RAILWAY TRACK AND TRACKBED LIFE CYCLE ASSESSMENT

AG2800 Life Cycle Assessment

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Group 12

Group Members:

Tove Gram tgram@kth.se

Wenjing Wei wenjingw@kth.se

Omnia Bakhiet omnia@kth.se

Mengyin Hu mengyin@kth.se

Project Supervisor:

Carolina Liljenström

Course Examiner:

Anna Björklund

ABSTRACT

The stretch of railway track between Skutskär and Furuvik has recently been built with a double track to increase the transport of people and goods. The project is a part of the extension and refurbishment of Ostkustbanan and this study is investigating the environmental impacts from cradle to grave of this extended part of the railway path. This study has estimated the environmental impacts of construction of railway track along the stretch by using the LCA tool and by modelling the life cycle in the software SimaPro7. The result of this LCA shows that the maintenance stage has the highest environmental impact during the entire life cycle span of the railway system (i.e. railway track and railway track foundation). The ballast used in the ground foundation has more impact than the production of rail and track. The operation of the tracks were beyond the scope of this report, as well as the electricity wires and noise cancelling walls which are parameters that would raise the total environmental impacts. This is left for further studies to reveal. The values brought up in this LCA report will be of interest for stakeholders involved in transportation planning, such as municipalities and Trafikverket.

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1.INTRODUCTION

Sweden's railway network is made up of roughly 16 500 km or railway which speaks for Sweden's dependence on this mode of transportation. A general understanding is that travelling or transporting goods by railway is an environmental friendly option, especially in Sweden where most of the railways run on electricity (Trafikverket, 2016c).

In the case of transportation systems, environmental impacts are usually analyzed with focus on the transportations operations themselves and not the other phases such as construction or maintenance of the railways. Understanding the system as a whole will contribute to the efforts made in today's work towards sustainability. As previously mentioned, most trains in Sweden run on electricity and are therefore considered a sustainable option for transportation. Nonetheless, studies have shown that the main sources of environmental impacts from railway systems come from the construction of railways (Liljenström & Le Bourhis, 2012). Construction of railways will contribute to emission of pollution to the surrounding environment among other environmental impacts. The construction phase of railways is therefore chosen as the focus point of this study. The report is the result of a study where a Life Cycle Assessment is conducted on the double-track stretch between Skutskär and Furuvik in Sweden.

Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle (UNEP, u.d.). An LCA consists of four stages where firstly the goal and scope are defined, which is followed by an inventory analysis. Then the impacts are assessed and are lastly interpreted (ISO, 2006). LCA can be used for different purposes such as finding ways to improve environmental operations. It can also be used in decision-making processes for organizations such as governments and industries. Furthermore, LCA can be used as a marketing tool such as for eco-labelling purposes. In this report the general structure of an LCA is followed in order to obtain results on the environmental impacts of the double track railway construction of the Skutskär-Furuvik stretch.

1.1 LITERATURE REVIEW

This section presents studies of similar nature to the problem presented in this report. The literature review is conducted in order to give insight on how similar studies have been conducted and what conclusions have been reached.

- Bothnia Line

The Bothnia Line is a single-track railway found in Northern Sweden. The line stretches from Ångermanälven to Umeå. Throughout the construction of the Bothnia Line, environmental aspects have been collected and analyzed. This has given insight on the overall picture of railway systems and their infrastructure. The study conducted on the Bothnia Line included all aspects from the construction of the railway system to the traffic on the railway. The Life Cycle Assessment tool was used to study the construction and operation of the Bothnian line in order to provide a holistic view. The study found that greenhouse gas emissions resulted mainly from the material used in the infrastructure, as well as construction and deforestation. In the case of the Bothnia Line, electric power from green sources is used and therefore the operation phase of the trains on the railway have a small contribution to the emissions of greenhouse gases (Stripple & Uppenberg, 2010).

- Citybanan

Citybanan in Stockholm is an infrastructure project which includes a new tunnel for commuter trains. Citybanan aims to improve the commuter traffic in the city of Stockholm as the city's population is steadily increasing. Citybanan also aims to reduce greenhouse gas emissions due to more people using commuter trains rather than personal cars. However, this assumption does not include environmental impacts such as the construction of the railway, as well as its operation and maintenance (Liljenström & Le Bourhis, 2012). Through modelling in the software SimaPro, a study conducted in 2012 found that the projects highest contribution to environmental impacts arise in the construction phase. More specifically, in order to improve and make the construction of Citybanan more environmentally friendly, from a life cycle point of view, focus should be put on manufacturing of steel (Liljenström & Le Bourhis, 2012).

- Klimatkalkyl

Klimatkalkyl is a model developed by the Swedish Transport Administration. The model is used in order to calculate the energy consumption and environmental impacts caused by infrastructure projects. The model uses the life cycle perspective and provides data on all phases of a project's life cycle (Trafikverket, 2016d). Klimatkalkyl pilot projects were carried out in 2014/2015 which included both roads and railways at costs rising about 50 million SEK. The model was applied at different phases of the different projects (Trafikverket, u.d.). The work presented in this report used data from the Swedish Transport Administration's Klimatkalkyl and information from the models was used to carry out calculation applied on the railway stretch Skutskär–Furuvik.

