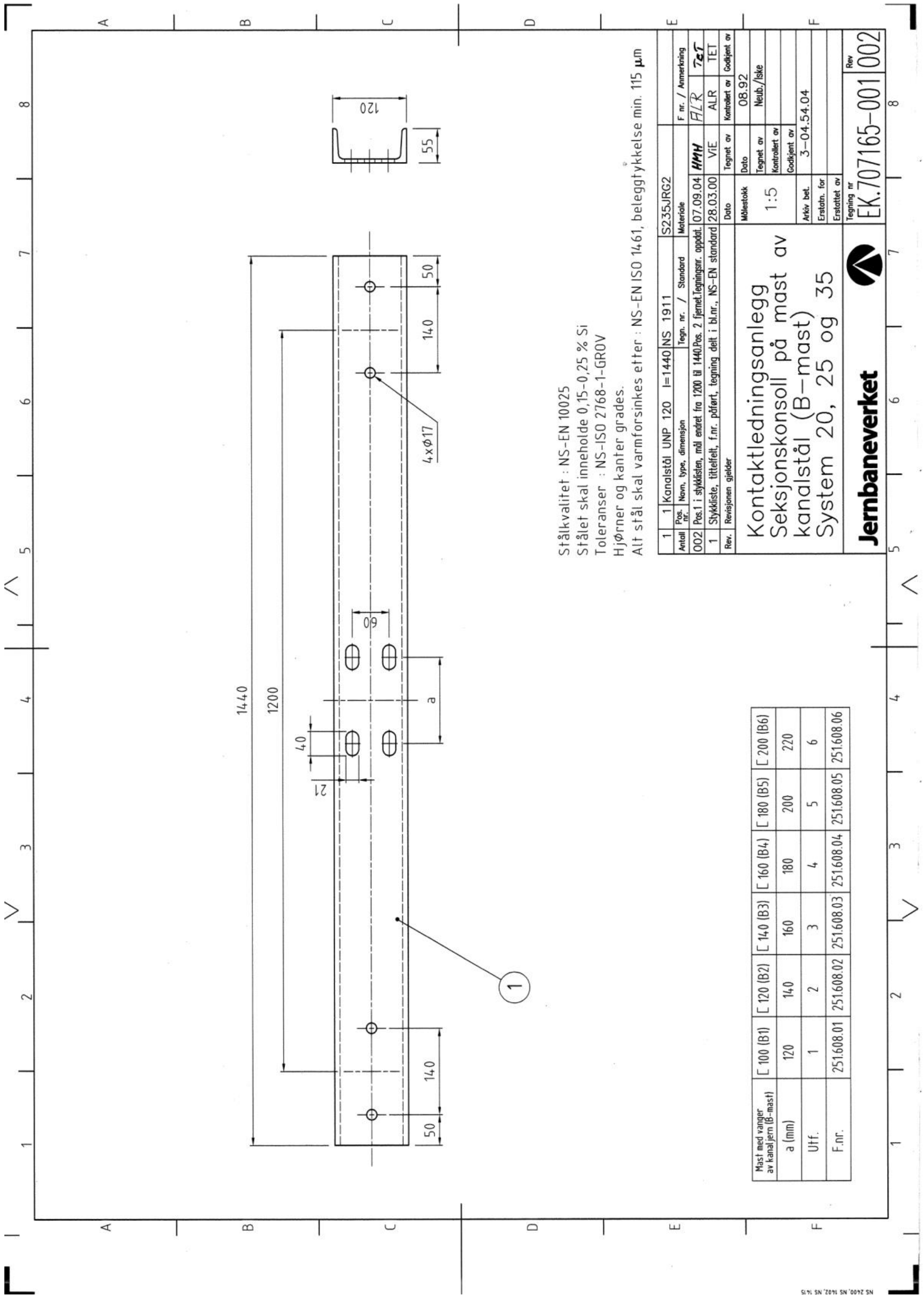
Mastelengder (m)	txl x b (mm)
7,0-9,5	50x620x620
10,0-13,0	50x760x760

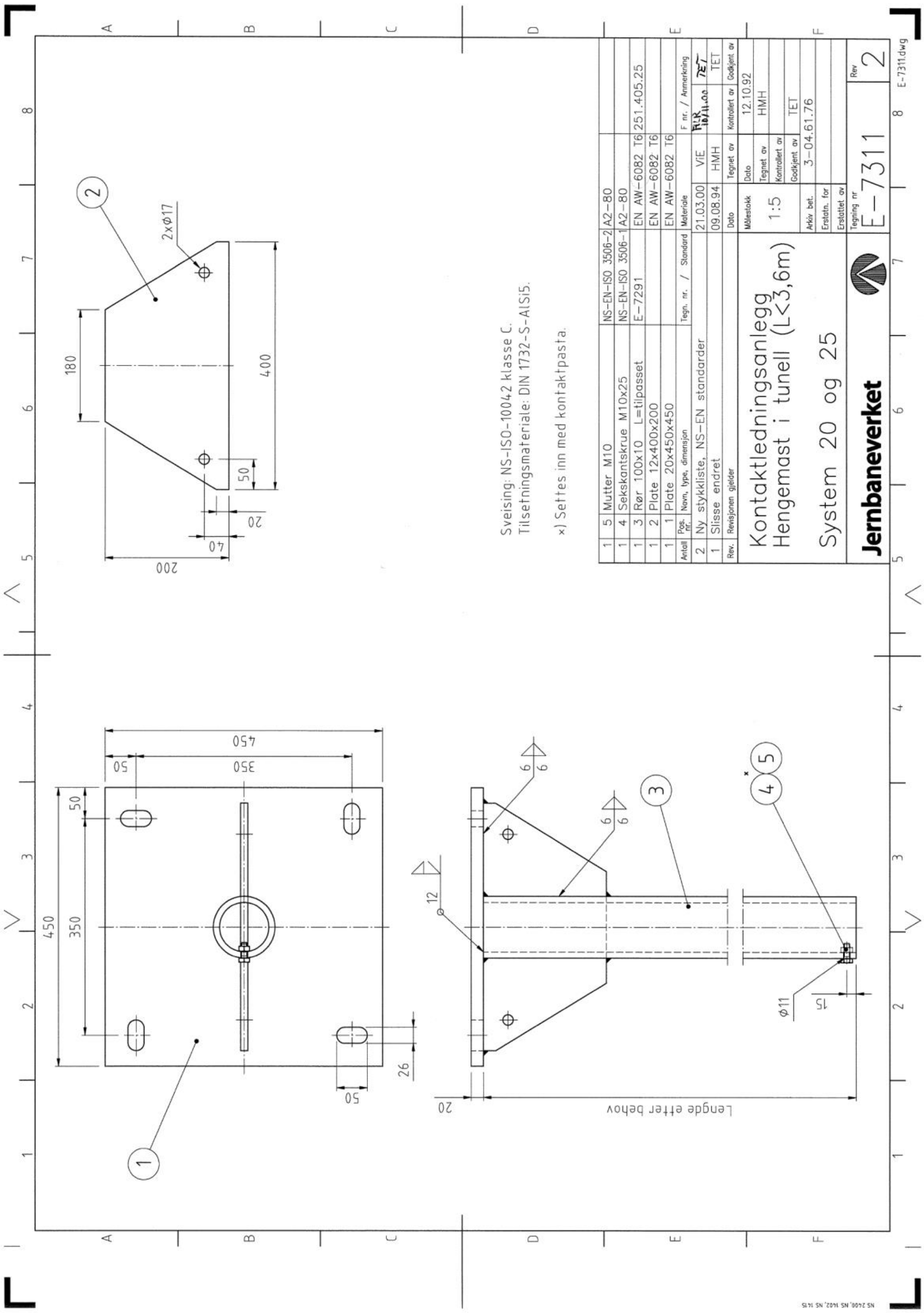
Tabell 3

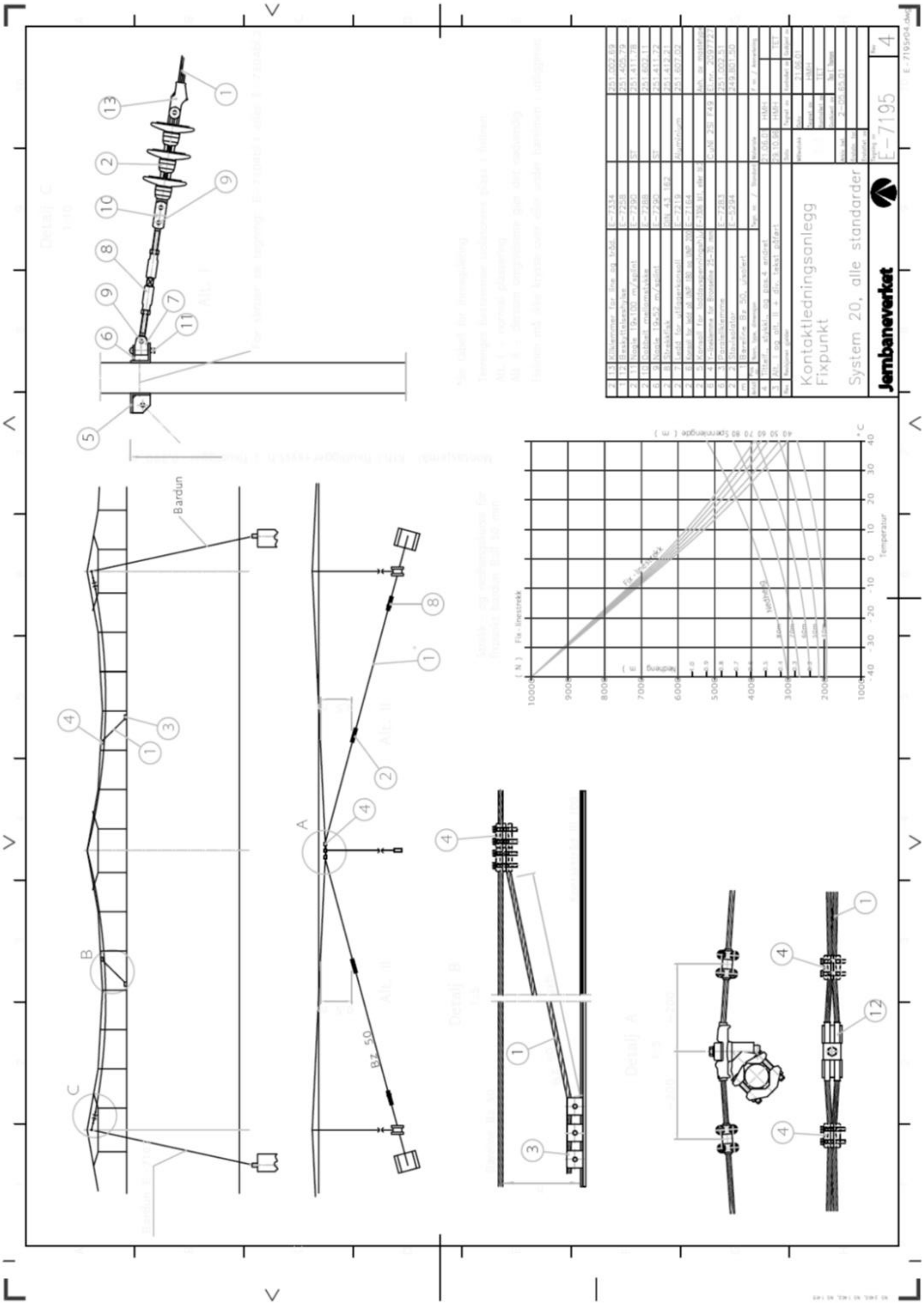
Angivelse av lengder av vinkelstål pos. 2

Pos.	L
A	354
B	355
C	383
D	390
E	420
F	425
G	458
H	467
I	499
J	508
K	544
L	555
M	618
N	635
O	674
P	692
Q	709
R*	427
S*	745
T*	763
U*	782
V*	800
W*	820
X*	839
Y*	858
Z*	878
Æ*	897
Ø*	917

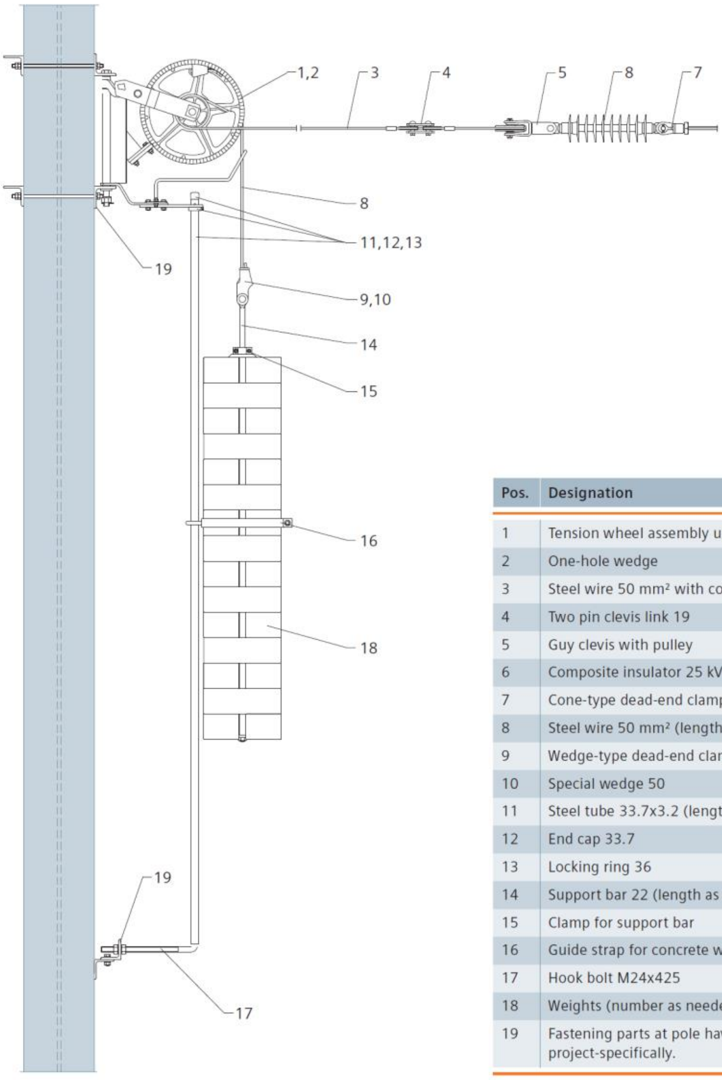
*Pos. 2 må tilpasses mål 235 mm fra fotplate.


Stålkvalitet : NS-EN 10025
Stålet skal inneholde 0,15-0,25 % Si
Toleranser : NS-ISO 2768-1-GROV
Hjørner og kanter grades.
Alt stål skal varmforsinkes etter : NS-EN ISO 1461, beleggtykkelse min. 115 µm
1440
1200
140
50
4xØ17
120
55
60
40
21
a
1
Mast med vanger av kanaljern (B-mast)
[100 (B1)
[120 (B2)
[140 (B3)
[160 (B4)
[180 (B5)
[200 (B6)
a (mm)
120
140
160
180
200
220
Utf.
1
2
3
4
5
6
F.nr.
251.608.01
251.608.02
251.608.03
251.608.04
251.608.05
251.608.06
1 1 Kanalstål UNP 120 l=1440 NS 1911 S235JRG2
Antall Pos. nr. Navn, type, dimensjon Tegn. nr. / Standard Materiale F nr. / Anmerkning
002 Pos.1 i stykklisten, mål endret fra 1200 til 1440.Pos. 2 fjernet.Tegningsnr. oppdd. 07.09.04 HMH FLR TeT
1 Stykkliste, tittelfelt, f.nr. påført, tegning delt i bl.nr., NS-EN standard 28.03.00 VIE ALR TET
Rev. Revisjonen gjelder Dato Tegnet av Kontrollert av Godkjent av
Kontaktledningsanlegg
Seksjonskonsoll på mast av
kanalstål (B-mast)
System 20, 25 og 35
Målestokk 1:5
Dato 08.92
Tegnet av Neub./Iske
Kontrollert av
Godkjent av
Arkiv bet. 3-04.54.04
Erstatn. for
Erstattet av
Jernbaneverket
Tegning nr EK.707165-001
Rev 002
NS 2400, NS 1402, NS 1415

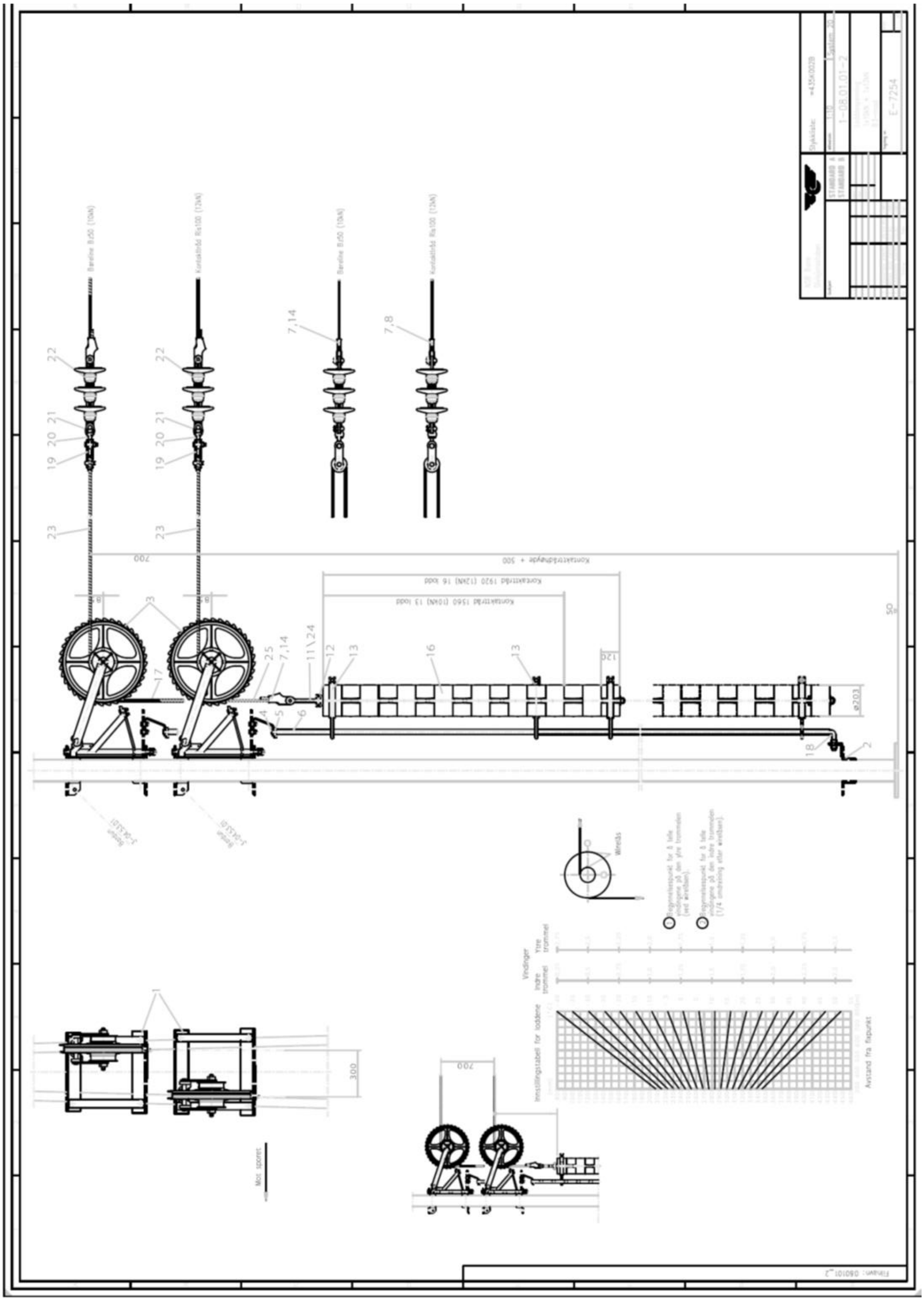

Sveising: NS-ISO-10042 klasse C.
Tilsetningsmateriale: DIN 1732-S-AlSi5.
x) Settes inn med kontaktpasta.
1 5 Mutter M10 NS-EN-ISO 3506-2 A2-80
1 4 Sekskantskrue M10x25 NS-EN-ISO 3506-1 A2-80
1 3 Rør 100x10 L=tilpasset E-7291 EN AW-6082 T6 251.405.25
1 2 Plate 12x400x200 EN AW-6082 T6
1 1 Plate 20x450x450 EN AW-6082 T6
Antall Pos. nr. Navn, type, dimensjon Tegn. nr. / Standard Materiale F nr. / Anmerkning
2 Ny stykkliste, NS-EN standarder 21.03.00 VIE TET
1 Slisse endret 09.08.94 HMH TET
Rev. Revisjonen gjelder Dato Tegnet av Kontrollert av Godkjent av
Kontaktledningsanlegg
Hengemast i tunell (L<3,6m)
System 20 og 25
Målestokk 1:5
Dato 12.10.92
Tegnet av HMH
Kontrollert av
Godkjent av TET
Arkiv bet. 3-04.61.76
Erstatn. for
Erstattet av
Tegning nr E-7311
Rev 2
Jernbaneverket
E-7311.dwg
Lengde etter behov
2xØ17
Ø11
NS 2400, NS 1402, NS 1415

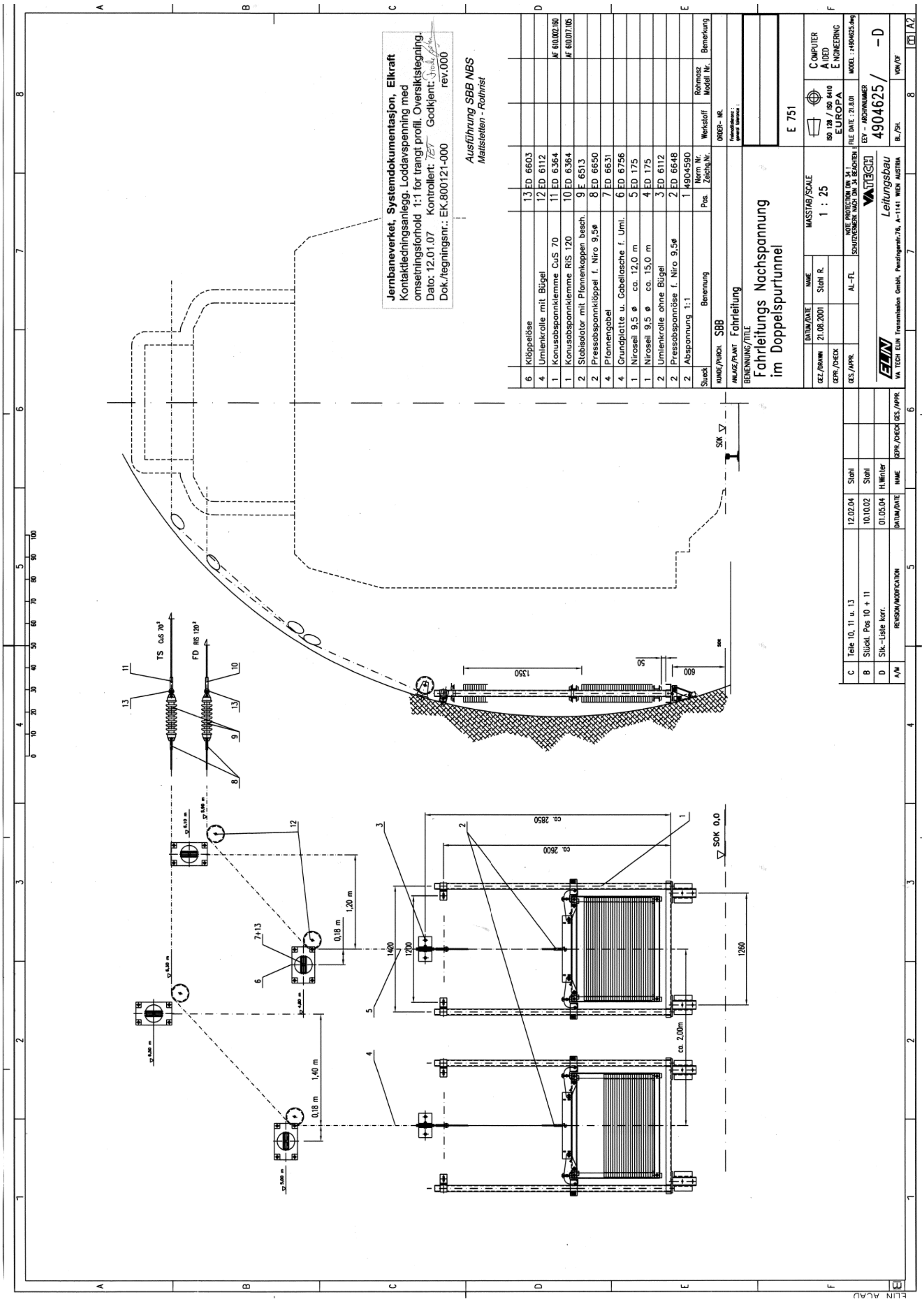

Kontaktledningsanlegg
Fixpunkt
System 20, alle standarder
Jernbaneverket
E-7195
Bardun
Bz 50
Temperatur

Flexible termination up to 40 kN at HE pole



Pos.	Designation	Order no.
1	Tension wheel assembly up to 40 kN	8WL5070-0B
2	One-hole wedge	8WL1201-0
3	Steel wire 50 mm² with connecting fittings	8WL7090-0C
4	Two pin clevis link 19	8WL1018-0
5	Guy clevis with pulley	8WL5167-5
6	Composite insulator 25 kV AC	8WL3078-1A
7	Cone-type dead-end clamp 19/AC-120	8WL1237-2
8	Steel wire 50 mm² (length as needed)	8WL7090-0
9	Wedge-type dead-end clamp 19	8WL1180-7
10	Special wedge 50	8WL1202-3
11	Steel tube 33.7x3.2 (length as needed)	8WL2175-1B
12	End cap 33.7	8WL2184-6
13	Locking ring 36	8WL5173-0
14	Support bar 22 (length as needed)	8WL5155-0
15	Clamp for support bar	8WL5170-0
16	Guide strap for concrete weights	8WL5130-0
17	Hook bolt M24x425	8WL5172-1
18	Weights (number as needed)	8WL5106-0
19	Fastening parts at pole have to be defined project-specifically.	