- Skutskär-Furuvik

In this study, an LCA is conducted for the specific railway track in the north of the Stockholm area. The studied stretch runs between Skutskär and Furuvik and is a part of Ostkustbanan. The new stretch is built to increase the capacity at Oskustbanan and according to Trafikverket it shall contribute to a sustainable development of society in terms of ecological, social and economic aspects (Trafikverket, 2016b). The rail tracks of the stretch are designed to make a shortcut between the endpoints compared to the old railway track that goes between Skutskär and Furuvik. The new railway track is a double track with a distance of 4859 meter and it was finished and open for rail traffic in July 2016. The track was constructed to handle trains with a speed of maximum 250 km/h. It is expected that by 2020 approximately 147 trains will pass the track daily (Järnvägsplan, 2013).

2. GOAL OF THE STUDY

The goal of this LCA is to identify the environmental impacts of Swedish railway for the stretch between Skutskär and Furuvik, which is part of Ostkustbanan. The impact assessment will be conducted through raw material extraction, material processing, production of components, construction of railway track, maintenance and waste management. The LCA has an attributional approach and the study results are aiming to contribute to the ongoing discussion about construction of railway infrastructure in Sweden. The information is of interest for the authorities such as Trafikverket that are in charge of planning, decision making and constructing railway tracks in Sweden, to identify potential opportunities for improving the Swedish railway track construction. By gaining knowledge of the environmental burdens connected to the different life cycle steps, the authorities such as Trafikverket can make better decisions while planning for new railway stretches.

The project is a stand-alone LCA and it will outline which processes and components in the life cycle of railway that has the most severe environmental impacts. By finding the hotspots for the environmental impacts suggestions for alternative solution can be made and thereby reduce the burdens on the environment. The result can also be of interest for future comparative studies within the field of railway research.

2.1 AIM

The aim of this report is to assess the environmental impacts of Swedish railway stretch between Skutskär and Furuvik by using the LCA tool to identify the most significant impacts from the life cycle of the railway and the processes and materials that may contribute the most to the environmental burdens. The project will help stakeholders to understand the environmental burden of railway track construction and can be useful for further studies were, for example, the environmental burden of different transporations will be compared which can aid decision making processes in the future.

3. SCOPE OF THE STUDY

3.1 FUNCTIONAL UNIT

In this study, the function of the railway is to increase the capacity of transporting persons and freight between between Skutskär and Furuvik in the way that a double tracked railway will replace the original single track. The functional unit will be defined according to the selected Swedish railway construction project which is the recently constructed railway track between Skutskär and Furuvik. The project is a part of Ostkustbanan and the specific stretch that the project considered is located north of the Stockholm area of Sweden. The railway track will be extended in order to increase the rail transportation of people and goods along the stretch. The functional unit of this project is 4859 meters of double track railway, since that is the length of the newly build railway track between Skutskär and Furuvik.

3.2 METHOD

In this project the following methods have been used:

Literature review

The project of constructing the double railway track between Skutskär and Furuvik will be investigated and provide the information needed to set up the base of the LCA and create the functional unit (Trafikverket, 2016b). Further, information from a previous LCA study of the rail construction of the Bothnian line railway track has been investigated and has been used as a base for some assumptions of our project (Stripple & Uppenberg, 2010). Another important source used for estimating accurate numbers and calculations were provided on the webpage Klimatkalkyl which is a part of the Trafikverket website (Klimatkalkyl, 2016).

Modelling

For modeling the LCA the software SimaPro 7 was used. SimaPro is a tool developed by the PRé Sustainability which is a Dutch company with over 25 years of experience in life cycle thinking (PRé Sustainability, n.d.).

3.3 IMPACT CATEGORIES AND IMPACT ASSESSMENT METHOD

There are many different impact assessment methods developed in SimaPro. In this study, the method ReCiPeTHe LCA method ReCiPe Midpoint (Hierarchist) is selected for the assessment. It means in total 18 impact categories will be assessed at the midpoint level. The impact categories considered in the model are:

1. Climate change
2. Ozone depletion
3. Terrestrial acidification
4. Freshwater eutrophication
5. Marine eutrophication

6. Human toxicity
7. Photochemical oxidant formation
8. Particulate matter formation
9. Terrestrial ecotoxicity
10. Freshwater ecotoxicity
11. Marine ecotoxicity
12. Ionising radiation
13. Agricultural land occupation
14. Urban land occupation
15. Natural land transformation
16. Water depletion
17. Metal depletion
18. Fossil depletion

Normalization is performed in the study in order to relate the result of the impacts to the total environmental impact in an area. In this way, the total contribution of the product can be determined. As normalization could facilitate comparison in LCA, thus it is conducted in this study.

3.4 DISCRIPTION OF OSTKUSTBANAN BETWEEN SKUTSKÄR AND FURUVIK

The railway track stretch that is extended into a double track is shown in figure 1. In 2009 there was the average of 94 trains passing between Skutskär and Furuvik every day. Trafikverket have estimated that 147 trains will pass the stretch daily in year 2020. The stretch of the double track is 4859 meter and the track is able to handle trains with a speed up to 250 km/h. The distance between the two double tracks is 4,5 meter, see figure X. The railway stretch is mainly crossing forest land, however also bridges and next to buildings. The width of the foundation bank crest varies between 12 and 22 meters. The railway passes in total 10 bridges along the stretch, 6 of them pass over existing roads, 3 over rivers and one passes over a walking path in Björnbo, as shown in figure 2. The center of the railway tracks must be placed at least 20 meters from high vegetation, therefore forest felling was necessary (Järnvägsplan, 2013).