Jernbaneverket, Systemdokumentasjon, Elkraft
Kontaktledningsanlegg. Loddavspenning med omsetningsforhold 1:1 for trangt profil. Oversiktstegning.
Dato: 12.01.07 Kontrollert: Godkjent:
Dok./tegningsnr.: EK.800121-000 rev.000
Ausführung SBB NBS
Mattstetten - Rothrist
Fahrleitungs Nachspannung im Doppelspurtunnel
E 751
1 : 25
4904625/ -D
Leitungsbau
SOK 0,0
TS CuS 70
FD RiS 120

Appendix D

Material input description

Overhead Contact System, Open Section - Re330

OCS, Open Section - Re330			Amount	Unit	One Kilometer of a rail			
					Construction		Maintenance	
					Amount	Unit	Amount	Unit
Catenary								
Contact wire (CuMg0.5(120mm2))			1	m	1	km	1	km
	Copper (Contact Wire) & (winding)		1.06	kg	1060	kg	1060	kg
	Magnesium		0.00535	kg	5.35	kg	5.35	kg
Dropper (Bz II 10)			1	m	104	m	104	m
	Copper (Contact Wire) & (winding)		0.0895	kg	9.28	kg	9.28	kg
	Magnesium		0.00045	kg	0.0467	kg	0.0467	kg
	Electricity, Production (European Mix)		0.05094	MJ	5.28	MJ	5.28	MJ
Messanger (Bz II 120)			1	m	1	km	1	km
	Copper (Contact Wire) & (winding)		1.05	kg	1060	kg	1060	kg
	Magnesium		0.0053	kg	5.31	kg	5.31	kg
	Electricity, Production (European Mix)		0.153	MJ	153	MJ	153	MJ
Stitch Wire (Bz II 35)			1	m	302	m	302	m
	Copper (Contact Wire) & (winding)		0.308	kg	93.2	kg	93.2	kg
	Magnesium		0.00155	kg	0.468	kg	0.468	kg
	Electricity, Production (European Mix)		0.05094	MJ	15.4	MJ	15.4	MJ

Cantilever								
Ø70 Al tube			2.6	m	43.3	m	43.3	m
	Aluminium (Cantilever/Tube)		8.4682	kg	141	kg	141	kg
Ø55 Al tube			2.7	m	45	m	45	m
	Aluminium (Cantilever/Tube)		6.7338	kg	121	kg	121	kg
Ø42 Al tube			2.315	m	38.6	m	38.6	m
	Aluminium (Cantilever/Tube)		2.984035	kg	49.8	kg	49.8	kg
Ø6 Steel wire			0.87	m	14.5	m	14.5	m
	Steel (Cantilever/Wire)		0.11658	kg	1.94	kg	1.94	kg
Cantilever additional componets			1	piece	16.7	piece	16.7	piece
	Aluminium (Cantilever/Tube)		6.29	kg	105.043	kg	105.043	kg

Tensioning Section								
Mid-point anchor			1	piece	0.79	piece	0.79	piece
	Messanger (Bz II 120)		125	m	98.75	m	98.75	m
		Copper (Contact Wire) & (winding)			104	kg	104	kg
		Magnesium			0.523	kg	0.523	kg
		Electricity, Production (European Mix)			15.1	MJ	15.1	MJ

	Insulators (cantilever)		4	piece	3.16	m	3.16	m
		Glass (Insulator)			12.3	kg	12.3	kg
		lead-antimony (insulator)			12.3	kg	12.3	kg
		Electricity, Production (European Mix)			23.4	MJ	23.4	MJ
	Anchor foundation		4.32	piece	3.4128			
		Concrete			7.38	m3	7.38	m3
	Anchoring of poles		7.672	kg	6.06088			
		Steel (Cantilever/Wire)			6.06	kg	6.06	kg
Overlap			1	piece	0.78	piece	0.78	piece
	Contact wire (CuMg0.5(120mm2))		0.24	km	0.1872	km	0.1872	km
		Copper (Contact Wire) & (winding)			202	kg	202	kg
		Magnesium			1.01	kg	1.01	kg
	Dropper (Bz II 10)		0.24	km	0.1872	km	0.1872	km
		Copper (Contact Wire) & (winding)			1.76	kg	1.76	kg
		Magnesium			0.00884	kg	0.00884	kg
		Electricity, Production (European Mix)			1	MJ	1	MJ
	Messanger (Bz II 120)		0.24	km	0.1872	km	0.1872	km
		Copper (Contact Wire) & (winding)			200	kg	200	kg
		Magnesium			1.01	kg	1.01	kg
		Electricity, Production (European Mix)			29	MJ	29	MJ
	Stitch Wire (Bz II 35)		0.24	km	0.1872	km	0.1872	km
		Copper (Contact Wire) & (winding)			17.7	kg	17.7	kg
		Magnesium			0.0888	kg	0.0888	kg
		Electricity, Production (European Mix)			2.92	MJ	2.92	MJ
	Ø70 Al tube		10.4	m				
		Aluminium (Cantilever/Tube)			26.42078	kg	26.42078	kg
	Ø55 Al tube		10.8	m				
		Aluminium (Cantilever/Tube)			21.00946	kg	21.00946	kg
	Ø42 Al tube		9.26	m				
		Aluminium (Cantilever/Tube)			9.310189	kg	9.310189	kg
	Ø6 Steel wire		3.48	m				
		Steel (Cantilever/Wire)			0.36373	g	0.36373	g
	Insulators (cantilever)		8	piece				
		Glass (Insulator)			24.3	kg	24.3	kg
		lead-antimony (insulator)			24.3	kg	24.3	kg
		Electricity, Production (European Mix)			46.3	MJ	46.3	MJ
Auto-Tensioning			1	piece	1.59	piece	1.59	piece
	Anchor foundation		1	piece				
		Concrete	2.16	m3	3.43	m3	3.43	m3
	Weight catenary wire		1	piece				
		Concrete			0.47223	m3	0.47223	m3
	Weight contact wire		1	piece				
		Concrete			0.60738	m3	0.60738	m3
	Tensioning wheel		2	piece				
		Aluminium (plate)			25.8375	kg	25.8375	kg
		Steel (plate)			77.5125	kg	77.5125	kg
	Insulators (cantilever)		2	piece				
		Glass (Insulator)			12.402	kg	12.402	kg
		lead-antimony (insulator)			12.402	kg	12.402	kg
		Electricity, Production (European Mix)			23.6	MJ	23.6	MJ
	Steel (Cantilever/Wire)		73.524	kg	116.9032	kg	116.9032	kg

Support structure			1	piece	16.7	piece	3.34	piece
	Fundament (Mast)		1	piece				
		Concrete	0.968	m3	16.1656	m3	3.23312	m3
	Mast HEB200		1	piece				
		Steel (Mast HEB200, seksjonsskonsoll)	597.614	kg	9960.233	kg	1992.047	kg
		Welding, arc, steel {RER}| processing | Alloc Def, U	0.5	m	8.33	m	1.666	m

Grounding				
Copper (Contact Wire) & (winding)	1189.9	kg	237.98	kg
Electricity, Production (European Mix)	2250	MJ	450	MJ
PEX	357	kg	71.4	kg

Overhead Contact System, Open Section - S25

OCS, Open Section - S25			Amount	Unit	One Kilometer of a rail			
					Construction		Maintenance	
					Amount	Unit	Amount	Unit
Catenary								
Contact wire (CuAg0.1 (120mm2)))			1	m	1	km	1	km
	Copper (Contact Wire) & (winding)		1.07	kg	1.07	ton	1.06893	ton
	Silver		0.001	kg	1.07	kg	1.07	kg
Dropper (Bz II 10)			1	m	104	m	104	m
	Copper (Contact Wire) & (winding)		0.0895	kg	9.28	kg	9.28	kg
	Magnesium		0.00045	kg	46.7	g	46.7	g
	Electricity, Production (European Mix)		0.05094	MJ	5.28	MJ	5.28	MJ
Messanger (Bz II 70)			1	m	1	km	1	km
	Copper (Contact Wire) & (winding)		0.593	kg	0.593	ton	0.593	ton
	Magnesium		0.00298	kg	2.98	kg	2.98	kg
	Electricity, Production (European Mix)		0.0283	MJ	28.3	MJ	28.3	MJ
Stitch Wire (Bz II 35)			1	m	302	m	302	m
	Copper (Contact Wire) & (winding)		0.308	kg	93.2	kg	93.2	kg
	Magnesium		0.00155	kg	468	g	468	g
	Electricity, Production (European Mix)		0.05094	MJ	15.4	MJ	15.4	MJ
Cantilever			1	piece				
Ø70 Al tube			2.6	m	43.3	m	43.3	m
	Aluminium (Cantilever/Tube)		8.4682	kg	141	kg	141	kg
Ø55 Al tube			2.7	m	45	m	45	m
	Aluminium (Cantilever/Tube)		6.7338	kg	121	kg	121	kg
Ø42 Al tube			2.315	m	38.6	m	38.6	m
	Aluminium (Cantilever/Tube)		2.984035	kg	49.8	kg	49.8	kg
Ø6 Steel wire			0.87	m	14.5	m	14.5	m
	Steel (Cantilever/Wire)		0.11658	kg	1.94	kg	1.94	kg
Cantilever additional componets			1	piece	16.7	piece	16.7	piece
	Aluminium (Cantilever/Tube)		6.29	kg	105.043	kg	105.043	kg
Tensioning Section								
Mid-point anchor			1	piece	0.79	piece	0.79	piece
	Messanger (Bz II 70)		125	m				
		Copper (Contact Wire) & (winding)			74.125	kg	74.125	kg
		Magnesium			0.3725	g	0.3725	g
		Electricity, Production (European Mix)			3.5375	MJ	3.5375	MJ
	Insulators (cantilever)		4	piece				
		Glass (Insulator)			12.3	kg	12.3	kg
		lead-antimony (insulator)			12.3	kg	12.3	kg
		Electricity, Production (European Mix)			23.4	MJ	23.4	MJ
	Anchor foundation		4.32	piece				
		Concrete			7.38	m3	7.38	m3
	Anchoring of poles		7.672	kg				
		Steel (Cantilever/Wire)			6.06	kg	6.06	kg
Overlap			1	piece	0.78	piece	0.78	piece
	Contact wire (CuAg0.1 (120mm2)))		0.12	km				
		Copper (Contact Wire) & (winding)			100.0518	kg	100.0518	kg
		Magnesium			0.100152	kg	0.100152	kg
	Dropper (Bz II 10)		0.12	km				
		Copper (Contact Wire) & (winding)			0.868608	kg	0.868608	kg
		Magnesium			4.37112	g	4.37112	g
		Electricity, Production (European Mix)			0.494208	MJ	0.494208	MJ
	Messanger (Bz II 70)		0.12	km				
		Copper (Contact Wire) & (winding)			0.055505	kg	0.055505	kg
		Magnesium			0.278928	kg	0.278928	kg
		Electricity, Production (European Mix)			2.64888	MJ	2.64888	MJ
	Stitch Wire (Bz II 35)		0.12	km				
		Copper (Contact Wire) & (winding)			8.72352	kg	8.72352	kg
		Magnesium			43.8048	g	43.8048	g
		Electricity, Production (European Mix)			1.44144	MJ	1.44144	MJ

			Amount	Unit	Construction Amount	Unit	Maintenance Amount	Unit
	Ø70 Al tube		5.2	m				
		Aluminium (Cantilever/Tube)			13.21039	kg	13.21039	kg
	Ø55 Al tube		5.4	m				
		Aluminium (Cantilever/Tube)			10.50473	kg	10.50473	kg
	Ø42 Al tube		4.63	m				
		Aluminium (Cantilever/Tube)			4.655095	kg	4.655095	kg
	Ø6 Steel wire		1.74	m				
		Steel (Cantilever/Wire)			0.181865	g	0.181865	g
	Insulators (cantilever)		4	piece				
		Glass (Insulator)			12.15	kg	12.15	kg
		lead-antimony (insulator)			12.15	kg	12.15	kg
		Electricity, Production (European Mix)			23.15	MJ	23.15	MJ
Auto-Tensioning			1	piece	1.59	piece	1.59	piece
	Anchor foundation		1	piece				
		Concrete			3.43	m3	3.43	m3
	Weight catenary and contact wires		2	piece				
		Concrete	0.416666667		0.6625	m3	0.6625	m3
	Tensioning wheel		2	piece				
		Aluminium (plate)			25.8375	kg	25.8375	kg
		Steel (plate)			77.5125	kg	77.5125	kg
	Insulators (cantilever)		2	piece				
		Glass (Insulator)			12.402	kg	12.402	kg
		lead-antimony (insulator)			12.402	kg	12.402	kg
		Electricity, Production (European Mix)			23.6	MJ	23.6	MJ
	Steel (Cantilever/Wire)		73.524	kg	116.9032	kg	116.9032	kg

			Amount	Unit	Construction Amount	Unit	Maintenance Amount	Unit
Support structure			1	piece	16.7	piece	3.34	piece
	Fundament (Mast)		1	piece				
		Concrete	0.968	m3	16.1656	m3	3.23312	m3
	Mast HEB200		1	piece				
		Steel (Mast HEB200, seksjonsskonsoll)	597.614	kg	9960.233	kg	1992.047	kg
		Welding, arc, steel {RER}| processing | Alloc Def, U	0.5	m	8.33	m	1.666	m

		Construction Amount	Unit	Maintenance Amount	Unit
Grounding					
	Copper (Contact Wire) & (winding)	1189.9	kg	237.98	kg
	Electricity, Production (European Mix)	2.25	GJ	0.45	GJ
	PEX	357	kg	71.4	kg

Overhead Contact System, Tunnel Section - Re330

OCS, Tunnel Section - Re330		Amount	Unit	One Kilometer of a rail			
				Construction		Maintenance	
				Amount	Unit	Amount	Unit
Catenary							
Contact wire (CuMg0.5(120mm2))		1	m	1	km		
	Copper (Contact Wire) & (winding)	1.06	kg	1060	kg	1060	kg
	Magnesium	0.00535	kg	5.35	kg	5.35	kg
Dropper (Bz II 10)		1	m	63.544	m	63.544	m
	Copper (Contact Wire) & (winding)	0.0895	kg	5.67	kg	5.67008	kg
	Magnesium	0.00045	kg	0.03	kg	0.028534	kg
	Electricity, Production (European Mix)	0.05094	MJ	3.23	MJ	3.22608	MJ
Messanger (Bz II 120)		1	m	1	km	1	km
	Copper (Contact Wire) & (winding)	1.05	kg	1060	kg	1060	kg
	Magnesium	0.0053	kg	5.31	kg	5.31	kg
	Electricity, Production (European Mix)	0.153	MJ	153	MJ	153	MJ
Stitch Wire (Bz II 35)		1	m				
	Copper (Contact Wire) & (winding)	0.308	kg	56.9452	kg	56.9452	kg
	Magnesium	0.00155	kg	0.285948	g	0.285948	g
	Electricity, Production (European Mix)	0.05094	MJ	9.4094	MJ	9.4094	MJ
Insulators (cantilever)		1	piece	25	piece		piece
	Glass (Insulator)	3.9	kg	97.5	kg	97.5	kg
	lead-antimony (insulator)	3.9	kg	97.5	kg	97.5	kg
	Electricity, Production (European Mix)	7.416	MJ	185.4	MJ	185.4	MJ

Cantilever								
Ø70 Al tube			2.6	m	39.8	m	39.8	m
	Aluminium (Cantilever/Tube)		8.4682	kg	129.6286	kg	129.6286	kg
Ø55 Al tube			2.7	m	67.5	m	67.5	m
	Aluminium (Cantilever/Tube)		6.7338	kg	168.345	kg	168.345	kg
Ø42 Al tube			2.315	m	57.9	m	57.9	m
	Aluminium (Cantilever/Tube)		2.98	kg	74.6331	kg	74.6331	kg
Ø6 Steel wire			0.87	m	13.3	m	13.3	m
	Steel (Cantilever/Wire)		0.11658	kg	1.7822	kg	1.7822	kg
Cantilever additional componets			1	piece	25	piece	25	piece
	Aluminium (Cantilever/Tube)		6.29	kg	157.25	kg	157.25	kg
Tensioning Section								
Mid-point anchor			1	piece	1.35	piece	1.35	piece
	Messanger (Bz II 120)		85	m	114.75	m	114.75	m
		Copper (Contact Wire) & (winding)			121.635	kg	121.635	kg
		Magnesium			0.609323	kg	0.609323	kg
		Electricity, Production (European Mix)			17.55675	MJ	17.55675	MJ
	Insulators (cantilever)		2	piece	2.7	piece	2.7	piece
		Glass (Insulator)	7.8	kg	10.53	kg	10.53	kg
		lead-antimony (insulator)	7.8	kg	2.7	kg	2.7	kg
		Electricity, Production (European Mix)	14.832	MJ	5.134154	MJ	5.134154	MJ
	Steel (Cantilever/Wire)		1.644	kg	2.2194	kg	2.2194	kg
Overlap			1	piece	1.3	piece	1.3	piece
	Contact wire (CuMg0.5(120mm2))		0.16	km	0.208	km	0.208	km
		Copper (Contact Wire) & (winding)			220.48	kg	220.48	kg
		Magnesium			0.00111	kg	0.00111	kg
	Dropper (Bz II 10)		0.0978	km	0.12714	km	0.12714	km
		Copper (Contact Wire) & (winding)			1.18	kg	1.18	kg
		Magnesium			0.00593	g	0.00593	g
		Electricity, Production (European Mix)			0.671	MJ	0.671	MJ
	Messanger (Bz II 120)		0.16	km	0.208	km	0.208	km
		Copper (Contact Wire) & (winding)			220	kg	220	kg
		Magnesium			0.0011	kg	0.0011	kg
		Electricity, Production (European Mix)			31.8	MJ	31.8	MJ
	Stitch Wire (Bz II 35)		0.0978	km	0.12714	km	0.12714	km
		Copper (Contact Wire) & (winding)			11.8	kg	11.8	kg
		Magnesium			0.0595	kg	0.0595	kg
		Electricity, Production (European Mix)			1.96	MJ	1.96	MJ
	Ø70 Al tube		10.4	m				
		Aluminium (Cantilever/Tube)			44.03464	kg	44.03464	kg
	Ø55 Al tube		10.8	m				
		Aluminium (Cantilever/Tube)			35.01576	kg	35.01576	kg
	Ø42 Al tube		9.26	m				
		Aluminium (Cantilever/Tube)			15.51698	kg	15.51698	kg
	Ø6 Steel wire		3.48	m				
		Steel (Cantilever/Wire)			0.606216	kg	0.606216	kg
	Insulators (cantilever)		8	piece				
		Glass (Insulator)			40.56	kg	40.56	kg
		lead-antimony (insulator)			40.56	kg	40.56	kg
		Electricity, Production (European Mix)			40.56	MJ	40.56	MJ
Auto-Tensioning			1	piece	2.7	piece	2.7	piece
	Weight catenary wire		1	piece	2.7	piece	2.7	piece
		Steel (plate)	713.6	kg	1926.607	kg	1926.607	kg
	Weight contact wire		1	piece	2.7	piece	2.7	piece
		Steel (plate)	917.43	kg	2477.061	kg	2477.061	kg
	Tensioning wheel		2	piece	5.4	piece	5.4	piece
		Aluminium (plate)	16.25	kg	43.875	kg	43.875	kg
		Steel (plate)	48.75	kg	131.625	kg	131.625	kg
	Insulators (cantilever)		2	piece	5.4	piece	5.4	piece
		Glass (Insulator)	7.8	kg	42.12	kg	42.12	kg
		lead-antimony (insulator)	7.8	kg	42.12	kg	42.12	kg
		Electricity, Production (European Mix)	14.832	MJ	80.0928	MJ	80.0928	MJ
	Steel (Cantilever/Wire)		134.674	kg	214.1317	kg	214.1317	kg
Support structure								
	Hanging Mast		1	piece	25	piece	5	piece
		Aluminium (Cantilever/Tube)	15.84	kg	396	kg	79.2	kg
		Aluminium (plate)	0.004746	kg	0.119	kg	0.0238	kg

		Welding, arc, aluminium {RER}| processing | Alloc Def, U	0.3	m	7.5	m	1.5	m
		Bolt - Steel (low quality)	29		725	kg	145	kg

Grounding						
	Copper (Contact Wire) & (winding)		1189.9	kg	237.98	kg
	Electricity, Production (European Mix)		2250	MJ	450	MJ
	PEX		357	kg	71.4	kg

Overhead Contact System, Tunnel Section - S25

OCS, Tunnel Section - S25			Amount	Unit	One Kilometer of a rail			
					Construction		Maintenance	
					Amount	Unit	Amount	Unit
Catenary								
Contact wire (CuAg0.1 (120mm2)))			1	m	1	km	1	km
	Copper (Contact Wire) & (winding)		1.07	kg	1.07	ton	1.06893	ton
	Silver		0.001	kg	1.07	kg	1.07	kg
Dropper (Bz II 10)			1	m	63.544	m	63.544	m
	Copper (Contact Wire) & (winding)		0.0895	kg	5.67	kg	5.67008	kg
	Magnesium		0.00045	kg	28.53	g	28.5337	g
	Electricity, Production (European Mix)		0.05094	MJ	3.23	MJ	3.22608	MJ
Messanger (Bz II 70)			1	m	1	km	1	km
	Copper (Contact Wire) & (winding)		0.593	kg	0.593	ton	0.593	ton
	Magnesium		0.00298	kg	2.98	kg	2.98	kg
	Electricity, Production (European Mix)		0.0283	MJ	28.3	MJ	28.3	MJ
Stitch Wire (Bz II 35)			1	m	302	m	302	m
	Copper (Contact Wire) & (winding)		0.308	kg	56.9452	kg	56.9452	kg
	Magnesium		0.00155	kg	285.948	g	285.948	g
	Electricity, Production (European Mix)		0.05094	MJ	9.4094	MJ	9.4094	MJ
Insulators (cantilever)			1	piece	25	piece	25	piece
	Glass (Insulator)		3.9	kg	97.5	kg	97.5	kg
	lead-antimony (insulator)		3.9	kg	97.5	kg	97.5	kg
	Electricity, Production (European Mix)		7.416	MJ	185.4	MJ	185.4	MJ
Cantilever			1	piece	16.65	piece	16.65	piece
Ø70 Al tube			2.6	m	43.3	m	43.3	m
	Aluminium (Cantilever/Tube)		8.4682	kg	141	kg	141	kg
Ø55 Al tube			2.7	m	45	m	45	m
	Aluminium (Cantilever/Tube)		6.7338	kg	121	kg	121	kg
Ø42 Al tube			2.315	m	38.6	m	38.6	m
	Aluminium (Cantilever/Tube)		2.984035	kg	49.8	kg	49.8	kg
Ø6 Steel wire			0.87	m	14.5	m	14.5	m
	Steel (Cantilever/Wire)		0.11658	kg	1.94	kg	1.94	kg
Cantilever additional componets			1	piece	16.7	piece	16.7	piece
	Aluminium (Cantilever/Tube)		6.29	kg	105.043	kg	105.043	kg
Tensioning Section								
Mid-point anchor			1	piece	1.35	piece	1.35	piece
	Messanger (Bz II 70)		85	m	114.75	m	114.75	m
		Copper (Contact Wire) & (winding)			68.04675	kg	68.04675	kg
		Magnesium			341.955	g	341.955	g
		Electricity, Production (European Mix)			3.247425	MJ	3.247425	MJ
	Insulators (cantilever)		2	piece	2.7	piece	2.7	piece
		Glass (Insulator)			10.53	kg	10.53	kg
		lead-antimony (insulator)			10.53	kg	10.53	kg
		Electricity, Production (European Mix)			20.0232	MJ	20.0232	MJ
	Anchor to tunnel		1	piece	1.35	piece	1.35	piece
		Steel (Cantilever/Wire)	1.644	kg	2.2194	kg	2.2194	kg
Overlap			1	piece	1.3	piece	1.3	piece
	Contact wire (CuAg0.1 (120mm2)))		0.16	km	0.208	km	0.208	km
		Copper (Contact Wire) & (winding)			222	kg	222	kg
		Magnesium			223	g	223	g
	Dropper (Bz II 10)		0.0978	km	0.12714	km	0.12714	km
		Copper (Contact Wire) & (winding)			1.18	kg	1.18	kg
		Magnesium			5.93	g	5.93	g
		Electricity, Production (European Mix)			671	MJ	671	MJ

	Messanger (Bz II 70)		0.16	km	0.208	km	0.208	km
		Copper (Contact Wire) & (winding)			123	kg	123	kg
		Magnesium			620	g	620	g
		Electricity, Production (European Mix)			21.2	MJ	21.2	MJ
	Stitch Wire (Bz II 35)		0.0978	km	0.12714	km	0.12714	km
		Copper (Contact Wire) & (winding)			11.8	kg	11.8	kg
		Magnesium			59.5	g	59.5	g
		Electricity, Production (European Mix)			1.96	MJ	1.96	MJ
	Ø70 Al tube		10.4	m				
		Aluminium (Cantilever/Tube)			44.03464	kg	44.03464	kg
	Ø55 Al tube		10.8	m				
		Aluminium (Cantilever/Tube)			4.826784	kg	4.826784	kg
	Ø42 Al tube		9.26	m				
		Aluminium (Cantilever/Tube)			3.509697	kg	3.509697	kg
	Ø6 Steel wire		3.48	m				
		Steel (Cantilever/Wire)			38.80597	g	38.80597	g
	Insulators (cantilever)		8	piece				
		Glass (Insulator)			40.56	kg	#REF!	kg
		lead-antimony (insulator)			40.56	kg	40.56	kg
		Electricity, Production (European Mix)			77.1264	MJ	77.1264	MJ
Auto-Tensioning			1	piece	2.7	piece	2.7	piece
	Weight catenary and contact wires		2	piece	2.7	piece	2.7	piece
		Steel (plate)	1,019.4	kg	2752.272	kg	2752.272	kg
	Tensioning wheel		2	piece	5.4	piece	5.4	piece
		Aluminium (plate)	16.25	kg	43.875	kg	43.875	kg
		Steel (plate)	48.75	kg	131.625	kg	131.625	kg
	Insulators (cantilever)		2	piece	5.4	piece	5.4	piece
		Glass (Insulator)	7.8	kg	42.12	kg	42.12	kg
		lead-antimony (insulator)	7.8	kg	42.12	kg	42.12	kg
		Electricity, Production (European Mix)	14.832	MJ	80.0928	MJ	80.0928	MJ
	Steel (Cantilever/Wire)		134.674	kg	214.1317	kg	214.1317	kg

Support structure								
	Hanging Mast		1	piece	25	piece	5	piece
		Aluminium (Cantilever/Tube)	15.84	kg	396	kg	79.2	kg
		Aluminium (plate)	0.004746	kg	0.119	kg	0.0238	kg
		Welding, arc, aluminium {RER}| processing | Alloc Def, U	0.3	m	7.5	m	1.5	m
		Bolt - Steel (low quality)	29	kg	725	kg	145	kg

Grounding						
	Copper (Contact Wire) & (winding)		1189.9	kg	237.98	kg
	Electricity, Production (European Mix)		2.25	GJ	0.45	GJ
	PEX		357	kg	71.4	kg

Power Supply (for all systems of design-speeds and section types)

Power Supply		Amount	Unit	One Kilometer of a rail			
				Construction		Maintenance	
				Amount	Unit	Amount	Unit
Fan cable		1	m	0.0025	m	0.0025	m
	Aluminium (Cable)	0.47	kg	0.001175	kg	0.001175	kg
	Copper (Contact Wire) & (winding)	0.13	kg	0.000325	kg	0.000325	kg
	PEX	0.25	kg	0.000625	kg	0.000625	kg
High voltage cables		1	m	514.375	m	102.875	m
	Aluminium (Cable)	2.7	kg	1388.813	kg	277.7625	kg
	PEX	1.5	kg	771.5625	kg	154.3125	kg
	Copper (Contact Wire) & (winding)	0.7	kg	360.0625	kg	72.0125	kg
	Electricity, Production (European Mix)	3.672	MJ	3657.42	MJ	731.484	MJ
Low voltage cables		1	m	1015.193	m	203.0386	m
	Copper (Contact Wire) & (winding)	0.645	kg	654.7994	kg	130.9599	kg
	Aluminium (Cable)	2.592	kg	331.7719	kg	66.35438	kg
	PEX	1.273	kg	1333.26	kg	266.652	kg
	Electricity, Production (European Mix)	3.65742	MJ	3657.42	MJ	731.484	MJ

Switchgear - SF6 breakers		1	piece	0.575	piece	0.575	piece
	Copper (Contact Wire) & (winding)	63.5	kg	36.5125	kg	36.5125	kg
	Aluminium (plate)	12.2	kg	7.015	kg	7.015	kg
	Steel (plate)	112.5	kg	64.6875	kg	64.6875	kg
	Steel (low-alloyed)	195.8	kg	112.585	kg	112.585	kg
	Zinc, primary, at regional storage/RER U	5.6	kg	3.22	kg	3.22	kg
	Polyethylene, HDPE, granulate, at plant/RER U	7.3	kg	4.1975	kg	4.1975	kg
	Epoxy resin insulator (Al2O3), at plant/RER U	37.6	kg	21.62	kg	21.62	kg
	Sulphur hexafluoride, liquid, at plant/RER U	3.2	kg	1.84	kg	1.84	kg

Trafo 11/22 transformer		1	piece	0.005263	piece	0.005263	piece
	Steel (low-alloyed)	16000	kg	84.21053	kg	84.21053	kg
	Copper (Contact Wire) & (winding)	5000	kg	26.31579	kg	26.31579	kg
	Tranformator oil	2000	kg	10.52632	kg	10.52632	kg

Transformer (small and without oil)			1	piece	0.575	piece	0.575	piece
	Copper (Contact Wire) & (winding)		462	kg	265.65	kg	265.65	kg
	Steel (low-alloyed)		110	kg	63.25	kg	63.25	kg
	Steel (low-alloyed)		660	kg	379.5	kg	379.5	kg
	Epoxy resin insulator (Al2O3), at plant/RER U		198	kg	113.85	kg	113.85	kg
	Steel (low-alloyed)		792	kg	455.4	kg	455.4	kg
	Technical room		1	piece				
		Steel (low quality)			3801.6	kg	3801.6	kg

Negative current (cable)		1	m	1000	m	200	m
	Aluminium (Cable)	0.648	kg	648	kg	129.6	kg
	PVC	0.000834	kg	0.834	kg	0.1668	kg
	PEX	0.00167	kg	1.67	kg	0.334	kg
	Electricity, Production (European Mix)	1.9692	MJ	1969.2	MJ	393.84	MJ

Positive current (cable)		1	m	1000	m	200	m
	Aluminium (Cable)	0.648	kg	648	kg	129.6	kg
	PVC	0.000834	kg	0.834	kg	0.1668	kg
	PEX	0.00167	kg	1.67	kg	0.334	kg
	Electricity, Production (European Mix)	1.9692	MJ	1969.2	MJ	393.84	MJ

Insulator - power supply		1	piece	16.7	piece	16.7	piece
	Porcelain (insulator)	3.9	kg	65.13	kg	65.13	kg
	lead-antimony (insulator)	3.9	kg	65.13	kg	65.13	kg
	Electricity, Production (European Mix)	7.416	MJ	123.8472	MJ	123.8472	MJ

Auto-Transformer		1	piece	0.1	piece	0.02	piece
	Steel (low-alloyed)	9964	kg	996.4	kg	199.28	kg
	Copper (Contact Wire) & (winding)	5640	kg	564	kg	112.8	kg
	Concrete	0.549	m3	0.0549	m3	0.01098	m3
	Tranformator oil	320	kg	32	kg	6.4	kg

Telecommunication (for all systems of design-speeds and section types)

Telecommunication			Amount	Unit	One Kilometer of a rail			
					Construction		Maintenance	
					Amount	Unit	Amount	Unit
Cables (tele)			1	m	1	km	1	km
	Optical fiber / fiber cable		0.26	m	2496	kg	7488	kg
	Beam Cable		1.10	m	1.2	km	1.2	km
		Copper (Contact Wire) & (winding)	0.73	m	876	kg	2628	kg
		PEX	0.37	m	444	kg	1332	kg
	Cable 7/8		0.43	m	1.2	km	1.2	km
		Copper (Contact Wire) & (winding)	0.22	m	79.2	kg	237.6	kg
		PEX	0.21	m	75.6	kg	226.8	kg

	Cable 1/2		0.22	m	1.2	km	1.2	km
		Copper (Contact Wire) & (winding)	0.09	m	16.2	kg	48.6	kg
		Aluminium (Cable)	0.05	m	9	kg	27	kg
		PEX	0.09	m	16.2	kg	48.6	kg

Computers (tele)								
	Repeater		1	piece	3.8	piece	11.4	piece
		Aluminium (Cable)	12	kg	45.6	kg	136.8	kg
		Steel (high-quality)	14	kg	51.3	kg	153.9	kg
		plastic (polycarbonate)	5	kg	17.1	kg	51.3	kg
		Assembly / Disassembly	30	kg	114	kg	342	kg
	Mouse device, optical, with cable, at plant/GLO U				2.45	piece	7.35	piece
	Steel (low-alloyed)		3.038	kg	10.4811	kg	31.4433	kg
	Transport, lorry >28t, Components		1	kg	0.248829	tkm	0.746488	tkm

Utility room for telecom equipment (Tele)								
	Technical room for telecom		1	piece	2.3	piece	-	-
		Steel (low-alloyed)	792	kg	1821.6	kg	-	-
	Racks for telecom		1	piece	7.35	piece	36.75	piece
		Steel (low-alloyed)	58.3	kg	428.505	kg	2142.525	kg
	Desktop computer, without screen, at plant/GLO U				7.35	piece	51.45	piece
	Router, IP network, at server/CH/I U				7.35	piece	51.45	piece
	Cable, data cable in infrastructure, at plant/GLO U		0.22	kg/m	16.17	m	113.19	m
	Transport, lorry >28t, Components				11.48464	tkm	80459.22	tkm

Others (Tele)								
	Technical room for UPS		1	piece	1.15	piece	-	-
		Steel (low-alloyed)	792	kg	910.8	kg	-	-
	Racks for UPS		1	piece	2.3	piece	11.5	piece
		Steel (low-alloyed)	58.3	kg	134.09	kg	670.45	kg
	UPS		1	piece	1.15	piece	8.05	piece
		Lead, at regional storage/RER U	4320	kg	4968	kg	34776	kg
		Polypropylene, granulate, at plant/RER U	720	kg	828	kg	6665.4	kg
		Sulphuric acid, liquid, at plant/RER U	720	kg	828	kg	6665.4	kg
		Transport, lorry >28t, Components	585.00288	tkm	672.7533	kg	5415.664	kg
	El-tavle		1	piece	1	piece	3	piece
		Aluminium (Cable)	1.2	kg	1.2	kg	3.6	kg
		Steel (high-quality)	1.35	kg	1.35	kg	4.05	kg
		plastic (polycarbonate)	0.45	kg	0.45	kg	1.35	kg
		Assembly / Disassembly	3	kg	3	kg	9	kg

Signaling, Open Section (for all systems of design-speeds)

Signaling, Open Section		Amount	Unit	One Kilometer of a rail			
				Construction		Maintenance	
				Amount	Unit	Amount	Unit
Optical fiber		1	m	1.5	km	1.5	km
	Cable, data cable in infrastructure {GLO}| production | Alloc De	2.88	m	4320	m	8640	m
	Transport, lorry >28t, Components	0.02	tkm	30.4689	tkm	60.9378	tkm
Copper (cable)		1	m	1.5	km	1.5	km
	Copper, at regional storage/RER U	0.6	kg	900	kg	1800	kg
	Wire drawing, copper {RER}| processing | Alloc Def, U	0.6	kg	900	kg	1800	kg
	Transport, lorry >28t, Components	0.06	tkm	91.4067	tkm	182.81	tkm
Cable box		1	m	1	km	1	km
	Concrete, normal {CH}| production | Alloc Def, U	0.003	m3	3.36	m3	6.72	m3
	Transport, lorry >28t, Components	0.82	tkm	819.00	tkm	1638.008	tkm
Mast		1	piece	1.82	piece	3.64	piece
	Steel (low-alloyed)	300	kg	546.00	kg	1092.00	kg
	Transport, lorry >28t, Components	30.4689	tkm	55.45	tkm	110.91	tkm
Signal		1	piece	5.45	piece	10.91	piece
	Aluminium (Cable)	5.001	kg	27.26	kg	54.51	kg
	Steel (high-quality)	5.001	kg	27.26	kg	54.51	kg

	plastic (polycarbonate)	20.01	kg	109.05	kg	218.11	kg
	Assembly / Disassembly	30	kg	163.50	kg	327.00	kg
Signal lighting		1	piece	90.91	piece	181.82	piece
	Light emitting diode {GLO}| production | Alloc Def, U	0.35	g	31.82	g	63.64	g
	Transport, lorry >28t, Components	3.55E-05	tkm	0.0032	tkm	0.01	tkm
Fundament		1	piece	1.82	piece	3.64	piece
	Concrete	0.21	m3	0.38	m3	0.76	m3
	Transport, lorry >28t, Components	51.19	tkm	93.16	tkm	186.32	tkm
Driving Machine		1	piece	5.45	piece	10.91	piece
	Aluminium (Cable)	10.12	kg	55.154	kg	110.31	kg
	Steel (high-quality)	80.04	kg	436.218	kg	872.44	kg
	plastic (polycarbonate)	1.84	kg	10.028	kg	20.06	kg
	Assembly / Disassembly	92	kg	501.4	kg	1002.80	kg
ATC-equipment		1	piece	4.55	piece	9.09	piece
	Aluminium (Cable)	5	kg	22.75	kg	45.50	kg
	Steel (high-quality)	5	kg	22.75	kg	45.50	kg
	plastic (polycarbonate)	1	kg	4.55	kg	9.10	kg
	Assembly / Disassembly	11	kg	50.05	kg	100.10	kg
Axle Counter		1	piece	3.64	piece	7.27	piece
	Aluminium (Cable)	5	kg	18.2	kg	36.40	kg
	Steel (high-quality)	3	kg	10.92	kg	21.84	kg
	plastic (polycarbonate)	2	kg	7.28	kg	14.56	kg
	Assembly / Disassembly	10	kg	36.4	kg	72.80	kg
Computer		1	piece	0.23	piece	0.45	piece
	Aluminium (Cable)	4	kg	0.92	kg	1.84	kg
	Steel (high-quality)	1	kg	0.23	kg	0.46	kg
	plastic (polycarbonate)	2	kg	0.46	kg	0.92	kg
	Assembly / Disassembly	7	kg	1.61	kg	3.22	kg

Signaling, Tunnel Section (for all systems of design-speeds)

Signaling, Tunnel Section		Amount	Unit	One Kilometer of a rail			
				Construction		Maintenance	
				Amount	Unit	Amount	Unit
Optical fiber		1	m	1.23	km	1.23	km
	Cable, data cable in infrastructure {GLO}| production | Alloc Def, U	2.88	m	3542.4	m	7084.8	m
	Transport, lorry >28t, Components	0.02	tkm	24.9845	tkm	49.969	tkm
Copper (cable)		1	m	1.23	km	1.23	km
	Copper, at regional storage/RER U	0.6	kg	738	kg	1476	kg
	Wire drawing, copper {RER}| processing | Alloc Def, U	0.6	kg	738	kg	1476	kg
	Transport, lorry >28t, Components	0.06	tkm	74.95349	tkm	149.91	tkm
Mast (tunnel)		1	piece	0.25	piece	0.49	piece
	Steel (low-alloyed)	50	kg	12.35	kg	24.70	kg
Signal (tunnel)		1	piece	0.25	piece	0.49	piece
	Aluminium	1	kg	0.25	kg	0.49	kg
	Steel (high-quality)	1	kg	0.25	kg	0.49	kg
	plastic (polycarbonate)	5	kg	1.24	kg	2.47	kg
	Assembly / Disassembly	7	kg	1.73	kg	3.46	kg
Signal lighting		1	piece	2.47	piece	4.94	piece
	Light emitting diode {GLO}| production | Alloc Def, U	0.35	g	0.86	g	1.73	g
	Transport, lorry >28t, Components	3.55E-05	tkm	0.0001	tkm	0.00	tkm
ATC-equipment		1	piece	0.62	piece	1.23	piece
	Aluminium (Cable)	5	kg	3.085	kg	6.17	kg
	Steel (high-quality)	5	kg	3.085	kg	6.17	kg
	plastic (polycarbonate)	1	kg	0.617	kg	1.23	kg
	Assembly / Disassembly	11	kg	6.787	kg	13.57	kg
Axle Counter		1	piece	0.15	piece	0.30	piece
	Aluminium (Cable)	5	kg	0.74	kg	1.48	kg
	Steel (high-quality)	3	kg	0.444	kg	0.89	kg
	plastic (polycarbonate)	2	kg	0.296	kg	0.59	kg
	Assembly / Disassembly	10	kg	1.48	kg	2.96	kg
Computer		1	piece	0.247	piece	0.49	piece
	Aluminium (Cable)	4	kg	0.99	kg	1.98	kg

	Steel (high-quality)	1	kg	0.25	kg	0.49	kg
	plastic (polycarbonate)	2	kg	0.49	kg	0.99	kg
	Assembly / Disassembly	7	kg	1.73	kg	3.46	kg

Other installations, Tunnel Section (lighting and fans)

Other Installations, Tunnel Section			Amount	Unit	One Kilometer of a rail			
					Construction		Maintenance	
					Amount	Unit	Amount	Unit
Belysning			1	piece	432	piece	864	piece
	copper (wire)		2.5	m	1080	m	2160	m
		Copper, at regional storage/RER U	0.25	kg	108	kg	216	kg
		Wire drawing, copper {RER}| processing | Alloc Def, U	0.25	kg	108	kg	216	kg
		Transport, lorry >28t, Components	0.02539075	tkm	10.9688	tkm	21.93761	tkm
	Steel (low-alloyed)		1.2	kg	518.4	kg	1036.8	kg
	Plastic (polykarbonat)		0.1	kg	43.2	kg	86.4	kg
	LED		12	piece	5184	piece	10368	piece
	Assembly / Disassembly. Metallpodukter		1.55	kg	669.6	kg	1339.2	kg

Vifter			1	piece	2.95	piece	8.85	piece
	Aluminium (cable)		250	m	737.5	m	2212.5	m
		Aluminium, production mix, at plant/RER U			1106.25	kg	9790.313	kg
		Sheet rolling, aluminium {RER}| processing | Alloc Def, U			1659.375	kg	14685.47	kg
		Transport, lorry >28t, Components			0.152345	tkm	1.348249	tkm
	Aluminium (plate)		50	kg	147.5	kg	442.5	kg
	Steel (low-alloyed)		100	kg	295	kg	885	kg
	Cast iron		150	kg	442.5	kg	1327.5	kg
	Assembly / Disassembly. Metallpodukter		675	kg	1991.25	kg	5973.75	kg

In company with the material inputs that have been mentioned at the beginning of this appendix, there are some sub-processes that are considered as manufacturing of the input materials such as aluminium (cable), steel (low-alloyed) etc. that are related to Ecoinvent processes.