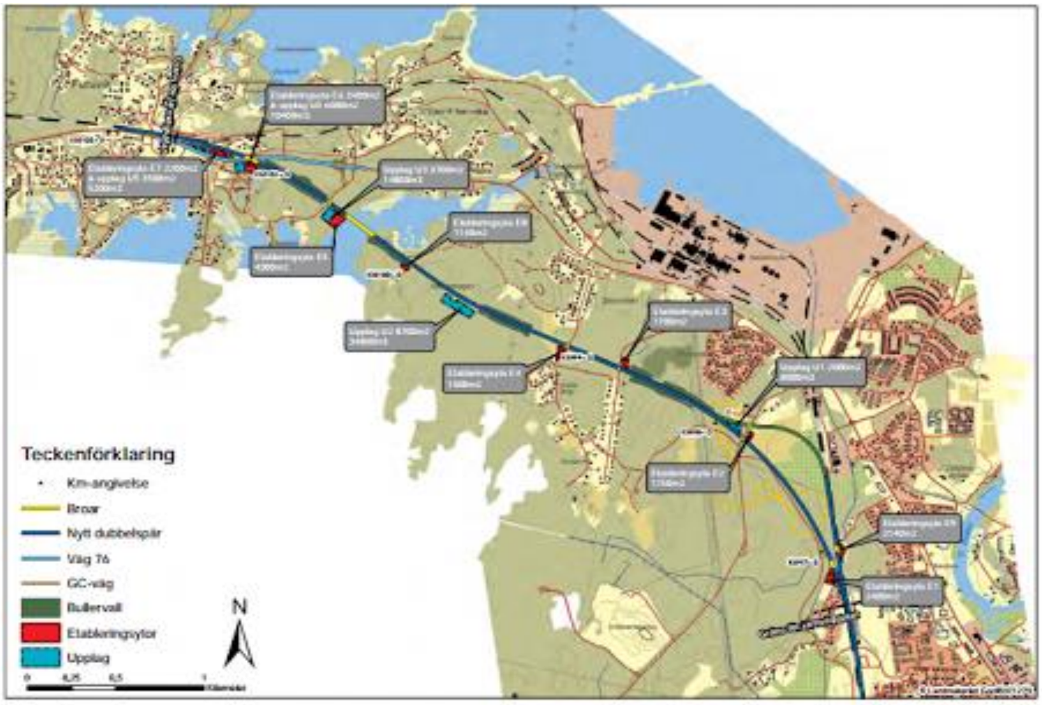
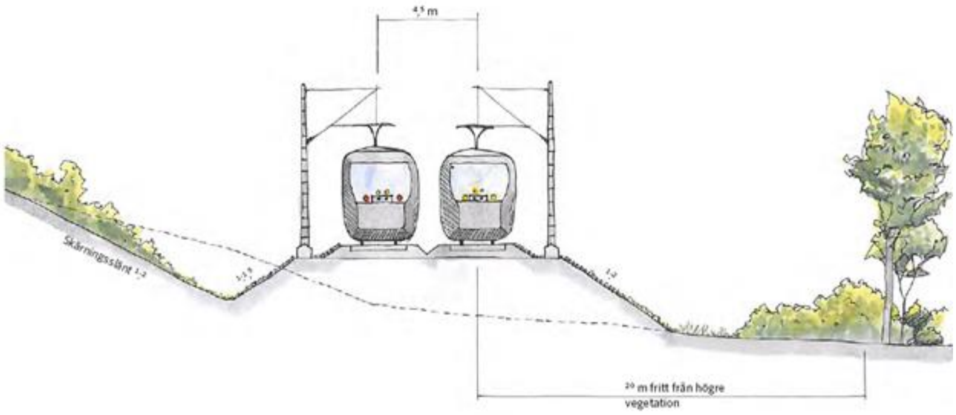


Figure 1 ***The stretch of the railway track between Skutskär and Furuvik, indicated in dark blue line.***



Figur 2.9.6 Vid passage av skogsmark görs bankar och skärningsslänt med en lutning på 1:2. Detta för att spara så mycket befintlig vegetation som möjligt. Beklädnad av slänter i skogsmark görs generellt upp till 2 m under RÖK (Rälsöverkant) med avbaningsmassor från motsvarande omgivande vegetation.

Figure 2 ***Side-cut of the double railway track between Skutskär and Furuvik.***

The stretch is mostly passing through forest area. The ground along the stretch for the double track consists mainly of moraine. The embankment of the route is about 2,5 meters, and slopes on each side of the track are constructed to protect the track from erosion. Vertical columns are used in the ground foundation to make the construction stable and withstand high pressures (Järnvägsplan, 2013).