Process	**Inputs**	**Amount**	**Unit**	**Comment**
Transport, lorry >28t, Components		1	tkm	Transportation of goods
	Transport, lorry >28t, fleet average/CH U	1	tkm	
Aluminium (Cable)		1	kg	
	Aluminium, production mix, at plant/RER U	1	kg	
	Sheet rolling, aluminium {RER}| processing | Alloc Def, U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Aluminium (Cantilever/Tube)		1	kg	Cantilever for system
	Section bar extrusion, aluminium {RER}| processing | Alloc Def, U	1	kg	Modeling tubes for cantilever
	Aluminium, production mix, at plant/RER U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Aluminium (plate)		1	kg	For masts in tunnels
	Aluminium, production mix, at plant/RER U	1	kg	
	Sheet rolling, aluminium {RER}| processing | Alloc Def, U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Bolt - Steel (low quality)		1	kg	For assembly of hanging masts in tunnel section
	Steel, low-alloyed, at plant/RER U	1	kg	
	Hot rolling, steel {RER}| processing | Alloc Def, U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Concrete		1	m3	
	Concrete, normal, at plant/CH U	1	m3	
	Transport, lorry >28t, Components	240	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	3.7512	tkm	Tranportaion on the line

Copper (Contact Wire) & (winding)		1	kg	It is a generic model of contact wires
	Wire drawing, copper {RER}| processing | Alloc Def, U	1	kg	
	Copper, at regional storage/RER U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Electricity, Production (European Mix)		1	kWh	
	Electricity, production mix RER/RER U	1	kWh	
Fundament (Mast)		1	p	Fundaments for masts
	Concrete, normal, at plant/CH U	0.968	m3	Cylindrical fundament Ø 555 mm - up to 4,5 m depth. In this project a depth of 4 meters is considered (Puschmann) Area: ((0.555/2)^2)*3.14 = 0.242 m2
	Transport, lorry >28t, Components	232.32	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	3.6311616	tkm	Tranportaion on the line
Glass (Insulator)		1	kg	
	Flat glass, uncoated {RER}| production | Alloc Def, U	1	kg	
	Tempering, flat glass {RER}| processing | Alloc Def, U	1	kg	Increase the strength of glass (Puschmann)
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
lead-antimony (insulator)		1	kg	Used in insulator
	Antimony {CN}| production | Alloc Def, U	0.02	kg	Puschmann book
	Lead, at regional storage/RER U	0.098	kg	Puschmann book & "http://www.battcon.com/PapersFinal2009/ClarkPaper2009FINAL_12.pdf"
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Optical fiber / fiber cable		0.26	kg	From COWI report - (Nytt Dobbeltspor Oslo – Ski). weight per length = 0.26 kg/m
	Cable, data cable in infrastructure, at plant/GLO U	1	m3	
	Transport, lorry >28t, Components	0.026	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.00040638	tkm	Tranportaion on the line
Magnesium		1	kg	Used in catenary
	Manganese {RER}| production | Alloc Def, U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
PEX		1	kg	
	Polyethylene, high density, granulate {RER}| production | Alloc Def, U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Porcelain (insulator)		1	kg	
	Sanitary ceramics {CH}| production | Alloc Def, U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
PVC		1	kg	
	Polyvinylchloride, at regional storage/RER U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Silver		1	kg	Used in cantenary
	Silver, at regional storage/RER U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Steel (Cantilever/tube)		1	kg	
	Steel, low-alloyed, at plant/RER U	1	kg	
	Drawing of pipe, steel {RER}| processing | Alloc Def, U	1	kg	Modeling tubes for cantilever
	Zinc coat, pieces {RER}| zinc coating, pieces | Alloc Def, U	0,00013	m2	Diameter 0.25 inch (=6.35 mm)
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Steel (Cantilever/Wire)		1	kg	
	Wire drawing, steel {RER}| processing | Alloc Def, U	1	kg	
	Steel, low-alloyed, at plant/RER U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Steel (low-alloyed)		1	kg	
	Steel, low-alloyed, at plant/RER U	1	kg	
	Hot rolling, steel {RER}| processing | Alloc Def, U	1	kg	

	Zinc coating, pieces/RER U	0.01	m2	Assumed 0.01 m2 is needed for zinc coating in accordance with "Steel (Mast HEB200, seksjonsskonsoll)" process
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Steel (Mast HEB200, seksjonsskonsoll)		1	kg	Mast Model: HEB200 seksjonsskonsoll: UPN 100
	Reinforcing steel, at plant/RER U	1	kg	
	Zinc coat, pieces {RER}| zinc coating, pieces | Alloc Def, U	0.018760196	m2	Coefficient of surface to weight Weight of model HEB200 (kg/m) = 61.3 Surface area (m2/m) = 1.15
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line
Steel (plate)		1	kg	
	Steel, unalloyed {RER}| steel production, converter, unalloyed | Alloc Def,	1	kg	
	Sheet rolling, steel {RER}| processing | Alloc Def, U	1	kg	
	Transport, lorry >28t, Components	0.1	tkm	100 kilometers average transportaion
	Transport, lorry >28t, Components	0.001563	tkm	Tranportaion on the line

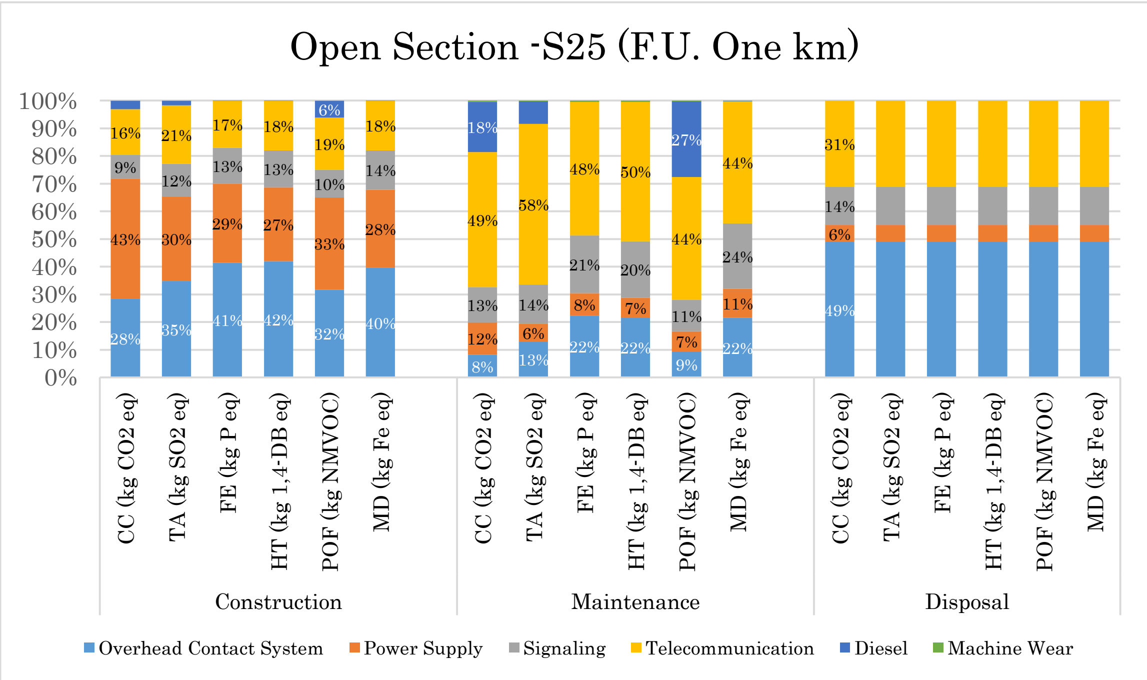
Appendix E

LCIA of S25 (F.U. of 1 km)

This appendix is comprised of all information related to system S25 for the functional unit of one kilometer that is decided not to illustrate in section 5.1 due to this fact that both systems of design-speed are showing similar results. Here, only figures are shown, but it could be possible to use the same interpretation as it is made for Re330. In addition, the appendix is following the same pattern as LCIA of Re330. This means first the result from open section and then tunnel section is shown.

Open section

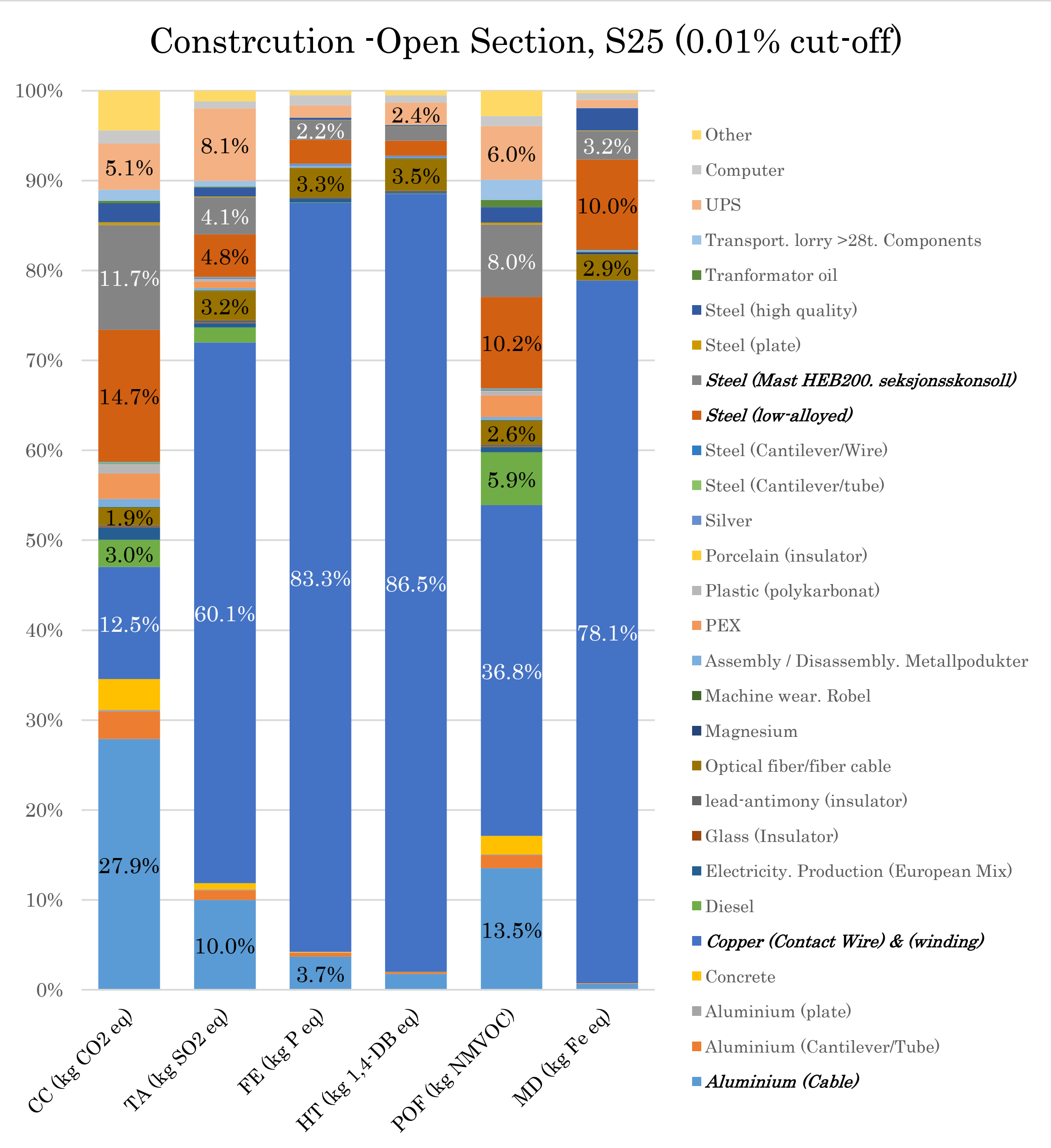
Figure below shows the three life cycle phases in a kilometer of open section are broken down to their components.



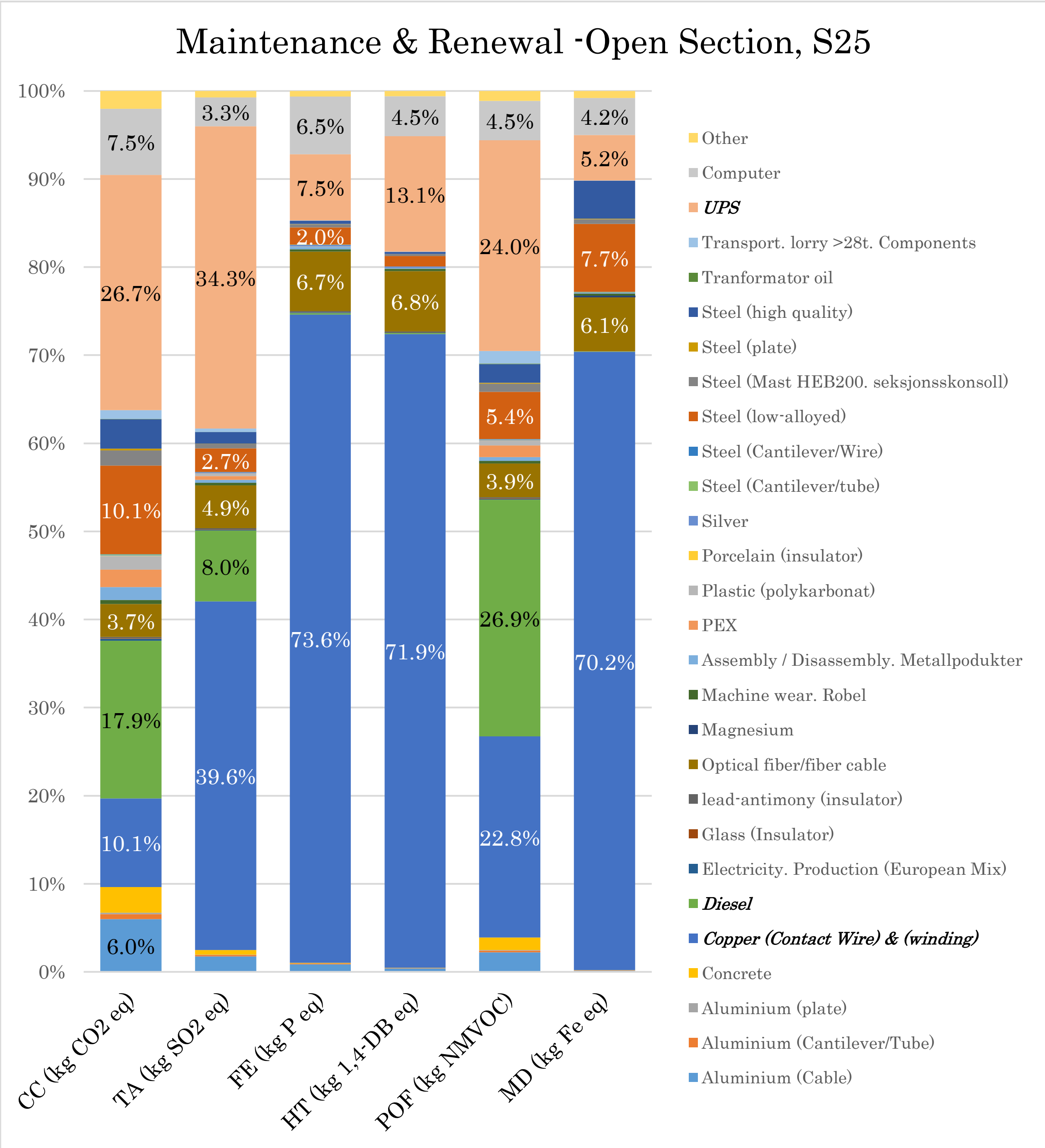
Qualitative data in the table below relates to the figure of open section – S25 for the functional unit of one kilometer.

Life Cycle Phase	Category	Overhead Contact System	Power Supply	Signaling	Telecommunication	Diesel	Machine Wear
Construction	CC (kg CO2 eq)	3.83E+04	5.89E+04	1.17E+04	2.23E+04	4.13E+03	1.20E+02
	TA (kg SO2 eq)	5.48E+02	4.80E+02	1.85E+02	3.33E+02	2.61E+01	1.10E+00
	FE (kg P eq)	1.95E+02	1.34E+02	6.09E+01	8.03E+01	1.23E-01	2.11E-01
	HT (kg 1,4-DB eq)	4.06E+05	2.59E+05	1.29E+05	1.74E+05	1.76E+02	4.45E+02
	POF (kg NMVOC)	2.24E+02	2.35E+02	7.08E+01	1.33E+02	4.24E+01	5.07E-01
	MD (kg Fe eq)	1.22E+05	8.66E+04	4.36E+04	5.50E+04	2.57E+01	1.25E+02
Maintenance	CC (kg CO2 eq)	1.50E+04	2.14E+04	2.33E+04	8.94E+04	3.31E+04	8.91E+02
	TA (kg SO2 eq)	3.38E+02	1.67E+02	3.70E+02	1.51E+03	2.10E+02	8.16E+00
	FE (kg P eq)	1.30E+02	4.73E+01	1.22E+02	2.80E+02	9.87E-01	1.56E+00
	HT (kg 1,4-DB eq)	2.74E+05	9.08E+04	2.57E+05	6.39E+05	1.41E+03	3.29E+03
	POF (kg NMVOC)	1.17E+02	9.04E+01	1.42E+02	5.54E+02	3.40E+02	3.75E+00
	MD (kg Fe eq)	7.98E+04	3.89E+04	8.72E+04	1.63E+05	2.06E+02	9.28E+02
Disposal	CC (kg CO2 eq)	3.33E+03	4.11E+02	9.49E+02	2.11E+03	-	-
	TA (kg SO2 eq)	1.84E+01	2.28E+00	5.26E+00	1.17E+01	-	-
	FE (kg P eq)	3.19E-01	3.94E-02	9.09E-02	2.02E-01	-	-
	HT (kg 1,4-DB eq)	4.22E+02	5.21E+01	1.20E+02	2.67E+02	-	-
	POF (kg NMVOC)	3.21E+01	3.96E+00	9.15E+00	2.03E+01	-	-
	MD (kg Fe eq)	1.80E+02	2.22E+01	5.14E+01	1.14E+02	-	-

The individual input factors and materials for construction of S25 in a kilometer of open section.

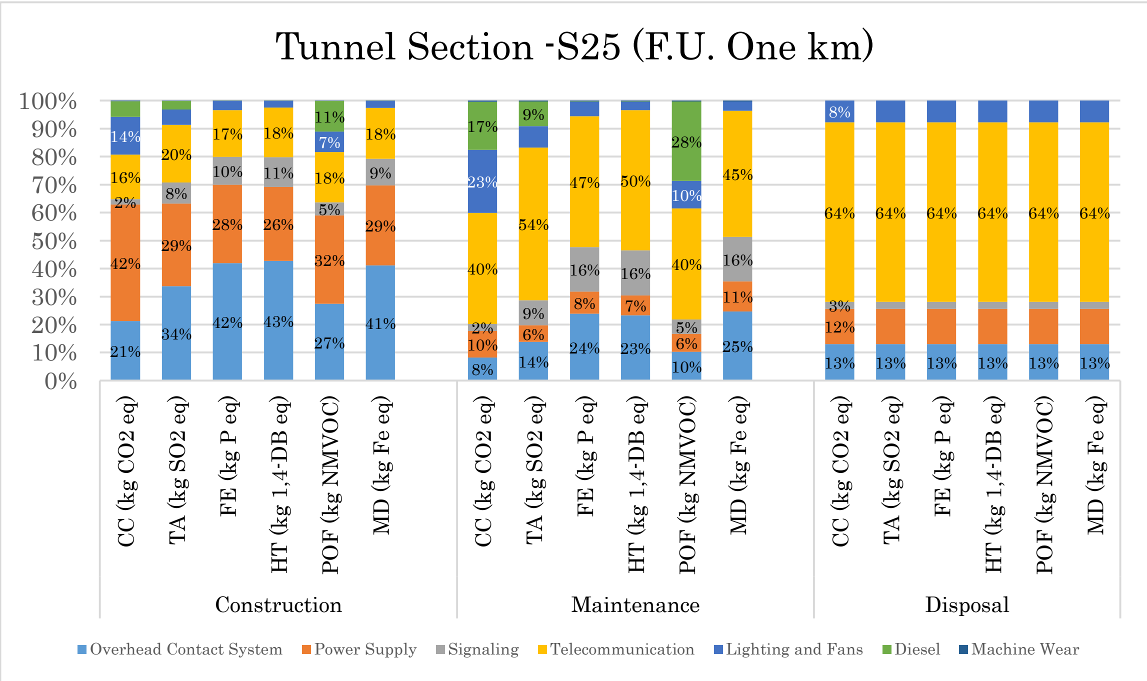


In maintenance & renewal phase of individual input factors/materials for system S25 in a kilometer of open section, the results are shifting slightly to other materials (through the 60 years of lifetime).



Tunnel Section

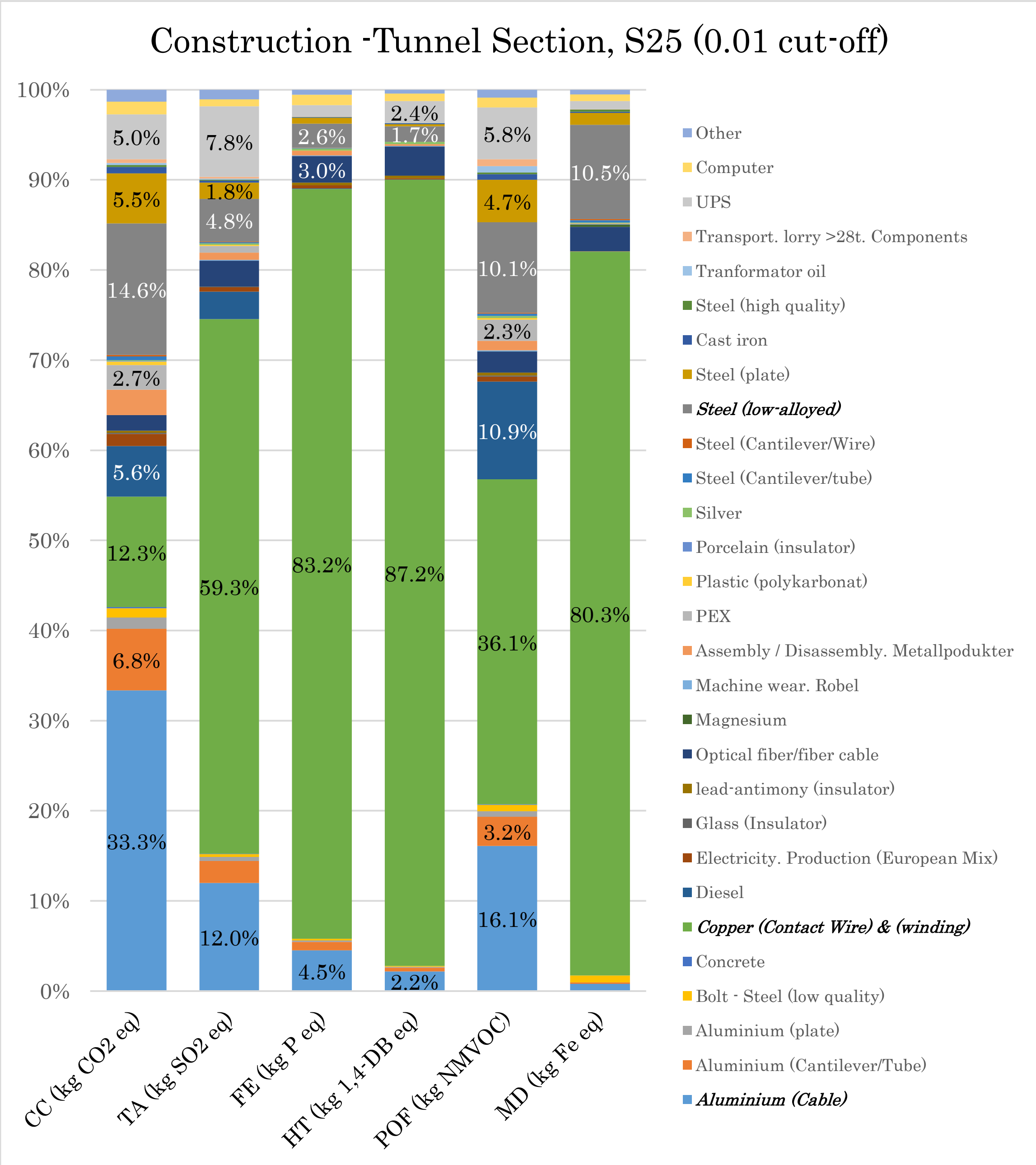
Figure below shows the three life cycle phases in a kilometer of tunnel section are broken down to their components.



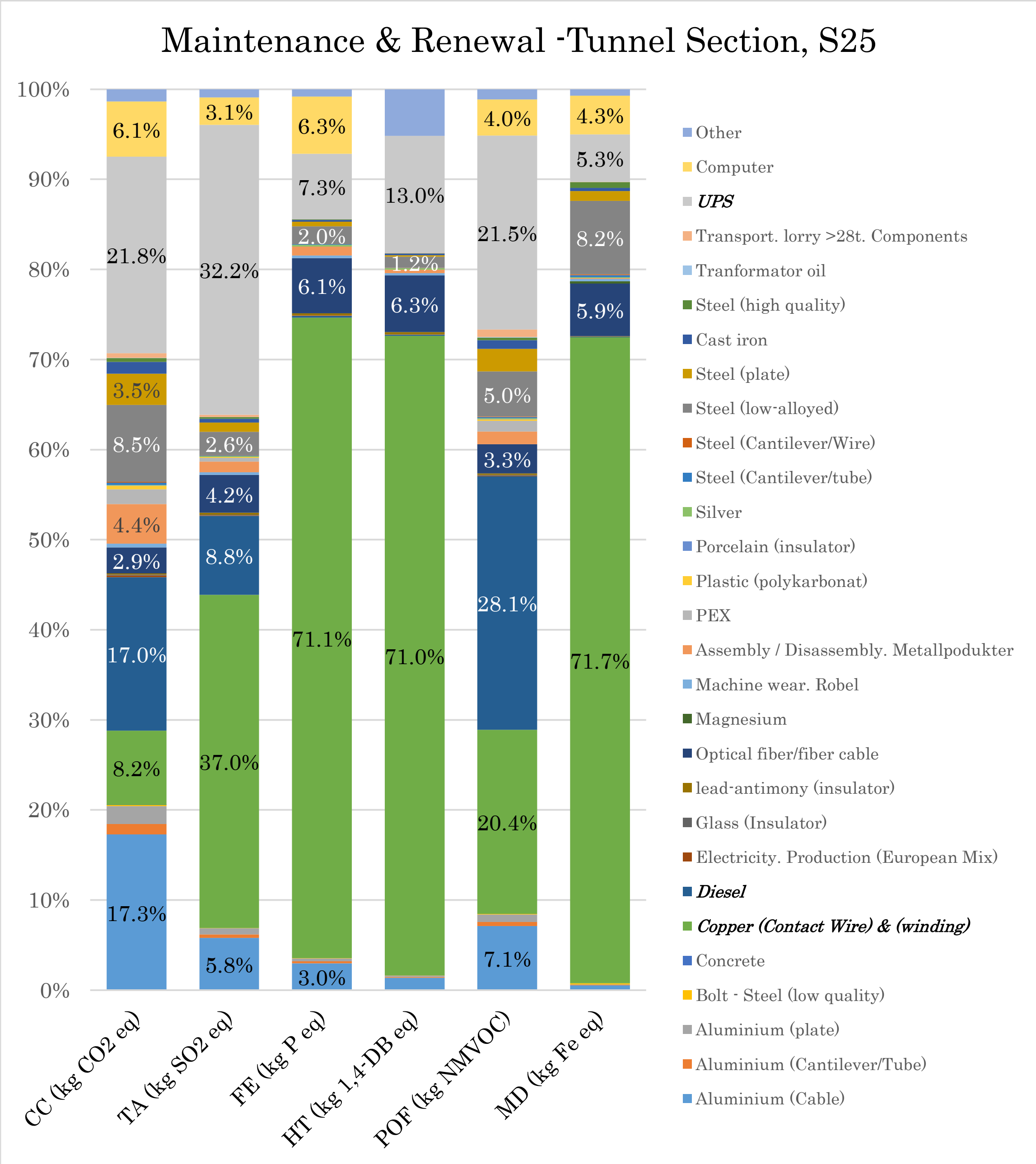
Qualitative data in the table below relates to the figure of tunnel section – S25 for the functional unit of one kilometer.

Life Cycle Phase	Category	Overhead Contact System	Power Supply	Signaling	Telecommunication	Lighting and Fans	Diesel	Machine Wear
Construction	CC (kg CO2 eq)	2.99E+04	5.89E+04	2.77E+03	2.23E+04	1.91E+04	7.93E+03	2.15E+02
	TA (kg SO2 eq)	5.50E+02	4.80E+02	1.24E+02	3.33E+02	8.97E+01	5.01E+01	1.97E+00
	FE (kg P eq)	2.01E+02	1.34E+02	4.77E+01	8.03E+01	1.54E+01	2.36E-01	3.77E-01
	HT (kg 1,4-DB eq)	4.17E+05	2.59E+05	1.03E+05	1.74E+05	2.27E+04	3.37E+02	7.94E+02
	POF (kg NMVOC)	2.04E+02	2.35E+02	3.54E+01	1.33E+02	5.46E+01	8.14E+01	9.05E-01
	MD (kg Fe eq)	1.24E+05	8.66E+04	2.87E+04	5.50E+04	7.67E+03	4.93E+01	2.24E+02
Maintenance	CC (kg CO2 eq)	1.86E+04	2.14E+04	5.54E+03	8.94E+04	5.09E+04	3.86E+04	8.91E+02
	TA (kg SO2 eq)	3.83E+02	1.67E+02	2.48E+02	1.51E+03	2.15E+02	2.44E+02	8.16E+00
	FE (kg P eq)	1.43E+02	4.73E+01	9.54E+01	2.80E+02	3.07E+01	1.15E+00	1.56E+00
	HT (kg 1,4-DB eq)	2.98E+05	9.08E+04	2.06E+05	6.39E+05	3.84E+04	1.64E+03	3.29E+03
	POF (kg NMVOC)	1.43E+02	9.04E+01	7.08E+01	5.54E+02	1.38E+02	3.96E+02	3.75E+00
	MD (kg Fe eq)	8.94E+04	3.89E+04	5.75E+04	1.63E+05	1.18E+04	2.40E+02	9.28E+02
Disposal	CC (kg CO2 eq)	4.30E+02	4.11E+02	8.36E+01	2.11E+03	2.56E+02	-	-
	TA (kg SO2 eq)	2.38E+00	2.28E+00	4.64E-01	1.17E+01	1.42E+00	-	-
	FE (kg P eq)	4.12E-02	3.94E-02	8.01E-03	2.02E-01	2.46E-02	-	-
	HT (kg 1,4-DB eq)	5.45E+01	5.21E+01	1.06E+01	2.67E+02	3.25E+01	-	-
	POF (kg NMVOC)	4.15E+00	3.96E+00	8.06E-01	2.03E+01	2.47E+00	-	-
	MD (kg Fe eq)	2.33E+01	2.22E+01	4.53E+00	1.14E+02	1.39E+01	-	-

The individual input factors and materials for construction of S25 in a kilometer of tunnel section.



In maintenance & renewal phase of individual input factors/materials for system S25 in a kilometer of tunnel section, the results are shifting slightly to other materials (through the 60 years of lifetime).



Appendix F

Impacts of input material

Impacts of Input Material, Construction, Open Section - Re330

	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	3.83E+04	1.58E+02	1.75E+01	1.71E+04	9.77E+01	1.96E+03
Aluminium (Cantilever/Tube)	4.42E+03	1.82E+01	2.05E+00	1.98E+03	1.10E+01	2.22E+02
Aluminium (plate)	2.99E+02	1.24E+00	1.37E-01	1.34E+02	7.65E-01	0.00E+00
Concrete	4.80E+03	1.15E+01	2.94E-01	4.53E+02	1.52E+01	1.18E+02
Copper (Contact Wire) & (winding)	1.90E+04	1.06E+03	4.36E+02	9.28E+05	2.94E+02	2.66E+05
Diesel	4.13E+03	2.61E+01	1.23E-01	1.76E+02	4.24E+01	2.57E+01
Electricity. Production (European Mix)	1.90E+03	7.55E+00	1.61E+00	1.05E+03	3.97E+00	0.00E+00
Glass (Insulator)	1.42E+02	1.13E+00	0.00E+00	0.00E+00	7.35E-01	0.00E+00
lead-antimony (insulator)	2.23E+02	4.63E+00	1.10E+00	2.35E+03	1.76E+00	1.01E+02
Optical fiber / fiber cable	2.64E+03	5.12E+01	1.54E+01	3.43E+04	1.89E+01	8.80E+03
Magnesium	4.28E+01	2.91E-01	0.00E+00	0.00E+00	3.00E-01	2.46E+03
Machine Wear	1.20E+02	1.10E+00	2.11E-01	4.45E+02	5.07E-01	1.25E+02
Assembly / Disassembly	1.24E+03	4.09E+00	7.37E-01	5.83E+02	2.46E+00	4.56E+01
PEX	3.89E+03	1.20E+01	5.84E-02	0.00E+00	1.76E+01	0.00E+00
Plastic (polycarbonate)	1.33E+03	3.98E+00	1.24E-01	1.58E+02	3.24E+00	0.00E+00
Porcelain (insulator)	6.93E+01	2.19E-01	0.00E+00	0.00E+00	1.86E-01	0.00E+00
Steel (Cantilever/tube)	1.84E+02	6.52E-01	1.03E-01	1.25E+02	5.99E-01	2.57E+02
Steel (Cantilever/Wire)	9.32E+01	3.18E-01	5.35E-02	0.00E+00	3.02E-01	1.35E+02
Steel (low-alloyed)	2.01E+04	7.54E+01	1.24E+01	1.61E+04	7.33E+01	3.08E+04
Steel (Mast HEB200. seksjonsskonsoll)	1.60E+04	6.48E+01	1.03E+01	1.53E+04	5.78E+01	9.78E+03
Steel (plate)	3.78E+02	1.41E+00	1.48E-01	1.06E+02	1.71E+00	1.91E+02
Steel (high quality)	2.93E+03	1.62E+01	1.05E+00	1.38E+03	1.26E+01	7.66E+03
Tranformator oil	3.58E+02	1.87E+00	9.64E-02	1.26E+02	5.47E+00	0.00E+00
Transport. lorry >28t. Components	1.71E+03	9.50E+00	1.64E-01	2.17E+02	1.65E+01	9.27E+01
UPS	7.06E+03	1.28E+02	6.24E+00	2.37E+04	4.32E+01	2.72E+03
Computer	1.98E+03	1.22E+01	5.43E+00	8.24E+03	8.05E+00	2.23E+03
Other	6.04E+03	1.85E+01	2.12E+00	4.94E+03	2.02E+01	9.44E+02

Impacts of Input Material, M&R, Open Section - Re330

	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	1.11E+04	4.59E+01	5.09E+00	4.98E+03	2.84E+01	5.68E+02
Aluminium (Cantilever/Tube)	1.31E+03	5.42E+00	6.12E-01	5.90E+02	3.27E+00	6.60E+01
Aluminium (plate)	2.99E+02	1.24E+00	1.37E-01	0.00E+00	7.65E-01	0.00E+00
Concrete	5.81E+03	1.49E+01	3.70E-01	5.77E+02	1.91E+01	1.51E+02
Copper (Contact Wire) & (winding)	2.05E+04	1.14E+03	4.71E+02	1.00E+06	3.19E+02	2.87E+05
Diesel	3.31E+04	2.10E+02	9.87E-01	1.41E+03	3.40E+02	2.06E+02
Electricity. Production (European Mix)	4.42E+02	1.75E+00	3.74E-01	2.43E+02	9.21E-01	0.00E+00
Glass (Insulator)	1.42E+02	1.13E+00	0.00E+00	0.00E+00	7.35E-01	0.00E+00
lead-antimony (insulator)	2.23E+02	4.63E+00	1.10E+00	2.35E+03	1.76E+00	1.01E+02
Optical fiber / fiber cable	6.93E+03	1.27E+02	3.92E+01	8.65E+04	4.88E+01	2.27E+04
Magnesium	4.28E+01	2.91E-01	0.00E+00	0.00E+00	3.00E-01	2.46E+03
Machine Wear	8.90E+02	8.16E+00	1.56E+00	3.29E+03	3.75E+00	9.28E+02
Assembly / Disassembly	2.65E+03	8.72E+00	1.57E+00	1.24E+03	5.25E+00	9.74E+01
PEX	3.70E+03	1.14E+01	0.00E+00	0.00E+00	1.67E+01	0.00E+00
Plastic (polycarbonate)	2.81E+03	8.42E+00	2.62E-01	3.35E+02	6.86E+00	0.00E+00
Porcelain (insulator)	6.93E+01	0.00E+00	0.00E+00	0.00E+00	1.86E-01	0.00E+00
Steel (Cantilever/tube)	1.84E+02	0.00E+00	1.03E-01	0.00E+00	5.99E-01	2.57E+02
Steel (Cantilever/Wire)	8.99E+01	3.06E-01	0.00E+00	0.00E+00	2.91E-01	1.30E+02
Steel (low-alloyed)	1.86E+04	6.99E+01	1.15E+01	1.49E+04	6.79E+01	2.86E+04
Steel (Mast HEB200. seksjonsskonsoll)	3.20E+03	1.30E+01	2.06E+00	3.05E+03	1.16E+01	1.96E+03
Steel (plate)	3.78E+02	1.41E+00	1.48E-01	0.00E+00	1.71E+00	1.91E+02
Steel (high quality)	6.15E+03	3.40E+01	2.21E+00	2.89E+03	2.64E+01	1.60E+04
Tranformator oil	8.08E+01	4.21E-01	0.00E+00	0.00E+00	1.23E+00	0.00E+00
Transport. lorry >28t. Components	1.88E+03	1.04E+01	1.80E-01	2.39E+02	1.82E+01	1.02E+02
UPS	4.94E+04	8.98E+02	4.37E+01	1.66E+05	3.03E+02	1.91E+04
Computer	1.39E+04	8.52E+01	3.80E+01	5.76E+04	5.64E+01	1.56E+04
Other	3.78E+03	2.05E+01	4.78E+00	8.30E+03	1.36E+01	2.76E+03

Impacts of Input Material, Construction, Open Section - S25

	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	3.83E+04	1.58E+02	1.75E+01	1.71E+04	9.77E+01	1.96E+03
Aluminium (Cantilever/Tube)	4.15E+03	1.71E+01	1.93E+00	1.86E+03	1.03E+01	2.08E+02
Aluminium (plate)	2.99E+02	1.24E+00	1.37E-01	1.34E+02	7.65E-01	0.00E+00
Concrete	4.68E+03	1.12E+01	2.87E-01	4.42E+02	1.48E+01	1.16E+02
Copper (Contact Wire) & (winding)	1.71E+04	9.52E+02	3.93E+02	8.37E+05	2.65E+02	2.40E+05
Diesel	4.13E+03	2.61E+01	1.23E-01	1.76E+02	4.24E+01	2.57E+01
Electricity. Production (European Mix)	1.89E+03	7.50E+00	1.60E+00	1.04E+03	3.94E+00	0.00E+00
Glass (Insulator)	1.27E+02	1.01E+00	0.00E+00	0.00E+00	6.57E-01	0.00E+00
lead-antimony (insulator)	2.08E+02	4.32E+00	1.02E+00	2.19E+03	1.64E+00	9.44E+01
Optical fiber / fiber cable	2.64E+03	5.12E+01	1.54E+01	3.43E+04	1.89E+01	8.80E+03
Magnesium	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.95E-02	7.36E+02
Machine Wear	1.20E+02	1.10E+00	2.11E-01	4.45E+02	5.07E-01	1.25E+02
Assembly / Disassembly	1.24E+03	4.09E+00	7.37E-01	5.83E+02	2.46E+00	4.56E+01
PEX	3.89E+03	1.20E+01	5.84E-02	0.00E+00	1.76E+01	0.00E+00
Plastic (polycarbonate)	1.33E+03	3.98E+00	1.24E-01	1.58E+02	3.24E+00	0.00E+00
Porcelain (insulator)	6.93E+01	2.19E-01	0.00E+00	0.00E+00	1.86E-01	0.00E+00
Silver	1.18E+02	2.43E+00	1.06E+00	2.06E+03	1.34E+00	2.89E+02
Steel (Cantilever/tube)	1.84E+02	6.52E-01	1.03E-01	1.25E+02	5.99E-01	2.57E+02
Steel (Cantilever/Wire)	9.28E+01	3.17E-01	5.33E-02	0.00E+00	3.01E-01	1.35E+02
Steel (low-alloyed)	2.01E+04	7.54E+01	1.24E+01	1.61E+04	7.33E+01	3.08E+04
Steel (Mast HEB200. seksjonsskonsoll)	1.60E+04	6.48E+01	1.03E+01	1.53E+04	5.78E+01	9.78E+03
Steel (plate)	3.79E+02	1.41E+00	1.48E-01	1.06E+02	1.71E+00	1.91E+02
Steel (high quality)	2.93E+03	1.62E+01	1.05E+00	1.38E+03	1.26E+01	7.66E+03
Tranformator oil	3.58E+02	1.87E+00	9.64E-02	1.26E+02	5.47E+00	0.00E+00

Transport. lorry >28t. Components	1.69E+03	9.36E+00	1.62E-01	2.14E+02	1.63E+01	9.13E+01
UPS	7.06E+03	1.28E+02	6.24E+00	2.37E+04	4.32E+01	2.72E+03
Computer	1.98E+03	1.22E+01	5.43E+00	8.24E+03	8.05E+00	2.23E+03
Other	6.08E+03	1.90E+01	2.36E+00	4.81E+03	2.03E+01	8.84E+02

Impacts of Input Material, M&R, Open Section - S25

	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	1.11E+04	4.59E+01	5.09E+00	4.98E+03	2.84E+01	5.68E+02
Aluminium (Cantilever/Tube)	1.02E+03	4.20E+00	4.73E-01	4.57E+02	2.53E+00	5.10E+01
Aluminium (plate)	2.79E+02	1.15E+00	1.28E-01		7.12E-01	
Concrete	5.42E+03	1.41E+01	3.48E-01	5.42E+02	1.79E+01	1.42E+02
Copper (Contact Wire) & (winding)	1.86E+04	1.04E+03	4.28E+02	9.11E+05	2.89E+02	2.60E+05
Diesel	3.31E+04	2.10E+02	9.87E-01	1.41E+03	3.40E+02	2.06E+02
Electricity. Production (European Mix)	4.27E+02	1.69E+00	3.62E-01	2.34E+02	8.90E-01	
Glass (Insulator)	1.23E+02	9.79E-01			6.35E-01	
lead-antimony (insulator)	2.04E+02	4.23E+00	1.00E+00	2.15E+03	1.61E+00	9.25E+01
Optical fiber / fiber cable	6.93E+03	1.27E+02	3.92E+01	8.65E+04	4.88E+01	2.27E+04
Magnesium						7.26E+02
Machine Wear	8.90E+02	8.16E+00	1.56E+00	3.29E+03	3.75E+00	9.28E+02
Assembly / Disassembly	2.65E+03	8.72E+00	1.57E+00	1.24E+03	5.25E+00	9.74E+01
PEX	3.70E+03	1.14E+01			1.67E+01	
Plastic (polycarbonate)	2.81E+03	8.42E+00	2.62E-01	3.35E+02	6.86E+00	
Porcelain (insulator)	6.93E+01				1.86E-01	
Silver	1.17E+02	2.41E+00	1.05E+00	2.05E+03	1.33E+00	2.86E+02
Steel (Cantilever/tube)	1.68E+02	5.95E-01	9.35E-02		5.46E-01	2.34E+02
Steel (Cantilever/Wire)	8.18E+01	2.79E-01			2.65E-01	1.19E+02
Steel (low-alloyed)	1.86E+04	6.99E+01	1.15E+01	1.49E+04	6.79E+01	2.86E+04
Steel (Mast HEB200. seksjonsskonsoll)	3.20E+03	1.30E+01	2.06E+00	3.05E+03	1.16E+01	1.96E+03
Steel (plate)	3.60E+02	1.34E+00	1.41E-01		1.63E+00	1.82E+02
Steel (high quality)	6.15E+03	3.40E+01	2.21E+00	2.90E+03	2.64E+01	1.60E+04
Tranformator oil	8.08E+01	4.21E-01			1.23E+00	
Transport. lorry >28t. Components	1.83E+03	1.01E+01	1.75E-01	2.32E+02	1.76E+01	9.89E+01
UPS	4.94E+04	8.98E+02	4.37E+01	1.66E+05	3.03E+02	1.91E+04
Computer	1.39E+04	8.52E+01	3.80E+01	5.76E+04	5.64E+01	1.56E+04
Other	3.76E+03	1.94E+01	3.80E+00	7.54E+03	1.39E+01	2.96E+03

Impacts of Input Material, Construction, Tunnel Section - Re330

	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	4.73E+04	1.96E+02	2.16E+01	2.11E+04	1.21E+02	2.88E+03
Aluminium (Cantilever/Tube)	9.69E+03	4.00E+01	4.51E+00	4.35E+03	2.42E+01	6.88E+01
Aluminium (plate)	1.81E+03	7.47E+00	8.28E-01	8.09E+02	4.62E+00	
Bolt - Steel (low alloyed)	1.45E+03	5.23E+00	8.70E-01	1.07E+03	5.26E+00	2.27E+03
Concrete	1.62E+02	3.45E-01			4.80E-01	
Copper (Contact Wire) & (winding)	1.89E+04	1.05E+03	4.34E+02	9.24E+05	2.93E+02	2.64E+05
Diesel	7.93E+03	5.01E+01	2.36E-01	3.37E+02	8.14E+01	4.93E+01
Electricity. Production (European Mix)	1.92E+03	7.61E+00	1.63E+00	1.05E+03	4.00E+00	
Glass (Insulator)	2.11E+02	1.68E+00			1.09E+00	
lead-antimony (insulator)	2.92E+02	6.07E+00	1.44E+00	3.08E+03	2.31E+00	1.33E+02
Optical fiber / fiber cable	1.66E+03	2.47E+01	8.51E+00	1.78E+04	1.09E+01	5.08E+03
Magnesium	4.30E+01	2.93E-01			3.01E-01	2.48E+03
Machine Wear	2.15E+02	1.97E+00	3.77E-01	7.94E+02	9.05E-01	2.24E+02
Assembly / Disassembly	3.98E+03	1.31E+01	2.36E+00	1.87E+03	7.89E+00	1.46E+02
PEX	3.89E+03	1.19E+01	5.84E-02		1.76E+01	
Plastic (polycarbonate)	5.65E+02	1.69E+00	5.26E-02		1.38E+00	
Porcelain (insulator)	6.93E+01	2.19E-01			1.86E-01	

Steel (Cantilever/tube)	5.87E+02	2.07E+00	3.26E-01	3.97E+02	1.90E+00	8.17E+02
Steel (Cantilever/Wire)	2.31E+02	7.89E-01	1.33E-01	1.61E+02	7.50E-01	3.35E+02
Steel (low-alloyed)	2.07E+04	7.76E+01	1.27E+01	1.66E+04	7.54E+01	3.17E+04
Steel (plate)	1.22E+04	4.56E+01	4.79E+00	3.43E+03	5.53E+01	6.18E+03
Cast iron	1.01E+03	3.83E+00	3.58E-01	8.87E+02	4.57E+00	4.24E+02
Steel (high quality)	3.02E+02	1.67E+00	1.08E-01	1.42E+02	1.30E+00	7.89E+02
Tranformator oil	3.58E+02	1.87E+00	5.85E-02	1.26E+02	5.47E+00	
Transport. lorry >28t. Components	6.10E+02	3.38E+00	5.85E-02		5.89E+00	3.30E+01
UPS	7.06E+03	1.28E+02	6.24E+00	2.37E+04	4.32E+01	2.72E+03
Computer	1.98E+03	1.22E+01	5.43E+00	8.24E+03	8.05E+00	2.23E+03
Other	1.70E+03	1.18E+01	2.14E+00	4.41E+03	6.84E+00	1.55E+03