3.5 SYSTEM BOUNDARIES

This assessment work is an attributional and cradle to grave study of the railway system, which in this study refers to the railtrack and ground foundation of the path between Skutskär and Furuvik. The electric wiring and noise cancelling walls is outside the system boundaries of this report due to time limitations of the project. The environmental impacts from the trains passing on the railway and operation of the track are also beyond the scope of this study; however, the maintenance of the rail track during the use phase of the lifetime is included. The cradle part starts with extraction of the materials used for production of components used for the functional unit of this project, and the grave concerns waste management of the materials.

The geographical boundaries of the project is set to the average data found for production of components in Europe and the electricity produced in Sweden were found in the SimaPro and at the website of Trafikverket. The geographical boundary of maintenance is taking place at the railway track between Skutskär and Furuvik. The recycling and incineration/landfill is also taking place in Sweden.

The time horizon of the project is stretching from the first production of materials about 7 years ago, in 2010, then the lifetime is 50 years, that means that the end of life occur 2066, then about two years is estimated to be the time of recycling/incineration/landfill, i.e. in 2068.

The system boundary is depicted in Figure 3, it shows the different steps that the impact estimations will cover following through the life cycle from cradle to grave. The foreground system includes the construction part, maintenance and waste treatment. In the background system raw material extraction, transportation, processing, production of components are included.

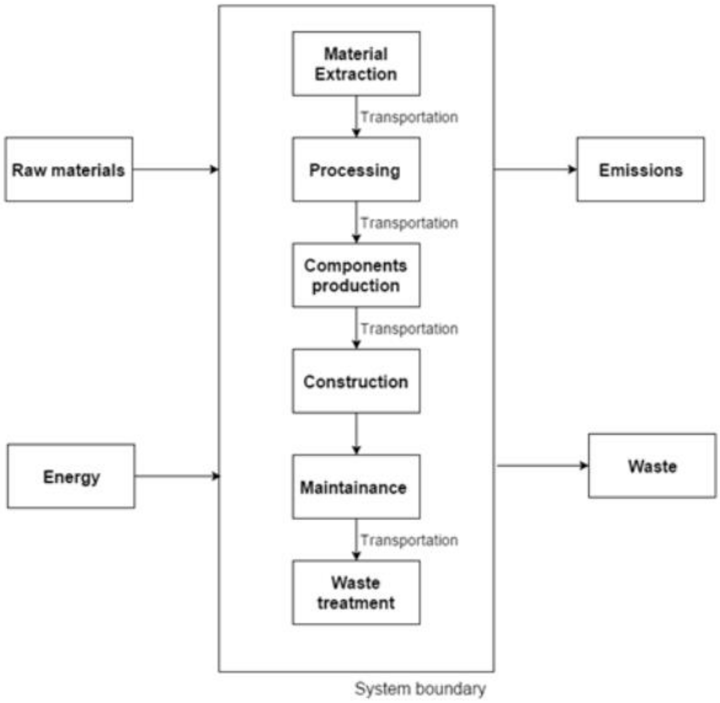


Figure 3 ***Simple process flow chart of railway construction system***

It has been necessary to use allocations in our study to be able to evaluate the different parts of the life cycle in a sufficient way and structure the model. The allocation will be described more in detail in Chapter 4 inventory part.

The main cut-off criteria in this study are considered the data availability for the railway system and for the stretch between Skutskär and Furuvik. The materials that are not documented are not included in the assessment, neither the processes that are not directly related to construction of railway. The cut-off consideration is also references from other similar study, hence only main processes and components of the railway system are considered.

3.6 ASSUMPTIONS AND LIMITATIONS

As previously mentioned this project will only consider the railway track and the ground foundation of the railway track. It would be of great interest to also investigate all the part included in the construction of railway construction; however, this project was conducted under a limited amount of time and resources and therefore the study was reduced to focus only on the railway track and foundation. Further assumptions of this project are;

- The components of the railway track, and the track foundation are produced in Germany or other European countries since there are numbers available for this in SimaPro.
- Lifetime of railway track is normally between 40-60 years. This study use 50 years as the life span of impact estimation for the railway track system. All activities from construction start to the following 50 years are included in the calculations.
- The railway track between Skutskär and Furuvik has several bridges along the path. In this study, only railway track and track foundation will be considered in the system, thus it is

estimated that the ground foundation and railway track are the same over the whole stretch between Skutskär and Furuvik, this is assumed because of the time limitations of the project.

- The energy use of traveling will not be included in the report since the project only concern the construction of the railway track and foundation, and not the impact by traveling on the track.
- The system is not including construction of noise and vibration structure, train operation and control system, service road, and protection fences.
- The whole LCA study is excluding the operation phase.

4. LIFE CYCLE INVENTORY ANALYSIS

4.1 PROCESS FLOW CHART

As described in previous part, this life cycle study is including following five stages: raw material extraction, material processing, transportation of materials to construction site, construction of railway system, maintenance and waste treatment. Figure 4-1 is illustrating a detailed process flow chart for the investigated Swedish railway system.

- *Extraction of raw materials*: Extraction of, for example iron ore, limestone, ballast, and additional materials.
- *Material processing*: E.g. production of gravel, steel, concrete, aggregates, supplementary materials, chemical admixture, neoprene and nylon.
- *Components production*: Production of sleepers, rail, fasteners and ballast foundation.
- *Construction of railway track*: Several steps will be divided in this process. Firstly deforesting, remove biomass; secondly excavation work such as remove soil and conduct rock cut; thirdly stabilizing ground by filling blast stone; lastly install different technical products such as track bed or track foundation, rails and sleepers.
- *Maintenance:* Several components e.g. gravel, sleeper, fasteners, rails may require maintenance according to their service life. In this project an average amount of maintenance is estimated and for this the material and energy input will be calculated.
- *Waste management*: Some materials such as steel, concrete, ballast materials will be considered as recyclable in other systems, while other unrecyclable materials will be disposed as waste.