Impacts of Input Material, M&R, Tunnel Section - Re330

	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	3.91E+04	1.62E+02	1.79E+01	1.75E+04	1.00E+02	2.01E+03
Aluminium (Cantilever/Tube)	2.66E+03	1.10E+01	1.24E+00	1.19E+03	6.62E+00	1.33E+02
Aluminium (plate)	4.49E+03	1.86E+01	2.06E+00	2.01E+03	1.15E+01	2.06E+02
Bolt - Steel (low quality)	2.90E+02	1.05E+00	1.74E-01	2.14E+02	1.05E+00	4.54E+02
Concrete	3.23E+01					
Copper (Contact Wire) & (winding)	2.00E+04	1.11E+03	4.60E+02	9.80E+05	3.11E+02	2.81E+05
Diesel	3.86E+04	2.44E+02	1.15E+00	1.64E+03	3.96E+02	2.40E+02
Electricity. Production (European Mix)	4.55E+02	1.81E+00	3.86E-01	2.50E+02	9.50E-01	
Glass (Insulator)	2.11E+02	1.68E+00			1.09E+00	
lead-antimony (insulator)	2.92E+02	6.07E+00	1.44E+00	3.08E+03	2.31E+00	1.33E+02
Optical fiber / fiber cable	6.58E+03	1.18E+02	3.68E+01	8.06E+04	4.59E+01	2.13E+04
Magnesium	4.30E+01	2.93E-01				2.48E+03
Machine Wear	8.90E+02	8.16E+00	1.56E+00	3.29E+03	3.75E+00	9.28E+02
Assembly / Disassembly	1.00E+04	3.29E+01	5.94E+00	4.70E+03	1.98E+01	3.68E+02
PEX	3.70E+03	1.14E+01			1.67E+01	
Plastic (polycarbonate)	9.01E+02	2.70E+00	8.39E-02		2.20E+00	
Porcelain (insulator)	6.93E+01				1.86E-01	
Steel (Cantilever/tube)	5.87E+02	2.07E+00	3.26E-01	3.97E+02	1.90E+00	8.17E+02
Steel (Cantilever/Wire)	2.28E+02	7.79E-01	1.31E-01	1.59E+02	7.40E-01	3.31E+02
Steel (low-alloyed)	1.93E+04	7.25E+01	1.19E+01	1.55E+04	7.04E+01	2.96E+04
Steel (plate)	1.22E+04	4.56E+01	4.79E+00	3.43E+03	5.53E+01	6.18E+03
Cast iron	3.02E+03	1.15E+01	1.07E+00	2.66E+03	1.37E+01	1.27E+03
Steel (high quality)	8.85E+02	4.90E+00	3.18E-01	4.17E+02	3.80E+00	2.31E+03
Tranformator oil	8.08E+01	4.21E-01			1.23E+00	
Transport. lorry >28t. Components	1.21E+03	6.71E+00	1.16E-01	1.53E+02	1.17E+01	6.55E+01
UPS	4.94E+04	8.98E+02	4.37E+01	1.66E+05	3.03E+02	1.91E+04
Computer	1.39E+04	8.52E+01	3.80E+01		5.64E+01	1.56E+04
Other	3.22E+03	2.06E+01	5.21E+00	6.64E+04	1.28E+01	2.49E+03

Impacts of Input Material, Construction, Tunnel Section - S25

	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	4.73E+04	1.96E+02	2.16E+01	2.11E+04	1.21E+02	2.40E+03
Aluminium (Cantilever/Tube)	9.69E+03	4.00E+01	4.51E+00	4.35E+03	2.42E+01	4.86E+02
Aluminium (plate)	1.81E+03	7.47E+00	8.28E-01	8.09E+02	4.62E+00	6.88E+01
Bolt - Steel (low quality)	1.45E+03	5.23E+00	8.70E-01	1.07E+03	5.26E+00	2.27E+03
Concrete	1.62E+02	3.45E-01			4.80E-01	
Copper (Contact Wire) & (winding)	1.74E+04	9.68E+02	3.99E+02	8.51E+05	2.70E+02	2.43E+05
Diesel	7.93E+03	5.01E+01	2.36E-01	3.37E+02	8.14E+01	4.93E+01
Electricity. Production (European Mix)	1.91E+03	7.57E+00	1.62E+00	1.05E+03	3.98E+00	
Glass (Insulator)	2.11E+02	1.68E+00			1.09E+00	

lead-antimony (insulator)	2.92E+02		1.44E+00	3.08E+03	2.31E+00	1.33E+02
Optical fiber / fiber cable	2.47E+03	4.65E+01	1.42E+01	3.14E+04	1.75E+01	8.15E+03
Magnesium					9.40E-02	7.73E+02
Machine Wear		1.97E+00	3.77E-01	7.94E+02	9.05E-01	2.24E+02
Assembly / Disassembly	3.98E+03	1.31E+01	2.36E+00	1.87E+03	7.89E+00	1.46E+02
PEX	3.89E+03	1.20E+01	5.84E-02		1.76E+01	
Plastic (polycarbonate)	5.65E+02	1.69E+00	5.26E-02		1.38E+00	
Porcelain (insulator)	6.93E+01	2.19E-01			1.86E-01	
Silver	1.30E+02	2.68E+00	1.17E+00	2.28E+03	1.48E+00	3.19E+02
Steel (Cantilever/tube)	5.87E+02	2.07E+00	3.26E-01	3.97E+02	1.90E+00	8.17E+02
Steel (Cantilever/Wire)	2.31E+02	7.89E-01	1.33E-01	1.61E+02	7.50E-01	3.35E+02
Steel (low-alloyed)	2.07E+04	7.76E+01	1.27E+01	1.66E+04	7.54E+01	3.17E+04
Steel (plate)	7.85E+03	2.92E+01	3.07E+00	2.20E+03	3.54E+01	3.96E+03
Cast iron	1.01E+03	3.83E+00	3.58E-01	8.87E+02	4.57E+00	4.24E+02
Steel (high quality)	3.02E+02	1.67E+00	1.08E-01	1.42E+02	1.30E+00	7.89E+02
Tranformator oil	3.58E+02	1.87E+00	9.64E-02	1.26E+02	5.47E+00	
Transport. lorry >28t. Components	5.79E+02	3.21E+00	5.55E-02		5.58E+00	3.13E+01
UPS	7.06E+03	1.28E+02	6.24E+00	2.37E+04	4.32E+01	2.72E+03
Computer	1.98E+03	1.22E+01	5.43E+00	8.24E+03	8.05E+00	2.23E+03
Other	1.89E+03	1.77E+01	2.75E+00	4.18E+03	6.65E+00	1.62E+03

Impacts of Input Material, M&R, Open Section - S25

	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	3.91E+04	1.62E+02	1.79E+01	1.75E+04	1.00E+02	2.01E+03
Aluminium (Cantilever/Tube)	2.66E+03	1.10E+01	1.24E+00	1.19E+03	6.62E+00	1.33E+02
Aluminium (plate)	4.49E+03	1.86E+01	2.06E+00	2.01E+03	1.15E+01	2.06E+02
Bolt - Steel (low quality)	2.90E+02	1.05E+00	1.74E-01	2.14E+02	1.05E+00	4.54E+02
Concrete	3.23E+01					
Copper (Contact Wire) & (winding)	1.86E+04	1.03E+03	4.26E+02	9.07E+05	2.88E+02	2.60E+05
Diesel	3.86E+04	2.44E+02	1.15E+00	1.64E+03	3.96E+02	2.40E+02
Electricity. Production (European Mix)	4.46E+02	1.77E+00	3.78E-01	2.45E+02	9.31E-01	
Glass (Insulator)	2.11E+02	1.68E+00			1.09E+00	
lead-antimony (insulator)	2.92E+02	6.07E+00	1.44E+00	3.08E+03	2.31E+00	1.33E+02
Optical fiber / fiber cable	6.58E+03	1.18E+02	3.68E+01	8.06E+04	4.59E+01	2.13E+04
Magnesium						7.73E+02
Machine Wear	8.90E+02	8.16E+00	1.56E+00	3.29E+03		9.28E+02
Assembly / Disassembly	1.00E+04	3.29E+01	5.94E+00	4.70E+03	1.98E+01	3.68E+02
PEX	3.70E+03	1.14E+01			1.67E+01	
Plastic (polycarbonate)	9.01E+02	2.70E+00	8.39E-02		2.20E+00	
Porcelain (insulator)	6.93E+01				1.86E-01	
Silver	1.30E+02	2.68E+00	1.17E+00	2.28E+03	1.48E+00	3.19E+02
Steel (Cantilever/tube)	5.87E+02	2.07E+00	3.26E-01	3.97E+02	1.90E+00	8.17E+02
Steel (Cantilever/Wire)	2.28E+02	7.79E-01	1.31E-01	1.59E+02	7.40E-01	3.31E+02
Steel (low-alloyed)	1.93E+04	7.25E+01	1.19E+01	1.55E+04	7.04E+01	2.96E+04
Steel (plate)	7.85E+03	2.92E+01	3.07E+00	2.20E+03	3.54E+01	3.96E+03
Cast iron	3.02E+03	1.15E+01	1.07E+00	2.66E+03	1.37E+01	1.27E+03
Steel (high quality)	8.85E+02	4.90E+00	3.18E-01	4.17E+02	3.80E+00	2.31E+03
Tranformator oil	8.08E+01	4.21E-01			1.23E+00	
Transport. lorry >28t. Components	1.18E+03	6.53E+00	1.13E-01	1.49E+02	1.14E+01	6.38E+01
UPS	4.94E+04	8.98E+02	4.37E+01	1.66E+05	3.03E+02	1.91E+04
Computer	1.39E+04	8.52E+01	3.80E+01		5.64E+01	1.56E+04
Other	3.08E+03	2.53E+01	4.85E+00	6.62E+04	1.62E+01	2.56E+03

Appendix G

LCIA of input material Re330

In this appendix, aggregated results from input materials of all life cycle phases for system Re330 (that comprise of two different section types) are shown to give a generic view of total input materials for the function unit of one kilometer. In addition, qualitative tables related to each chart are provided.

Figure below shows the total share of input materials for the functional unit of one kilometer for system Re330.

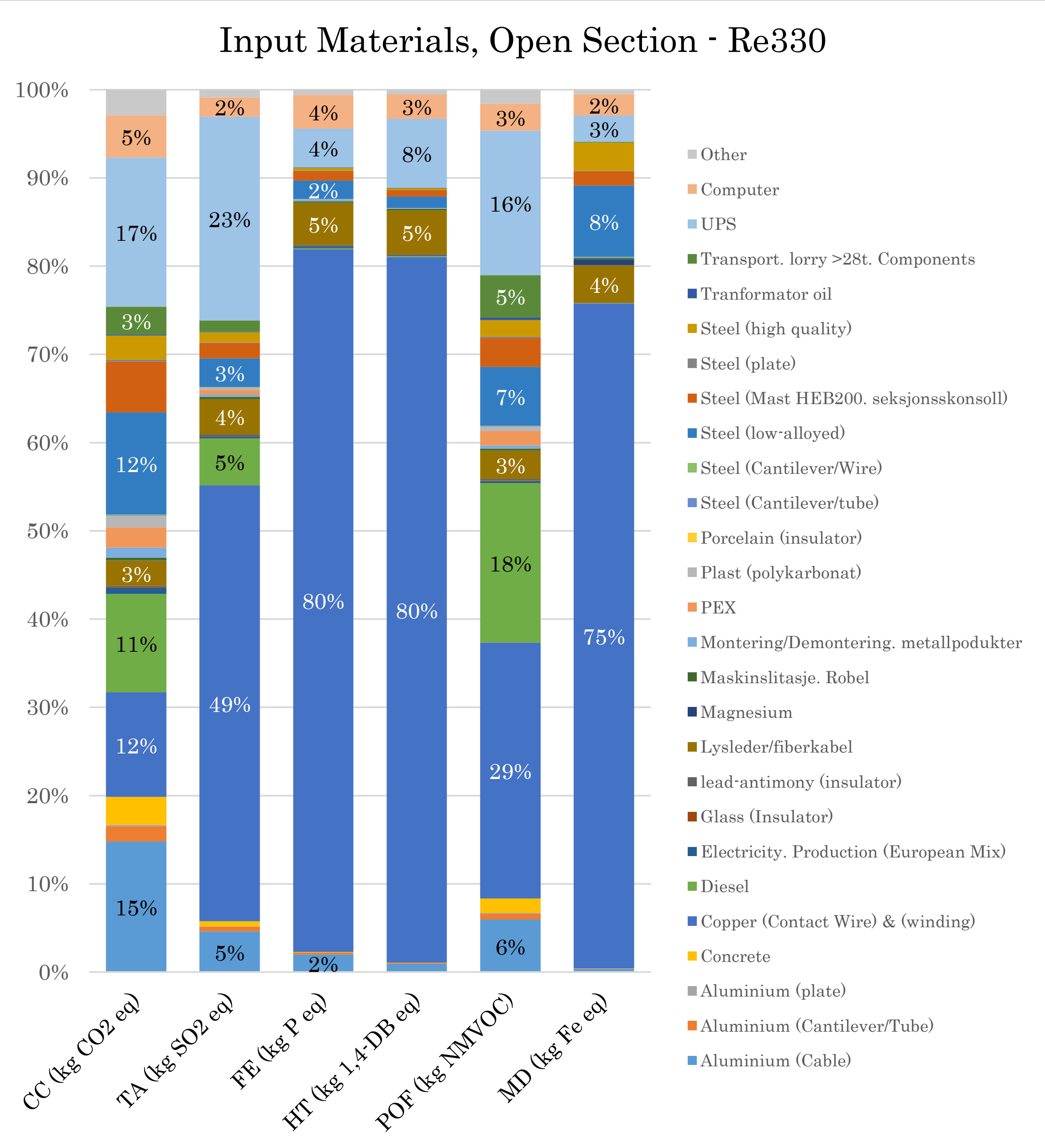


Figure below is a representative of total input materials contribution in the entire life cycle of HSR electrification for the functional unit of one kilometer.

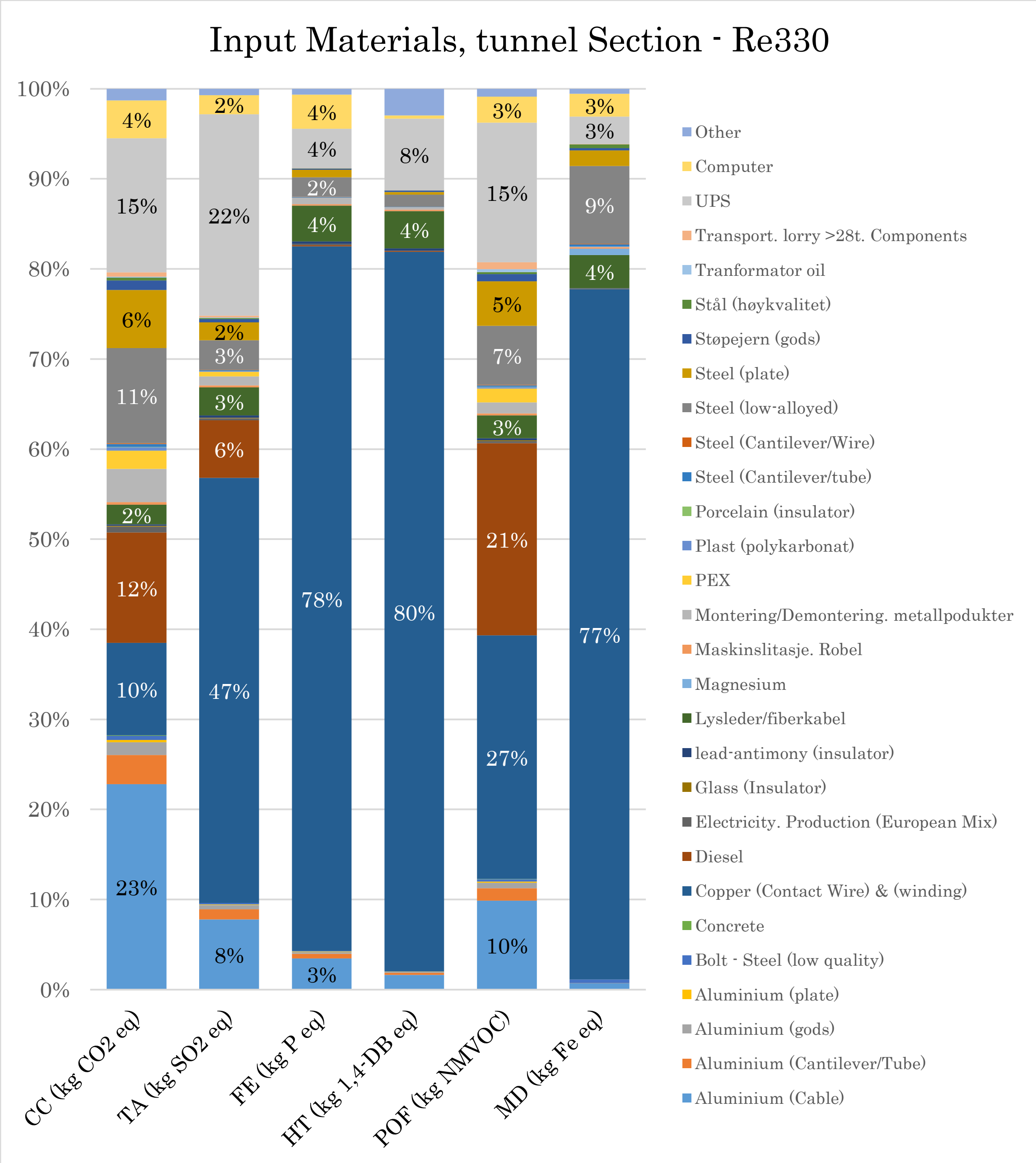


Table below provides a qualitative data for the total input materials in a kilometer of open section for the figure that is related to the figure of “Input Materials, Open Section - Re330”.

Input Material	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	4.94E+04	2.04E+02	2.26E+01	2.21E+04	1.26E+02	2.53E+03
Aluminium (Cantilever/Tube)	5.73E+03	2.36E+01	2.66E+00	2.57E+03	1.43E+01	2.88E+02
Aluminium (plate)	5.98E+02	2.48E+00	2.74E-01	1.34E+02	1.53E+00	0.00E+00
Concrete	1.06E+04	2.64E+01	6.64E-01	1.03E+03	3.43E+01	2.69E+02
Copper (Contact Wire) & (winding)	3.96E+04	2.20E+03	9.07E+02	1.93E+06	6.13E+02	5.53E+05
Diesel	3.72E+04	2.36E+02	1.11E+00	1.59E+03	3.82E+02	2.32E+02
Electricity. Production (European Mix)	2.34E+03	9.30E+00	1.98E+00	1.29E+03	4.89E+00	0.00E+00
Glass (Insulator)	2.84E+02	2.26E+00	0.00E+00	0.00E+00	1.47E+00	0.00E+00
lead-antimony (insulator)	4.46E+02	9.26E+00	2.20E+00	4.70E+03	3.52E+00	2.02E+02
Lysleder/fiberkabel	9.57E+03	1.78E+02	5.46E+01	1.21E+05	6.77E+01	3.15E+04
Magnesium	8.56E+01	5.82E-01	0.00E+00	0.00E+00	6.00E-01	4.92E+03
Maskinslitasje. Robel	1.01E+03	9.26E+00	1.77E+00	3.74E+03	4.26E+00	1.05E+03
Montering/Demontering. metallpodukter	3.89E+03	1.28E+01	2.31E+00	1.82E+03	7.71E+00	1.43E+02
PEX	7.59E+03	2.34E+01	5.84E-02	0.00E+00	3.43E+01	0.00E+00
Plast (polykarbonat)	4.14E+03	1.24E+01	3.86E-01	4.93E+02	1.01E+01	0.00E+00
Porcelain (insulator)	1.39E+02	2.19E-01	0.00E+00	0.00E+00	3.72E-01	0.00E+00
Steel (Cantilever/tube)	3.68E+02	6.52E-01	2.06E-01	1.25E+02	1.20E+00	5.14E+02
Steel (Cantilever/Wire)	1.83E+02	6.24E-01	5.35E-02	0.00E+00	5.93E-01	2.65E+02
Steel (low-alloyed)	3.87E+04	1.45E+02	2.39E+01	3.10E+04	1.41E+02	5.94E+04
Steel (Mast HEB200. seksjonsskonsoll)	1.92E+04	7.78E+01	1.24E+01	1.84E+04	6.94E+01	1.17E+04
Steel (plate)	7.56E+02	2.82E+00	2.96E-01	1.06E+02	3.42E+00	3.82E+02
Steel (high quality)	9.08E+03	5.02E+01	3.26E+00	4.27E+03	3.90E+01	2.37E+04
Tranformator oil	4.39E+02	2.29E+00	9.64E-02	1.26E+02	6.70E+00	0.00E+00
Transport. lorry >28t. Components	1.05E+04	5.81E+01	1.00E+00	1.33E+03	1.01E+02	5.68E+02
UPS	5.65E+04	1.03E+03	4.99E+01	1.90E+05	3.46E+02	2.18E+04
Computer	1.59E+04	9.74E+01	4.34E+01	6.58E+04	6.45E+01	1.78E+04
Other	9.82E+03	3.90E+01	6.90E+00	1.32E+04	3.37E+01	3.70E+03

Moreover, related to the figure of “Input Materials, tunnel Section - Re330”, table below provides a qualitative data for the total input materials in a kilometer of open section.

Input Material	CC (kg CO2 eq)	TA (kg SO2 eq)	FE (kg P eq)	HT (kg 1,4-DB eq)	POF (kg NMVOC)	MD (kg Fe eq)
Aluminium (Cable)	8.64E+04	3.58E+02	3.95E+01	3.86E+04	2.21E+02	4.89E+03
Aluminium (Cantilever/Tube)	1.24E+04	5.10E+01	5.75E+00	5.54E+03	3.08E+01	2.02E+02
Aluminium (gods)	5.37E+03	2.23E+01	2.47E+00	2.40E+03	1.37E+01	2.06E+02
Aluminium (plate)	9.29E+02	3.84E+00	4.25E-01	4.16E+02	2.38E+00	0.00E+00
Bolt - Steel (low quality)	1.74E+03	6.28E+00	1.04E+00	1.28E+03	6.31E+00	2.72E+03
Concrete	1.94E+02	3.45E-01	0.00E+00	0.00E+00	4.80E-01	0.00E+00
Copper (Contact Wire) & (winding)	3.89E+04	2.17E+03	8.94E+02	1.90E+06	6.04E+02	5.45E+05
Diesel	4.65E+04	2.94E+02	1.39E+00	1.98E+03	4.77E+02	2.89E+02
Electricity. Production (European Mix)	2.38E+03	9.42E+00	2.02E+00	1.30E+03	4.95E+00	0.00E+00
Glass (Insulator)	4.22E+02	3.36E+00	0.00E+00	0.00E+00	2.18E+00	0.00E+00
lead-antimony (insulator)	5.84E+02	1.21E+01	2.88E+00	6.16E+03	4.62E+00	2.66E+02
Lysleder/fiberkabel	8.24E+03	1.42E+02	4.53E+01	9.84E+04	5.68E+01	2.64E+04
Magnesium	8.60E+01	5.86E-01	0.00E+00	0.00E+00	3.01E-01	4.96E+03
Maskinslitasje. Robel	1.11E+03	1.01E+01	1.94E+00	4.08E+03	4.66E+00	1.15E+03
Montering/Demontering. metallpodukter	1.40E+04	4.60E+01	8.30E+00	6.57E+03	2.77E+01	5.14E+02
PEX	7.59E+03	2.33E+01	5.84E-02	0.00E+00	3.43E+01	0.00E+00
Plast (polykarbonat)	1.47E+03	4.39E+00	1.37E-01	0.00E+00	3.58E+00	0.00E+00
Porcelain (insulator)	1.39E+02	2.19E-01	0.00E+00	0.00E+00	3.72E-01	0.00E+00
Steel (Cantilever/tube)	1.17E+03	4.14E+00	6.52E-01	7.94E+02	3.80E+00	1.63E+03
Steel (Cantilever/Wire)	4.59E+02	1.57E+00	2.64E-01	3.20E+02	1.49E+00	6.66E+02
Steel (low-alloyed)	4.00E+04	1.50E+02	2.46E+01	3.21E+04	1.46E+02	6.13E+04
Steel (plate)	2.44E+04	9.12E+01	9.58E+00	6.86E+03	1.11E+02	1.24E+04
Støpejern (gods)	4.03E+03	1.53E+01	1.43E+00	3.55E+03	1.83E+01	1.69E+03
Stål (høykvalitet)	1.19E+03	6.57E+00	4.26E-01	5.59E+02	5.10E+00	3.10E+03
Tranformator oil	4.39E+02	2.29E+00	5.85E-02	1.26E+02	6.70E+00	0.00E+00
Transport. lorry >28t. Components	1.82E+03	1.01E+01	1.75E-01	1.53E+02	1.76E+01	9.85E+01
UPS	5.65E+04	1.03E+03	4.99E+01	1.90E+05	3.46E+02	2.18E+04
Computer	1.59E+04	9.74E+01	4.34E+01	8.24E+03	6.45E+01	1.78E+04
Other	4.92E+03	3.24E+01	7.35E+00	7.08E+04	1.97E+01	4.04E+03

Appendix H

Corridor planning

The tables in this appendix are the information from LCIA of HSR electrification in corridor planning that project the results of LCIA from HSR electrification and other infrastructures (that are noted by "Alignment's Construction" and "Alignment's Maintenance" that are representatives of infrastructure that are not related to electrification). In addition to the quantitative results from this thesis, the tables shows the results from electrification of previous study by (Bergsdal et al. 2012) named as "Initial Study" in the tables.