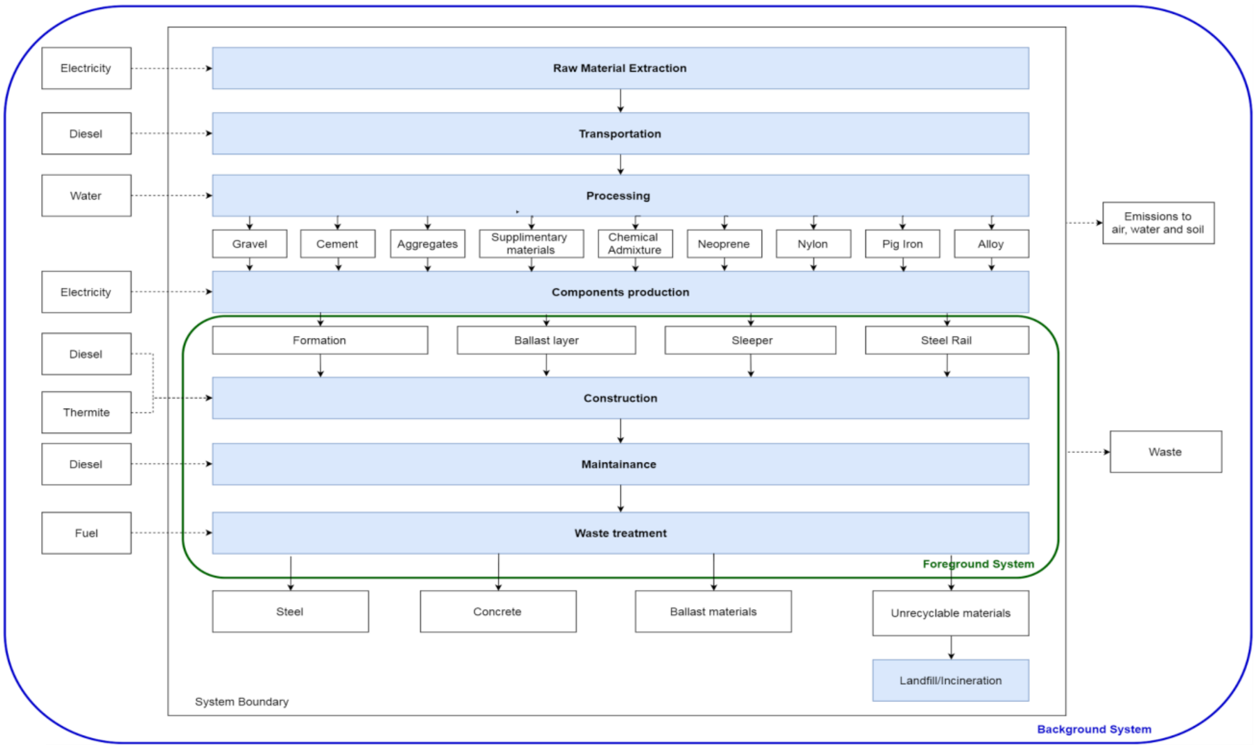


Figure 4 ***Detailed flowchart of Swedish double track railway system***

Detailed flow chart is shown in figure 4. Within the system boundary the foreground system involves mainly stages of construction, maintenance and waste treatment. These three stages will have direct influences on the construction of railway system. For instance, volumes of soil excavation and forest felling, filling volumes of ballast and soil, diesel use during construction phase and maintenance, as well as material recycling, will all be considered as primary data and can obtained by direct measurement. Due to limitation of data access, some primary data like diesel use during construction phase and maintenance, material use for ground stabilization etc. are referring to the relevant data in the LCA project of Bothnia line, as well as the database Klimatkalkyl, which has been described during the literature review part. Since the LCA project of Bothnia line is an environment product declaration (EPD), the inventory data is relatively transparent. As Bothnia line is a single track railway system, hence the inventory data that are referenced from Bothnia report is double in order to fits the study of double track. This assessment of the study can contribute to investigating the impacts of Swedish double track railway system in some extent by using external data as primary data. If more direct measurement data can be applied during assessment, it will no doubt improve the data certainty and result accuracy.

On the other hand, the background system is referring to the stages of raw material extraction and material processing and waste management. In this case, secondary data will be such as extraction of iron ore, limestone and oil, production of steel, lime and diesel etc. These secondary data is collected directly from the database Ecoinvent in SimaPro.

4.2 DATA

The railway system can be basically divided into two parts, rail track and track foundation. In this section the inventory data will be present separately.

4.2.1 CONSTRUCTION OF RAIL TRACK

Rail track is also termed as permanent way which directly supports the running of trains. Following components such as rails, sleepers and superstructure ballast have been considered for rail track part, as shown in figure 5

Rail track is normally consisting two steel rails. For double track railway it will be four rails in total. Rails are fixed and supported above sleepers.