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment Ø2:P	CC (kg CO2 eq)	New Electrification	2.87E+09	1.71E+09	1.16E+08	**2.38%**	1.67E+08	**3.44%**	4.45E+06	**0.09%**
		Initial Study	2.87E+09	1.71E+09	4.81E+07	**0.99%**	9.94E+07	**2.04%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	2.87E+07	5.86E+06	1.38E+06	**3.62%**	2.27E+06	**5.94%**	2.47E+04	**0.06%**
		Initial Study	2.87E+07	5.86E+06	4.48E+05	**1.17%**	9.00E+05	**2.35%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	8.32E+05	7.21E+05	4.19E+05	**16.85%**	5.13E+05	**20.64%**	4.26E+02	**0.02%**
		Initial Study	8.32E+05	7.21E+05	1.30E+05	**5.25%**	2.49E+05	**10.03%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	1.19E+09	1.01E+09	8.58E+08	**20.63%**	1.11E+09	**26.56%**	5.64E+05	**0.01%**
		Initial Study	1.19E+09	1.01E+09	2.57E+08	**6.16%**	4.87E+08	**11.69%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	3.33E+07	6.70E+06	6.17E+05	**1.48%**	1.10E+06	**2.63%**	4.29E+04	**0.10%**
		Initial Study	3.33E+07	6.70E+06	2.08E+05	**0.50%**	4.21E+05	**1.01%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	7.87E+08	1.13E+09	2.70E+08	**10.77%**	3.21E+08	**12.79%**	2.41E+05	**0.01%**
		Initial Study	7.87E+08	1.13E+09	9.29E+07	**3.60%**	1.89E+08	**7.34%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment G3:Y	CC (kg CO2 eq)	New Electrification	4.18E+09	2.33E+09	1.28E+08	**1.87%**	1.91E+08	**2.79%**	4.28E+06	**0.06%**
		Initial Study	4.18E+09	2.33E+09	5.53E+07	**0.81%**	1.17E+08	**1.70%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	4.11E+07	7.60E+06	1.52E+06	**2.88%**	2.51E+06	**4.76%**	2.37E+04	**0.04%**
		Initial Study	4.11E+07	7.60E+06	5.29E+05	**1.00%**	1.02E+06	**1.94%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	1.20E+06	9.30E+05	4.58E+05	**14.54%**	5.62E+05	**17.85%**	4.10E+02	**0.01%**
		Initial Study	1.20E+06	9.30E+05	1.55E+05	**4.92%**	2.80E+05	**8.90%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	1.71E+09	1.29E+09	9.37E+08	**18.21%**	1.21E+09	**23.45%**	5.42E+05	**0.01%**
		Initial Study	1.71E+09	1.29E+09	3.06E+08	**5.94%**	5.45E+08	**10.59%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	4.74E+07	8.60E+06	6.83E+05	**1.18%**	1.23E+06	**2.12%**	4.13E+04	**0.07%**
		Initial Study	4.74E+07	8.60E+06	2.40E+05	**0.41%**	4.81E+05	**0.83%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	1.07E+09	1.37E+09	2.94E+08	**9.53%**	3.49E+08	**11.31%**	2.32E+05	**0.01%**
		Initial Study	1.07E+09	1.37E+09	1.09E+08	**3.43%**	2.08E+08	**6.58%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment S2:P	CC (kg CO2 eq)	New Electrification	4.51E+09	2.51E+09	1.38E+08	**1.87%**	2.05E+08	**2.78%**	4.58E+06	**0.06%**
		Initial Study	4.51E+09	2.51E+09	5.89E+07	**0.80%**	1.25E+08	**1.70%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	4.42E+07	8.17E+06	1.64E+06	**2.89%**	2.70E+06	**4.76%**	2.54E+04	**0.04%**
		Initial Study	4.42E+07	8.17E+06	5.66E+05	**1.00%**	1.10E+06	**1.94%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	1.30E+06	1.00E+06	4.93E+05	**14.49%**	6.05E+05	**17.78%**	4.39E+02	**0.01%**
		Initial Study	1.30E+06	1.00E+06	1.66E+05	**4.88%**	3.01E+05	**8.84%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	1.87E+09	1.39E+09	1.01E+09	**18.14%**	1.30E+09	**23.33%**	5.81E+05	**0.01%**
		Initial Study	1.87E+09	1.39E+09	3.28E+08	**5.89%**	5.85E+08	**10.51%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	5.09E+07	9.25E+06	7.35E+05	**1.18%**	1.32E+06	**2.12%**	4.42E+04	**0.07%**
		Initial Study	5.09E+07	9.25E+06	2.56E+05	**0.41%**	5.16E+05	**0.83%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	1.15E+09	1.48E+09	3.17E+08	**9.56%**	3.76E+08	**11.33%**	2.48E+05	**0.01%**
		Initial Study	1.15E+09	1.48E+09	1.16E+08	**3.50%**	2.23E+08	**6.74%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment S8:Q	CC (kg CO2 eq)	New Electrification	4.01E+09	2.24E+09	1.28E+08	**1.94%**	1.89E+08	**2.89%**	4.53E+06	**0.07%**
		Initial Study	4.01E+09	2.24E+09	5.58E+07	**0.85%**	1.18E+08	**1.79%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	3.88E+07	7.42E+06	1.48E+06	**2.94%**	2.48E+06	**4.95%**	2.51E+04	**0.05%**
		Initial Study	3.88E+07	7.42E+06	5.30E+05	**1.05%**	1.05E+06	**2.08%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	1.17E+06	9.07E+05	4.38E+05	**14.30%**	5.44E+05	**17.77%**	4.34E+02	**0.01%**
		Initial Study	1.17E+06	9.07E+05	1.55E+05	**5.06%**	2.88E+05	**9.40%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	1.67E+09	1.26E+09	8.95E+08	**17.89%**	1.17E+09	**23.41%**	5.75E+05	**0.01%**
		Initial Study	1.67E+09	1.26E+09	3.06E+08	**6.11%**	5.61E+08	**11.20%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	4.48E+07	8.44E+06	6.69E+05	**1.21%**	1.22E+06	**2.22%**	4.37E+04	**0.08%**
		Initial Study	4.48E+07	8.44E+06	2.42E+05	**0.44%**	4.91E+05	**0.89%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	1.06E+09	1.37E+09	2.81E+08	**9.21%**	3.37E+08	**11.06%**	2.45E+05	**0.01%**
		Initial Study	1.06E+09	1.37E+09	1.09E+08	**3.58%**	2.16E+08	**7.08%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment Ha2:P	CC (kg CO2 eq)	New Electrification	3.14E+09	1.78E+09	1.00E+08	**1.94%**	1.47E+08	**2.84%**	3.63E+06	**0.07%**
		Initial Study	3.14E+09	1.78E+09	4.32E+07	**0.83%**	9.11E+07	**1.76%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	3.11E+07	5.84E+06	1.20E+06	**2.99%**	1.97E+06	**4.91%**	2.01E+04	**0.05%**
		Initial Study	3.11E+07	5.84E+06	4.12E+05	**1.03%**	8.04E+05	**2.01%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	9.05E+05	7.15E+05	3.62E+05	**14.92%**	4.43E+05	**18.27%**	3.48E+02	**0.01%**
		Initial Study	9.05E+05	7.15E+05	1.21E+05	**4.98%**	2.21E+05	**9.09%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	1.29E+09	9.96E+08	7.41E+08	**18.60%**	9.54E+08	**23.93%**	4.61E+05	**0.01%**
		Initial Study	1.29E+09	9.96E+08	2.38E+08	**5.98%**	4.29E+08	**10.77%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	3.58E+07	6.62E+06	5.35E+05	**1.22%**	9.57E+05	**2.17%**	3.51E+04	**0.08%**
		Initial Study	3.58E+07	6.62E+06	1.88E+05	**0.43%**	3.78E+05	**0.86%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	8.06E+08	1.07E+09	2.33E+08	**9.78%**	2.77E+08	**11.61%**	1.97E+05	**0.01%**
		Initial Study	8.06E+08	1.07E+09	8.48E+07	**3.56%**	1.65E+08	**6.90%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment N1:Q	CC (kg CO2 eq)	New Electrification	2.65E+09	1.55E+09	1.14E+08	**2.54%**	1.67E+08	**3.72%**	4.29E+06	**0.10%**
		Initial Study	2.65E+09	1.55E+09	4.24E+07	**0.95%**	8.81E+07	**1.96%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	2.62E+07	5.27E+06	1.35E+06	**3.85%**	2.24E+06	**6.38%**	2.38E+04	**0.07%**
		Initial Study	2.62E+07	5.27E+06	3.96E+05	**1.13%**	7.95E+05	**2.27%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	7.75E+05	6.47E+05	4.05E+05	**17.41%**	4.99E+05	**21.45%**	4.11E+02	**0.02%**
		Initial Study	7.75E+05	6.47E+05	1.16E+05	**4.97%**	2.20E+05	**9.45%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	1.11E+09	9.05E+08	8.29E+08	**21.18%**	1.08E+09	**27.45%**	5.44E+05	**0.01%**
		Initial Study	1.11E+09	9.05E+08	2.28E+08	**5.81%**	4.29E+08	**10.96%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	3.03E+07	6.02E+06	6.05E+05	**1.59%**	1.09E+06	**2.86%**	4.13E+04	**0.11%**
		Initial Study	3.03E+07	6.02E+06	1.84E+05	**0.48%**	3.73E+05	**0.98%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	7.23E+08	1.01E+09	2.61E+08	**11.32%**	3.11E+08	**13.51%**	2.32E+05	**0.01%**
		Initial Study	7.23E+08	1.01E+09	8.22E+07	**3.57%**	1.67E+08	**7.24%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment H1:P	CC (kg CO2 eq)	New Electrification	5.64E+09	3.13E+09	1.46E+08	**1.59%**	2.28E+08	**2.49%**	4.90E+06	**0.05%**
		Initial Study	5.64E+09	3.13E+09	7.09E+07	**0.77%**	1.50E+08	**1.64%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	5.58E+07	1.01E+07	1.77E+06	**2.51%**	2.98E+06	**4.22%**	2.72E+04	**0.04%**
		Initial Study	5.58E+07	1.01E+07	6.84E+05	**0.97%**	1.31E+06	**1.85%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	1.61E+06	1.23E+06	5.42E+05	**13.38%**	6.67E+05	**16.45%**	4.70E+02	**0.01%**
		Initial Study	1.61E+06	1.23E+06	2.01E+05	**4.96%**	3.57E+05	**8.82%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	2.30E+09	1.71E+09	1.12E+09	**17.04%**	1.43E+09	**21.80%**	6.22E+05	**0.01%**
		Initial Study	2.30E+09	1.71E+09	3.97E+08	**6.05%**	6.93E+08	**10.57%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	6.42E+07	1.14E+07	7.76E+05	**1.00%**	1.46E+06	**1.88%**	4.73E+04	**0.06%**
		Initial Study	6.42E+07	1.14E+07	3.08E+05	**0.40%**	6.16E+05	**0.79%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	1.41E+09	1.79E+09	3.54E+08	**8.92%**	4.13E+08	**10.43%**	2.66E+05	**0.01%**
		Initial Study	1.41E+09	1.79E+09	1.40E+08	**3.53%**	2.63E+08	**6.65%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment BS1:P	CC (kg CO2 eq)	New Electrification	2.22E+09	1.23E+09	6.61E+07	**1.83%**	9.88E+07	**2.73%**	2.15E+06	**0.06%**
		Initial Study	2.22E+09	1.23E+09	2.84E+07	**0.79%**	6.02E+07	**1.67%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	2.18E+07	3.98E+06	7.86E+05	**2.82%**	1.30E+06	**4.64%**	1.19E+04	**0.04%**
		Initial Study	2.18E+07	3.98E+06	2.73E+05	**0.98%**	5.26E+05	**1.88%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	6.37E+05	4.87E+05	2.36E+05	**14.33%**	2.90E+05	**17.58%**	2.06E+02	**0.01%**
		Initial Study	6.37E+05	4.87E+05	8.02E+04	**4.86%**	1.44E+05	**8.71%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	9.09E+08	6.76E+08	4.84E+08	**17.97%**	6.22E+08	**23.12%**	2.73E+05	**0.01%**
		Initial Study	9.09E+08	6.76E+08	1.58E+08	**5.89%**	2.79E+08	**10.36%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	2.51E+07	4.49E+06	3.53E+05	**1.15%**	6.35E+05	**2.07%**	2.08E+04	**0.07%**
		Initial Study	2.51E+07	4.49E+06	1.23E+05	**0.40%**	2.47E+05	**0.81%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	5.58E+08	7.13E+08	1.52E+08	**9.47%**	1.80E+08	**11.23%**	1.17E+05	**0.01%**
		Initial Study	5.58E+08	7.13E+08	5.60E+07	**3.49%**	1.06E+08	**6.63%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment ST3:R	CC (kg CO2 eq)	New Electrification	9.12E+08	5.64E+08	5.01E+07	**3.13%**	7.03E+07	**4.40%**	2.20E+06	**0.14%**
		Initial Study	9.12E+08	5.64E+08	2.02E+07	**1.26%**	4.06E+07	**2.54%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	8.84E+06	2.10E+06	5.98E+05	**4.77%**	9.80E+05	**7.82%**	1.22E+04	**0.10%**
		Initial Study	8.84E+06	2.10E+06	1.81E+05	**1.45%**	3.81E+05	**3.04%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	2.79E+05	2.59E+05	1.81E+05	**19.24%**	2.22E+05	**23.58%**	2.10E+02	**0.02%**
		Initial Study	2.79E+05	2.59E+05	5.23E+04	**5.56%**	1.07E+05	**11.35%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	3.94E+08	3.66E+08	3.72E+08	**23.05%**	4.80E+08	**29.78%**	2.79E+05	**0.02%**
		Initial Study	3.94E+08	3.66E+08	1.03E+08	**6.36%**	2.10E+08	**13.00%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	1.04E+07	2.45E+06	2.66E+05	**1.96%**	4.70E+05	**3.46%**	2.12E+04	**0.16%**
		Initial Study	1.04E+07	2.45E+06	8.71E+04	**0.64%**	1.78E+05	**1.31%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	2.97E+08	4.43E+08	1.17E+08	**11.76%**	1.40E+08	**14.04%**	1.19E+05	**0.01%**
		Initial Study	2.97E+08	4.43E+08	3.81E+07	**3.82%**	8.32E+07	**8.34%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment ST5:U	CC (kg CO2 eq)	New Electrification	1.03E+09	5.88E+08	4.81E+07	**2.77%**	6.79E+07	**3.92%**	2.07E+06	**0.12%**
		Initial Study	1.03E+09	5.88E+08	1.99E+07	**1.15%**	4.04E+07	**2.33%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	9.44E+06	2.16E+06	5.70E+05	**4.34%**	9.38E+05	**7.15%**	1.15E+04	**0.09%**
		Initial Study	9.44E+06	2.16E+06	1.79E+05	**1.37%**	3.77E+05	**2.87%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	3.18E+05	2.64E+05	1.72E+05	**17.80%**	2.11E+05	**21.86%**	1.98E+02	**0.02%**
		Initial Study	3.18E+05	2.64E+05	5.18E+04	**5.38%**	1.05E+05	**10.93%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	4.47E+08	3.72E+08	3.52E+08	**21.64%**	4.56E+08	**28.03%**	2.62E+05	**0.02%**
		Initial Study	4.47E+08	3.72E+08	1.02E+08	**6.25%**	2.07E+08	**12.71%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	1.10E+07	2.51E+06	2.54E+05	**1.78%**	4.52E+05	**3.17%**	1.99E+04	**0.14%**
		Initial Study	1.10E+07	2.51E+06	8.58E+04	**0.60%**	1.76E+05	**1.23%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	3.32E+08	4.44E+08	1.11E+08	**10.90%**	1.33E+08	**13.03%**	1.12E+05	**0.01%**
		Initial Study	3.32E+08	4.44E+08	3.77E+07	**3.69%**	8.19E+07	**8.03%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment GO1:S	CC (kg CO2 eq)	New Electrification	1.09E+09	6.73E+08	5.42E+07	**2.87%**	7.69E+07	**4.07%**	2.28E+06	**0.12%**
		Initial Study	1.09E+09	6.73E+08	2.23E+07	**1.18%**	4.50E+07	**2.38%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	1.08E+07	2.43E+06	6.42E+05	**4.30%**	1.06E+06	**7.07%**	1.26E+04	**0.08%**
		Initial Study	1.08E+07	2.43E+06	2.02E+05	**1.35%**	4.17E+05	**2.79%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	3.22E+05	3.00E+05	1.93E+05	**18.36%**	2.38E+05	**22.55%**	2.18E+02	**0.02%**
		Initial Study	3.22E+05	3.00E+05	5.84E+04	**5.55%**	1.17E+05	**11.07%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	4.58E+08	4.22E+08	3.97E+08	**22.15%**	5.14E+08	**28.68%**	2.89E+05	**0.02%**
		Initial Study	4.58E+08	4.22E+08	1.15E+08	**6.41%**	2.29E+08	**12.77%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	1.26E+07	2.82E+06	2.87E+05	**1.76%**	5.10E+05	**3.14%**	2.20E+04	**0.14%**
		Initial Study	1.26E+07	2.82E+06	9.61E+04	**0.59%**	1.95E+05	**1.20%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	3.31E+08	4.98E+08	1.25E+08	**11.34%**	1.49E+08	**13.54%**	1.23E+05	**0.01%**
		Initial Study	3.31E+08	4.98E+08	4.23E+07	**3.83%**	9.02E+07	**8.17%**	0.00E+00	**0.00%**

			Environmental impact assessment (with share of railway electrification)							
			Alignment's Construction	Alignment's Maintenance	Construction - electrification		Maintenance - electrification		Disposal - electrification	
Alignment GO3:Q	CC (kg CO2 eq)	New Electrification	9.94E+08	6.11E+08	5.08E+07	**2.94%**	7.20E+07	**4.16%**	2.19E+06	**0.13%**
		Initial Study	9.94E+08	6.11E+08	2.11E+07	**1.21%**	4.25E+07	**2.45%**	0.00E+00	**0.00%**
	TA (kg SO2 eq)	New Electrification	9.69E+06	2.25E+06	5.90E+05	**4.36%**	9.84E+05	**7.27%**	1.22E+04	**0.09%**
		Initial Study	9.69E+06	2.25E+06	1.90E+05	**1.40%**	3.96E+05	**2.92%**	0.00E+00	**0.00%**
	FE (kg P eq)	New Electrification	3.00E+05	2.76E+05	1.76E+05	**18.12%**	2.18E+05	**22.43%**	2.10E+02	**0.02%**
		Initial Study	3.00E+05	2.76E+05	5.48E+04	**5.65%**	1.11E+05	**11.44%**	0.00E+00	**0.00%**
	HT (kg 1,4-DB eq)	New Electrification	4.24E+08	3.90E+08	3.60E+08	**21.88%**	4.71E+08	**28.63%**	2.78E+05	**0.02%**
		Initial Study	4.24E+08	3.90E+08	1.08E+08	**6.54%**	2.18E+08	**13.23%**	0.00E+00	**0.00%**
	POF (kg NMVOC)	New Electrification	1.13E+07	2.61E+06	2.66E+05	**1.80%**	4.77E+05	**3.24%**	2.12E+04	**0.14%**
		Initial Study	1.13E+07	2.61E+06	9.09E+04	**0.62%**	1.85E+05	**1.26%**	0.00E+00	**0.00%**
	MD (kg Fe eq)	New Electrification	3.16E+08	4.66E+08	1.14E+08	**11.00%**	1.37E+08	**13.25%**	1.19E+05	**0.01%**
		Initial Study	3.16E+08	4.66E+08	3.99E+07	**3.86%**	8.62E+07	**8.35%**	0.00E+00	**0.00%**

In addition to the tables of corridor planning, there are some corridors that have shown different variation in the design-speeds in table 4.1. Here, some of important ones are describes more in detail.

Alignment Ø2:P	Total Length (km)	Tunnel section (km)	Open section (open section + bridge section) (km)
Gardermoen - Vallset (330 km/h)	48.032	21.734	26.298
Vallset - Elverum Parkway (330 km/h)	187.523	54.55	132.973
Elverum Parkway - Tynset (330 km/h)	87.173	34.155	53.018
Tynset - Trondheim/Lerkendal (330 km/h)	59.796	39.907	19.889
Trondheim/Lerkendal - Værnes (250 km/h)	26.962	20.886	6.076
Total	**409.486**	**171.232**	**238.254**

Alignment G3:Y	Total Length (km)	Tunnel section (km)	Open section (open section + bridge section) (km)
Gardermoen - Tangen (330 km/h)	19.16	3.554	15.606
Vallset - Elverum Parkway (330 km/h)	341.63	206.81	134.82
Elverum Parkway - Tynset (330 km/h)	59.397	39.907	19.49
Trondheim/Lerkendal - Værnes (250 km/h)	27.361	20.886	6.475
Total	**447.548**	**271.157**	**176.391**

Alignment N1:Q	Total Length (km)	Tunnel section (km)	Open section (open section + bridge section) (km)
Bergen - voss (250 km/h)	72	46.2	25.8
Voss - Geilo (250 km/h)	100.4	72.2	47.00
Geilo - Veggli (330 km/h)	86.5	53.4	74.8
Veggli - Kongsberg (330 km/h)	48.1	11.7	45.00
Kongesberg - Drammen (330 km/h)	32.1	3.1	29.00
Total	**339.1**	**186.6**	**152.5**

Alignment ST3:R	Total Length (km)	Tunnel section (km)	Open section (open section + bridge section) (km)
Lillestrøm - Arvika (330 km/h)	129.45	28.23	101.22
Arvika - Edane (250 km/h)	26.93	11.66	15.27
Edane - Fagerås (250 km/h)	23.86	0.00	23.858
Total	**180.24**	**39.884**	**140.35**

Alignment ST5:U	Total Length (km)	Tunnel section (km)	Open section (open section + bridge section) (km)
Ski - Askim station (250 km/h)	25.33	1.11	24.218
Askim - Arvika (330 km/h)	96.62	31.35	65.268
Arvika - Fagerås (250 km/h)	51.29	11.67	39.621
Total	**173.231**	**44.124**	**129.107**

Alignment GO1:S	Total Length (km)	Tunnel section (km)	Open section (open section + bridge section) (km)
Ski - Sarpdborg (330 km/h)	54.72	18.51	36.205
Sarsborg - Ed (330 km/h)	62.66	30.94	31.725
Ed - Öxnered (250 km/h)	77.16	6.49	70.671
Total	**194.539**	**55.938**	**138.601**

Appendix I

Sensitivity analysis

Here, all the results of sensitivity analysis in section 5.3 are provided to bring a better understanding of relative bar charts in the corresponding section. In addition to the results of system of design-speed Re330, the results of the same sensitivities are provided for system of design-speed S25 The order of all tables are following the same sequence of section 5.3.