Sleepers is functioning partly to hold the rails to the correct distance, meanwhile they are able to transfer the loads of rails to the ballast layer in the foundation part. The distance between sleepers is around 650mm to 760 mm and they can use either steel or concrete materials (Railway technical web page). Concrete sleepers have been selected in this study. Other than concrete material, reinforcement steel, fastener materials such as E-clips (steel), steel blocks, neoprene (polychloroprene) pads, nylon isolator have also been taking into consideration in the modelling.

Superstructure ballast is distributed along the whole rails. It is typically referring to crushed stone or rock which is used to support sleepers and disperse burden from railway, as well as drains out water.

Energy consumption during construction of rail track includes diesel use for mechanical work such as excavating ballast, transportation of materials and application of laying track, as well as electricity for general use such as lighting and heating.

Figure 5 ***Rail track system***

The inventory data for rail track can be described in Table 4.1. Detailed assumption regarding construction of rail track can be found in the Appendix A.

Table 1 Inventory table for construction rail track

Input material	SimaPro	Amount	Comments(Stripple & Uppenberg, 2010) (Trafikverket Klimatkalkyl)	Reference
	1 Rail (4 pieces and each piece is 4859 m long)			
Steel	Steel, low-alloyed {RER}|steel production, conveter	1 173 934 kg	60.4 kg/meter	Bothnia line (Stripple & Uppenberg, 2010)
Transport	Transport, freight train{Europe without Switzerland} diesel	3 873 984 tkm	Transport distance is 3300 km	
Sleeper (Distance between sleepers is 0.6m and 16199 sleepers in total for double track)				
Reinforcement steel	Reinforcing steel{RER}|production|Alloc Def, S	84233 kg	6.2 kg per sleeper	Bothnia line (Stripple & Uppenberg, 2010)
Concrete	Concrete block {DE}|Production|Alloc Def, S	38877 kg	250 kg per sleeper	Bothnia line (Stripple & Uppenberg, 2010)
Steel blocks for attachment	Reinforcing steel{RER}|production|Alloc Def, S	2981 kg	5.2 kg per sleeper	Bothnia line (Stripple & Uppenberg, 2010)

E-clips	Reinforcing steel{RER}|production|Alloc Def, S	4487 kg	2.4 kg per sleeper	Bothnia line (Stripple & Uppenberg, 2010)
Neoprene pad	Synthetic rubber{ RoW} production |Alloc Def, S	4 049 667 kg	0.277 kg per sleeper	Bothnia line (Stripple & Uppenberg, 2010)
Nylon 66	Nylon 6-6 {RoW} |Production|Alloc Def. S	98 812 kg	0.184 kg per sleeper	Bothnia line (Stripple & Uppenberg, 2010)
Transport	Transport, freight train{Europe without Switzerland} diesel	8 986 018 tkm	Transport distance is 2100 km	Trafikverket Klimatkalkyl
Superstructure ballast				
Crushed gravel	Gravel, crushed{Glo}market for|Alloc Def, S	270 000 ton	Gravel volume 150000 m3, density 1.8 ton/m3	Trafikverket Klimatkalkyl
Diesel	Diesel, burned in building machine{Glo}|processing|Alloc Def, S	950 000 MJ	The diesel is used for excavator. Diesel use 0.19 L/m3 gravel. Diesel energy conversion is 0.03 liter/MJ.	Trafikverket Klimatkalkyl
Diesel	Diesel, burned in building	4 779 000 MJ	For transport gravel to site. Average distance	Trafikverket Klimatkalkyl

	machine{Glo}|processing|Alloc Def, S		10 km, energy use 1.77 MJ/tkm	
Laying rail track				
Diesel	Diesel, burned in building machine{Glo}|processing|Alloc Def, S	1 137 006 MJ	117 MJ/m track	Trafikverket Klimatkalkyl

4.2.2 CONSTRUCTION OF TRACK FOUNDATION

Track foundation or track bed is usually constructed according to local geographical situation. In the Ostkustbanan (between Skutskär and Furuvik) project the railway mainly passes through forest area, so rock excavation is excluded from the study. Besides, several processes such as noise protection application, cable channel applications are also not included in this study. The processes related to construction of foundation are demonstrating as below:

- ***Forest felling***: According to the description of Ostkusbana, the railway mainly passes through forest area so it is necessary to deforest before construction of foundation. The trees contribute to reduce CO_2 in the atmosphere, deforestation will have negative influence on climate change, so biogenic CO_2 will be added in this process. In addition, wood will be considered as output in this process. It is possible to use these wood in other system, for example, sawing mill, heating etc.
- ***Soil clearing***: It involves clearing vegetation of local areas. In the Ostkusbana project, these vegetation will be used together with soil filling as filling substance. The same as forest felling, biogenic CO_2 will be added in this process due to cutting of vegetation.
- ***Soil excavation and removal***: In this step soil is excavated by excavator and removed by dumper. From the aspect of economic and environmental, the project will utilize materials from construction site as much as possible. The removed soil will be firstly displayed in temporary storage site, where marked as blue area in Figure 3.2. They will be recycled used in soil filling process. The extra soil is considered as recycled in other construction site, in other words, impact allocation is applied according to the soil. The main direct contributor to environment is the diesel use for operating excavator and dumper.
- ***Ground stabilisation***: A few methods can be used for ground stabilisation, for example concrete piles or cement/lime columns. In this study concrete method is used for stabilising ground.
- ***Soil filling:*** Recycle use the soil from excavation process. The main direct contributor to environment is the diesel use for operating excavator and dumper.
- ***Laying underground ballast***: The function of underground ballast is the similar as superstructure ballast which use crushed stone to bear the burden of railway system.

- ***Application of geotextiles***: Geotextile is a type of material that placed at the tension surface to strengthen the soil. Typical material for geotextile is polypropylene.

During construction period, electricity use for heating offices and other illumination of construction site is also included in the study.

The inventory data for track foundation can be described in Table 4-2. Detailed assumption regarding construction of foundation can be found in the Appendix A.

Table 2 Inventory table for construction rail track

Input	Output	Simapro	Amount	Comment	Reference
Forest felling input					
Diesel		Diesel, burned in building machine{Glo}|processing|Alloc Def, S	528388MJ	Land area 152 449 m2, Forest volume 250 m3sk/hectare, energy use 69.32 MJ/m3sk	Trafikverket Klimatkalkyl
	Felled wood		1543546kg	Wood density 405 kg/m3	(The wood database)
	Biogenic CO2		3212863kg	CO2 indicator 843 kg CO2/m3 fub	Trafikverket Klimatkalkyl
Soil clearing					
Diesel		Diesel, burned in building machine{Glo}|processing|Alloc Def, S	2 772 800 MJ	energy use 69.32 MJ/m3sk	Trafikverket Klimatkalkyl
Vegetation			9 080 000 kg	Vegetation area 40 000 m3	(Del-1-planbeskrivning)
	Biogenic CO2		7654 440 000 kg	CO2 indicator 843 kg CO2/m3 fub	Trafikverket Klimatkalkyl

Soil excavation					
Soil			348 000 000 kg	Soil volume, 290 000 m3, soil density 1200 kg/m3	Trafikverket Klimatkalkyl
Diesel		Diesel, burned in building machine{Glo}|processing|Alloc Def, S	2126860MJ	Fore excavator, diesel volume 0.19 L/m3	Trafikverket Klimatkalkyl
Diesel		Diesel, burned in building machine{Glo}|processing|Alloc Def, S	6380580MJ	For dumper, diesel volume 0.57 L/m3	Trafikverket Klimatkalkyl
Ground stabilisation					
Concrete		Concrete block {DE}|Production|Alloc Def, S	238 550 kg	Concrete volume 0.06 m3/m, concrete density 1.506 kg/m3	Trafikverket Klimatkalkyl
Reinforcement steel		Reinforcing steel{RER}|production|Alloc Def, S	16 632 kg	Steel 6.3 kg/meter	Trafikverket Klimatkalkyl
Diesel		Diesel, burned in building machine{Glo}|processing|Alloc Def, S	26 875 MJ	Energy use for pilling 10.18 MJ/meter	Trafikverket Klimatkalkyl
Soil filling					
Diesel		Diesel, burned in building machine{Glo}|processing|Alloc Def, S	1 026 760 MJ	Fore excavator, diesel volume 0.19 L/m3	Trafikverket Klimatkalkyl
Diesel		Diesel, burned in building machine{Glo}|processing|Alloc Def, S	3 080 280 MJ	For dumper, diesel volume 0.57 L/m3	Trafikverket Klimatkalkyl

Laying underground ballast					
Crushed gravel		Gravel, crushed{Glo}market for|Alloc Def, S	20 991 ton	Gravel volume 150000 m3, density 1.8 ton/m3	Trafikverket Klimatkalkyl
Diesel		Diesel, burned in building machine{Glo}|processing|Alloc Def, S	73 857 MJ	The diesel is used for excavator. Diesel use 0.19L/m3 gravel. Diesel energy conversion is 0.03 liter/MJ.	Trafikverket Klimatkalkyl
Diesel		Diesel, burned in building machine{Glo}|processing|Alloc Def, S	371 539 MJ	For transport gravel to site. Average distance 10 km, energy use 1.77 MJ/tkm	Trafikverket Klimatkalkyl
Application of geotextile					
Polypropylene		Polypropylene(PP) carbon content(dry matter)	7684 kg	Geotextile area 6082 m2/km, geotextile density 0.26kg/m2	(Del-1-planbeskrivning)(Trafikverket Klimatkalkyl) Bothnia line (Stripple & Uppenberg, 2010)
Illumination during construction					
Electricity		Electricity, medium voltage{SE}market for |Alloc Def, S	225944MJ	46,5MJ/m foundation	Bothnia line (Stripple & Uppenberg, 2010)

4.2.3 RAILWAY MAINTENANCE

Railway system requires regular maintenance. For instance, track needs milling to remain in a good condition. Besides, change of components may happen during maintenance. This depends on the service life of each component. Table 3 is showing an example of lifetime for different railway component. In this case, several materials and energy input will be required for maintenance phase. For simplication purpose, the LCA study is only considering energy use in track milling.

Table 3 Lifetime of railway component (Lee & Lee & Kim, 2008)

Component	Lifetime(year)
Rail	50
Ballast	20
Concrete sleeper	50
Fastening clip	25
Rubber Pad	25

The inventory data for maintenance is presented in Table 4. Detailed assumption regarding construction of rail track can be found in the Appendix A.