Copper

Increase in amount of copper in overhead contact system

- System Re330

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.30E+05	3.31E+05	3.31E+05	3.33E+05	3.82E+05	3.82E+05	3.83E+05	3.84E+05
TA (kg SO2 eq)	4.43E+03	4.46E+03	4.49E+03	4.55E+03	4.62E+03	4.65E+03	4.68E+03	4.74E+03
FE (kg P eq)	1.14E+03	1.15E+03	1.16E+03	1.19E+03	1.15E+03	1.16E+03	1.17E+03	1.20E+03
HT (kg 1,4-DB eq)	2.42E+06	2.44E+06	2.47E+06	2.52E+06	2.40E+06	2.42E+06	2.45E+06	2.50E+06
POF (kg NMVOC)	2.08E+03	2.09E+03	2.10E+03	2.11E+03	2.26E+03	2.27E+03	2.27E+03	2.29E+03
MD (kg Fe eq)	7.34E+05	7.42E+05	7.50E+05	7.65E+05	7.14E+05	7.22E+05	7.30E+05	7.45E+05

- System S25

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.25E+05	3.26E+05	3.26E+05	3.27E+05	3.70E+05	3.70E+05	3.71E+05	3.72E+05
TA (kg SO2 eq)	4.22E+03	4.24E+03	4.27E+03	4.31E+03	4.43E+03	4.45E+03	4.47E+03	4.52E+03
FE (kg P eq)	1.05E+03	1.06E+03	1.07E+03	1.09E+03	1.08E+03	1.09E+03	1.10E+03	1.12E+03
HT (kg 1,4-DB eq)	2.23E+06	2.26E+06	2.28E+06	2.32E+06	2.25E+06	2.27E+06	2.30E+06	2.34E+06
POF (kg NMVOC)	2.02E+03	2.03E+03	2.03E+03	2.05E+03	2.17E+03	2.18E+03	2.19E+03	2.20E+03
MD (kg Fe eq)	6.78E+05	6.84E+05	6.90E+05	7.03E+05	6.65E+05	6.71E+05	6.77E+05	6.89E+05

Copper increase in entire HSR electrification system

- System Re330

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.30E+05	3.32E+05	3.34E+05	3.38E+05	3.82E+05	3.84E+05	3.86E+05	3.89E+05
TA (kg SO2 eq)	4.43E+03	4.54E+03	4.65E+03	4.87E+03	4.62E+03	4.73E+03	4.84E+03	5.06E+03
FE (kg P eq)	1.14E+03	1.19E+03	1.23E+03	1.32E+03	1.15E+03	1.20E+03	1.24E+03	1.33E+03
HT (kg 1,4-DB eq)	2.42E+06	2.52E+06	2.61E+06	2.80E+06	2.40E+06	2.50E+06	2.59E+06	2.78E+06
POF (kg NMVOC)	2.08E+03	2.11E+03	2.14E+03	2.20E+03	2.26E+03	2.29E+03	2.32E+03	2.38E+03
MD (kg Fe eq)	7.34E+05	7.63E+05	7.89E+05	8.45E+05	7.14E+05	7.43E+05	7.69E+05	8.24E+05

- System S25

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.25E+05	3.27E+05	3.29E+05	3.33E+05	3.70E+05	3.72E+05	3.74E+05	3.77E+05
TA (kg SO2 eq)	4.22E+03	4.32E+03	4.42E+03	4.62E+03	4.43E+03	4.53E+03	4.63E+03	4.83E+03
FE (kg P eq)	1.05E+03	1.10E+03	1.14E+03	1.22E+03	1.08E+03	1.12E+03	1.16E+03	1.24E+03
HT (kg 1,4-DB eq)	2.23E+06	2.33E+06	2.41E+06	2.59E+06	2.25E+06	2.35E+06	2.43E+06	2.61E+06
POF (kg NMVOC)	2.02E+03	2.05E+03	2.07E+03	2.13E+03	2.17E+03	2.20E+03	2.23E+03	2.28E+03
MD (kg Fe eq)	6.78E+05	7.04E+05	7.28E+05	7.78E+05	6.65E+05	6.92E+05	7.16E+05	7.66E+05

Changing the share of primary and secondary copper

- System Re330

Category	O.S				T.S			
	Base	40% decrease	70% decrease	100% decrease	Base	40% decrease	70% decrease	100% decrease
CC (kg CO2 eq)	3.30E+05	3.30E+05	3.30E+05	3.30E+05	3.82E+05	3.82E+05	3.81E+05	3.81E+05
TA (kg SO2 eq)	4.43E+03	4.37E+03	4.32E+03	4.27E+03	4.62E+03	4.56E+03	4.51E+03	4.47E+03
FE (kg P eq)	1.14E+03	1.10E+03	1.07E+03	1.04E+03	1.15E+03	1.11E+03	1.08E+03	1.06E+03
HT (kg 1,4-DB eq)	2.42E+06	2.35E+06	2.30E+06	2.25E+06	2.40E+06	2.33E+06	2.28E+06	2.23E+06
POF (kg NMVOC)	2.08E+03	2.05E+03	2.03E+03	2.01E+03	2.26E+03	2.23E+03	2.21E+03	2.19E+03
MD (kg Fe eq)	7.34E+05	6.62E+05	6.08E+05	5.54E+05	7.14E+05	6.43E+05	5.90E+05	5.37E+05

- System S25

Category	O.S				T.S			
	Base	40% decrease	70% decrease	100% decrease	Base	40% decrease	70% decrease	100% decrease
CC (kg CO2 eq)	3.25E+05	3.25E+05	3.25E+05	3.25E+05	3.70E+05	3.70E+05	3.70E+05	3.70E+05
TA (kg SO2 eq)	4.22E+03	4.16E+03	4.12E+03	4.08E+03	4.43E+03	4.37E+03	4.33E+03	4.28E+03
FE (kg P eq)	1.05E+03	1.02E+03	9.94E+02	9.68E+02	1.08E+03	1.04E+03	1.02E+03	9.93E+02
HT (kg 1,4-DB eq)	2.23E+06	2.17E+06	2.13E+06	2.08E+06	2.25E+06	2.19E+06	2.15E+06	2.10E+06
POF (kg NMVOC)	2.02E+03	1.99E+03	1.97E+03	1.96E+03	2.17E+03	2.15E+03	2.13E+03	2.11E+03
MD (kg Fe eq)	6.78E+05	6.13E+05	5.64E+05	5.16E+05	6.65E+05	6.00E+05	5.51E+05	5.02E+05

Diesel

Elevation of diesel consumption

- System Re330

Category	O.S				T.S			
	Base	10% increase	20% increase	30% increase	Base	10% increase	20% increase	30% increase
CC (kg CO2 eq)	3.30E+05	3.35E+05	3.40E+05	3.46E+05	3.82E+05	3.87E+05	3.93E+05	4.02E+05
TA (kg SO2 eq)	4.43E+03	4.45E+03	4.49E+03	4.53E+03	4.62E+03	4.65E+03	4.69E+03	4.75E+03
FE (kg P eq)	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.15E+03	1.15E+03	1.15E+03	1.15E+03
HT (kg 1,4-DB eq)	2.42E+06	2.42E+06	2.42E+06	2.42E+06	2.40E+06	2.40E+06	2.40E+06	2.40E+06
POF (kg NMVOC)	2.08E+03	2.12E+03	2.17E+03	2.24E+03	2.26E+03	2.31E+03	2.38E+03	2.46E+03
MD (kg Fe eq)	7.34E+05	7.34E+05	7.34E+05	7.34E+05	7.14E+05	7.14E+05	7.14E+05	7.14E+05

- System S25

Category	O.S				T.S			
	Base	10% increase	20% increase	30% increase	Base	10% increase	20% increase	30% increase
CC (kg CO2 eq)	3.25E+05	3.30E+05	3.35E+05	3.41E+05	3.70E+05	3.75E+05	3.81E+05	3.90E+05
TA (kg SO2 eq)	4.22E+03	4.24E+03	4.28E+03	4.32E+03	4.43E+03	4.46E+03	4.50E+03	4.55E+03
FE (kg P eq)	1.05E+03	1.05E+03	1.05E+03	1.05E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03
HT (kg 1,4-DB eq)	2.23E+06	2.23E+06	2.23E+06	2.24E+06	2.25E+06	2.25E+06	2.25E+06	2.25E+06
POF (kg NMVOC)	2.02E+03	2.06E+03	2.11E+03	2.18E+03	2.17E+03	2.23E+03	2.29E+03	2.38E+03
MD (kg Fe eq)	6.78E+05	6.78E+05	6.78E+05	6.78E+05	6.65E+05	6.65E+05	6.65E+05	6.65E+05

Reduction of diesel consumption

- System Re330

Category	O.S				T.S			
	Base	10% decrease	20% decrease	30% decrease	Base	10% decrease	20% decrease	30% decrease
CC (kg CO2 eq)	3.30E+05	3.27E+05	3.24E+05	3.22E+05	3.82E+05	3.77E+05	3.74E+05	3.71E+05
TA (kg SO2 eq)	4.43E+03	4.41E+03	4.39E+03	4.37E+03	4.62E+03	4.59E+03	4.57E+03	4.55E+03
FE (kg P eq)	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.15E+03	1.15E+03	1.15E+03	1.15E+03
HT (kg 1,4-DB eq)	2.42E+06	2.42E+06	2.42E+06	2.42E+06	2.40E+06	2.40E+06	2.40E+06	2.40E+06
POF (kg NMVOC)	2.08E+03	2.04E+03	2.02E+03	1.99E+03	2.26E+03	2.21E+03	2.18E+03	2.15E+03
MD (kg Fe eq)	7.34E+05	7.34E+05	7.34E+05	7.34E+05	7.14E+05	7.14E+05	7.14E+05	7.14E+05

- System S25

Category	O.S				T.S			
	Base	10% decrease	20% decrease	30% decrease	Base	10% decrease	20% decrease	30% decrease
CC (kg CO2 eq)	3.25E+05	3.22E+05	3.19E+05	3.17E+05	3.70E+05	3.66E+05	3.62E+05	3.59E+05
TA (kg SO2 eq)	4.22E+03	4.20E+03	4.18E+03	4.16E+03	4.43E+03	4.40E+03	4.38E+03	4.36E+03
FE (kg P eq)	1.05E+03	1.05E+03	1.05E+03	1.05E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03
HT (kg 1,4-DB eq)	2.23E+06	2.23E+06	2.23E+06	2.23E+06	2.25E+06	2.25E+06	2.25E+06	2.25E+06
POF (kg NMVOC)	2.02E+03	1.98E+03	1.95E+03	1.93E+03	2.17E+03	2.13E+03	2.09E+03	2.06E+03
MD (kg Fe eq)	6.78E+05	6.78E+05	6.78E+05	6.78E+05	6.65E+05	6.65E+05	6.65E+05	6.65E+05

Aluminium

Aluminium (cable) increase

- System Re330

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.30E+05	3.33E+05	3.36E+05	3.43E+05	3.82E+05	3.86E+05	3.91E+05	4.01E+05
TA (kg SO2 eq)	4.43E+03	4.44E+03	4.45E+03	4.48E+03	4.62E+03	4.64E+03	4.66E+03	4.70E+03
FE (kg P eq)	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.15E+03	1.15E+03	1.15E+03	1.16E+03
HT (kg 1,4-DB eq)	2.42E+06	2.42E+06	2.42E+06	2.42E+06	2.40E+06	2.40E+06	2.40E+06	2.41E+06
POF (kg NMVOC)	2.08E+03	2.09E+03	2.09E+03	2.11E+03	2.26E+03	2.27E+03	2.28E+03	2.31E+03
MD (kg Fe eq)	7.34E+05	7.34E+05	7.34E+05	7.34E+05	7.14E+05	7.14E+05	7.15E+05	7.15E+05

- System S25

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.25E+05	3.28E+05	3.31E+05	3.38E+05	3.70E+05	3.74E+05	3.79E+05	3.90E+05
TA (kg SO2 eq)	4.22E+03	4.23E+03	4.24E+03	4.27E+03	4.43E+03	4.44E+03	4.46E+03	4.51E+03
FE (kg P eq)	1.05E+03	1.05E+03	1.06E+03	1.06E+03	1.08E+03	1.08E+03	1.08E+03	1.09E+03
HT (kg 1,4-DB eq)	2.23E+06	2.24E+06	2.24E+06	2.24E+06	2.25E+06	2.26E+06	2.26E+06	2.26E+06
POF (kg NMVOC)	2.02E+03	2.02E+03	2.03E+03	2.05E+03	2.17E+03	2.18E+03	2.20E+03	2.22E+03
MD (kg Fe eq)	6.78E+05	6.78E+05	6.78E+05	6.79E+05	6.65E+05	6.65E+05	6.66E+05	6.66E+05

Changing the share of primary and secondary aluminium

- System Re330

Category	O.S				T.S			
	Base	40% decrease	70% decrease	100% decrease	Base	40% decrease	70% decrease	100% decrease
CC (kg CO2 eq)	3.30E+05	3.12E+05	2.98E+05	2.83E+05	3.82E+05	3.46E+05	3.20E+05	2.93E+05
TA (kg SO2 eq)	4.43E+03	4.35E+03	4.29E+03	4.24E+03	4.62E+03	4.48E+03	4.37E+03	4.26E+03
FE (kg P eq)	1.14E+03	1.13E+03	1.13E+03	1.12E+03	1.15E+03	1.13E+03	1.12E+03	1.11E+03
HT (kg 1,4-DB eq)	2.42E+06	2.41E+06	2.41E+06	2.40E+06	2.40E+06	2.39E+06	2.38E+06	2.37E+06
POF (kg NMVOC)	2.08E+03	2.03E+03	2.00E+03	1.96E+03	2.26E+03	2.17E+03	2.10E+03	2.04E+03
MD (kg Fe eq)	7.34E+05	7.33E+05	7.33E+05	7.33E+05	7.14E+05	7.14E+05	7.13E+05	7.13E+05

- System S25

Category	O.S				T.S			
	Base	40% decrease	70% decrease	100% decrease	Base	40% decrease	70% decrease	100% decrease
CC (kg CO2 eq)	3.25E+05	3.07E+05	2.93E+05	2.79E+05	3.70E+05	3.34E+05	3.08E+05	2.81E+05
TA (kg SO2 eq)	4.22E+03	4.14E+03	4.08E+03	4.03E+03	4.43E+03	4.28E+03	4.17E+03	4.07E+03
FE (kg P eq)	1.05E+03	1.05E+03	1.04E+03	1.03E+03	1.08E+03	1.06E+03	1.05E+03	1.04E+03
HT (kg 1,4-DB eq)	2.23E+06	2.23E+06	2.22E+06	2.22E+06	2.25E+06	2.24E+06	2.23E+06	2.22E+06
POF (kg NMVOC)	2.02E+03	1.97E+03	1.94E+03	1.90E+03	2.17E+03	2.08E+03	2.02E+03	1.95E+03
MD (kg Fe eq)	6.78E+05	6.78E+05	6.77E+05	6.77E+05	6.65E+05	6.65E+05	6.64E+05	6.64E+05

Steel (low-alloyed)

Steel (low-alloyed) increase

- System Re330

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.30E+05	3.32E+05	3.35E+05	3.40E+05	3.82E+05	3.84E+05	3.86E+05	3.92E+05

TA (kg SO2 eq)	4.43E+03	4.44E+03	4.44E+03	4.46E+03	4.62E+03	4.63E+03	4.64E+03	4.66E+03
FE (kg P eq)	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.15E+03	1.15E+03	1.15E+03	1.15E+03
HT (kg 1,4-DB eq)	2.42E+06	2.42E+06	2.42E+06	2.42E+06	2.40E+06	2.40E+06	2.40E+06	2.41E+06
POF (kg NMVOC)	2.08E+03	2.09E+03	2.10E+03	2.12E+03	2.26E+03	2.27E+03	2.27E+03	2.29E+03
MD (kg Fe eq)	7.34E+05	7.37E+05	7.40E+05	7.49E+05	7.14E+05	7.17E+05	7.21E+05	7.30E+05

- System S25

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.25E+05	3.27E+05	3.30E+05	3.35E+05	3.70E+05	3.72E+05	3.74E+05	3.80E+05
TA (kg SO2 eq)	4.22E+03	4.22E+03	4.23E+03	4.25E+03	4.43E+03	4.43E+03	4.44E+03	4.46E+03
FE (kg P eq)	1.05E+03	1.05E+03	1.06E+03	1.06E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03
HT (kg 1,4-DB eq)	2.23E+06	2.24E+06	2.24E+06	2.24E+06	2.25E+06	2.26E+06	2.26E+06	2.26E+06
POF (kg NMVOC)	2.02E+03	2.03E+03	2.03E+03	2.05E+03	2.17E+03	2.18E+03	2.19E+03	2.21E+03
MD (kg Fe eq)	6.78E+05	6.81E+05	6.85E+05	6.93E+05	6.65E+05	6.68E+05	6.72E+05	6.81E+05

UPS (batteries)

Increase in the amount of UPS

- System Re330

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.30E+05	3.33E+05	3.37E+05	3.45E+05	3.82E+05	3.85E+05	3.88E+05	3.96E+05
TA (kg SO2 eq)	4.43E+03	4.48E+03	4.54E+03	4.69E+03	4.62E+03	4.67E+03	4.74E+03	4.88E+03
FE (kg P eq)	1.14E+03	1.14E+03	1.14E+03	1.15E+03	1.15E+03	1.15E+03	1.15E+03	1.16E+03
HT (kg 1,4-DB eq)	2.42E+06	2.43E+06	2.44E+06	2.46E+06	2.40E+06	2.41E+06	2.42E+06	2.45E+06
POF (kg NMVOC)	2.08E+03	2.10E+03	2.12E+03	2.17E+03	2.26E+03	2.28E+03	2.30E+03	2.35E+03
MD (kg Fe eq)	7.34E+05	7.35E+05	7.36E+05	7.39E+05	7.14E+05	7.15E+05	7.17E+05	7.20E+05

- System S25

Category	O.S				T.S			
	Base	5% increase	10% increase	20% increase	Base	5% increase	10% increase	20% increase
CC (kg CO2 eq)	3.25E+05	3.28E+05	3.32E+05	3.40E+05	3.70E+05	3.73E+05	3.76E+05	3.84E+05
TA (kg SO2 eq)	4.22E+03	4.27E+03	4.33E+03	4.48E+03	4.43E+03	4.48E+03	4.54E+03	4.68E+03
FE (kg P eq)	1.05E+03	1.06E+03	1.06E+03	1.07E+03	1.08E+03	1.08E+03	1.08E+03	1.09E+03
HT (kg 1,4-DB eq)	2.23E+06	2.24E+06	2.26E+06	2.28E+06	2.25E+06	2.26E+06	2.27E+06	2.30E+06
POF (kg NMVOC)	2.02E+03	2.04E+03	2.06E+03	2.11E+03	2.17E+03	2.19E+03	2.21E+03	2.26E+03
MD (kg Fe eq)	6.78E+05	6.79E+05	6.80E+05	6.83E+05	6.65E+05	6.66E+05	6.68E+05	6.71E+05

Reduction of UPS

- System Re330

Category	O.S				T.S			
	Base	5% decrease	10% decrease	20% decrease	Base	5% decrease	10% decrease	20% decrease
CC (kg CO2 eq)	3.30E+05	3.28E+05	3.25E+05	3.19E+05	3.82E+05	3.79E+05	3.76E+05	3.70E+05
TA (kg SO2 eq)	4.43E+03	4.38E+03	4.32E+03	4.22E+03	4.62E+03	4.57E+03	4.52E+03	4.41E+03
FE (kg P eq)	1.14E+03	1.14E+03	1.13E+03	1.13E+03	1.15E+03	1.15E+03	1.14E+03	1.14E+03

HT (kg 1,4-DB eq)	2.42E+06	2.41E+06	2.40E+06	2.38E+06	2.40E+06	2.39E+06	2.38E+06	2.36E+06
POF (kg NMVOC)	2.08E+03	2.06E+03	2.04E+03	2.01E+03	2.26E+03	2.24E+03	2.22E+03	2.19E+03
MD (kg Fe eq)	7.34E+05	7.33E+05	7.32E+05	7.29E+05	7.14E+05	7.13E+05	7.12E+05	7.10E+05

- System S25

Category	O.S				T.S			
	Base	5% decrease	10% decrease	20% decrease	Base	5% decrease	10% decrease	20% decrease
CC (kg CO2 eq)	3.25E+05	3.23E+05	3.20E+05	3.14E+05	3.70E+05	3.67E+05	3.64E+05	3.58E+05
TA (kg SO2 eq)	4.22E+03	4.17E+03	4.11E+03	4.01E+03	4.43E+03	4.38E+03	4.32E+03	4.22E+03
FE (kg P eq)	1.05E+03	1.05E+03	1.05E+03	1.04E+03	1.08E+03	1.08E+03	1.07E+03	1.07E+03
HT (kg 1,4-DB eq)	2.23E+06	2.23E+06	2.22E+06	2.20E+06	2.25E+06	2.24E+06	2.23E+06	2.22E+06
POF (kg NMVOC)	2.02E+03	2.00E+03	1.98E+03	1.95E+03	2.17E+03	2.16E+03	2.14E+03	2.10E+03
MD (kg Fe eq)	6.78E+05	6.77E+05	6.76E+05	6.74E+05	6.65E+05	6.64E+05	6.63E+05	6.61E+05

Changing the share of primary and secondary lead

- System Re330

Category	O.S		T.S	
	Base	100% reduction of primary lead	Base	100% reduction of primary lead
CC (kg CO2 eq)	3.30E+05	3.16E+05	3.82E+05	3.67E+05
TA (kg SO2 eq)	4.43E+03	4.10E+03	4.62E+03	4.29E+03
FE (kg P eq)	1.14E+03	1.11E+03	1.15E+03	1.12E+03
HT (kg 1,4-DB eq)	2.42E+06	2.25E+06	2.40E+06	2.23E+06
POF (kg NMVOC)	2.08E+03	1.95E+03	2.26E+03	2.13E+03
MD (kg Fe eq)	7.34E+05	7.14E+05	7.14E+05	6.95E+05

- System S25

Category	O.S		T.S	
	Base	100% reduction of primary lead	Base	100% reduction of primary lead
CC (kg CO2 eq)	3.25E+05	3.11E+05	3.70E+05	3.55E+05
TA (kg SO2 eq)	4.22E+03	3.89E+03	4.43E+03	4.09E+03
FE (kg P eq)	1.05E+03	1.02E+03	1.08E+03	1.05E+03
HT (kg 1,4-DB eq)	2.23E+06	2.06E+06	2.25E+06	2.08E+06
POF (kg NMVOC)	2.02E+03	1.89E+03	2.17E+03	2.05E+03
MD (kg Fe eq)	6.78E+05	6.58E+05	6.65E+05	6.46E+05