Table 4 Inventory table of railway maintenance

Input	Simapro	Amount	Comment	Reference
Diesel	Diesel, burned in building machine{Glo}|processing|Alloc Def, S	528388MJ	4.188MJ/m single track	Trafikverket Klimatkalkyl

4.2.4 WASTE MANAGEMENT

With proper waste treatment several railway materials can be reused. Ballast material and concrete material can be recycled and crushed for road construction. Reforeinacement steel and steel rails could be disassembled and collected as steel scrap. They can easily use in metallurgical melting process. The manufacturing process of concrete and primary steel are both energy and pollution intensive process. The recycling use of these waste materials would ease the environmental burden.

The waste treatment of railway system is presented in Table 5. Detailed assumption regarding construction of rail track can be found in the Appendix A.

Table 5 Inventory table of railway waste treatment

Waste materials	Amount	Waste Treatment
Steel	94230 kg	100% recycled in steelmaking process. Allocation criteria: System extension Avoided burden: production of primary steel material.
Concrete	238800 kg	100% recycled in road construction. Allocation criteria: System extension Avoided burden: manufacturing burden of crushed gravel.
Ballast	290991 ton	100% Dummy waste (zero environment impact)
Soil	190000 m3	Recycled use in other construction site. Allocation criteria: mass based Allocation:65% Avoided burden: energy use in excavating soil
Felled wood	1543546 kg	100% Dummy waste (zero environmental impact)
polypropylene	7684 kg	100% Dummy waste (zero environmental impact)
Nylon	2981 kg	100% Dummy waste (zero environmental impact)
Neoprene elastomer	4487 kg	100% Dummy waste (zero environmental impact)

5. LIFE CYCLE INTERPRETATION

5.1 GENERAL RESULTS

The network of the SimaPro model is presented in AppendixB. Figure 6 shows the normalization result of the life cycle of railway system. From the figure it can be clearly seen that the life cycle of railway system has the highest environmental burden on natural land transformation. It is likely due to that Skutskär-Furuvik line passes mainly the forest area that brings a big impact through deforestation process. It is also shown that waste scenario we assumed in this study has little positive impacts to decrease the burden though 100% recycling of steel and concrete.

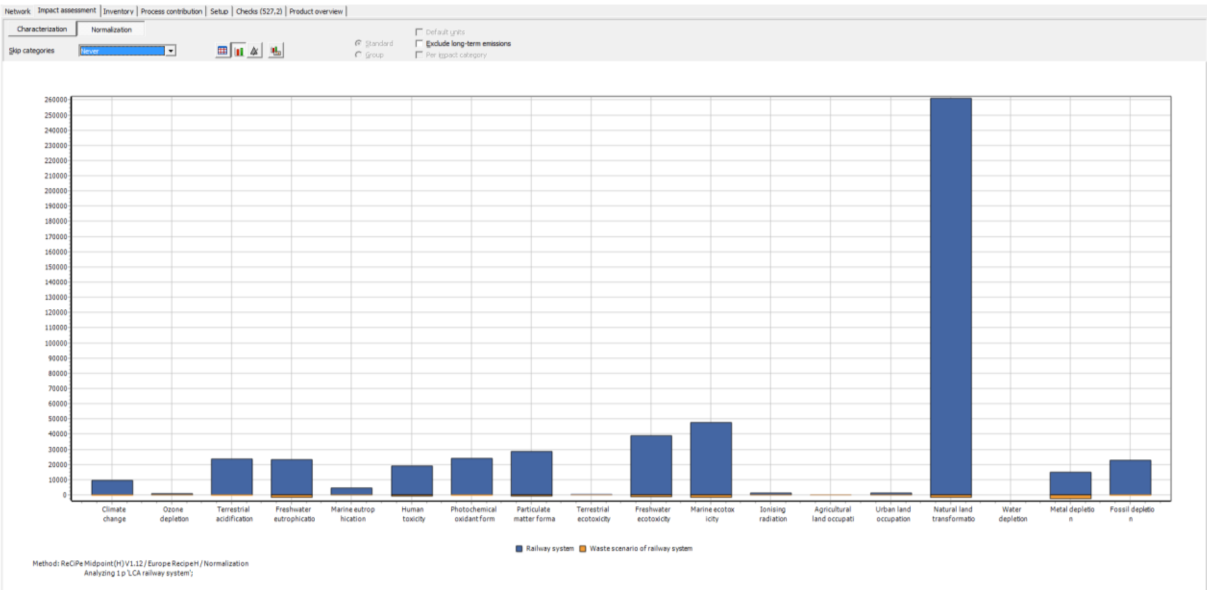


Figure 6 ***Life cycle impact assessment of railway system.***

Figure 7 shows the life cycle impact assessment of product stage of Skutskär-Furuvik stretch. Out of our expectation that maintenance phase contributes the most of the environmental loads. Then the construction and maintenance phases are compared in figure 8. The reason for the maintenance has high environmental burden is mainly due to the fuel consumption of the maintenance train for milling processes. In this project, maintenance is assumed to be done in every other year. If the frequencies could be reduced, the impact would also be lowered.

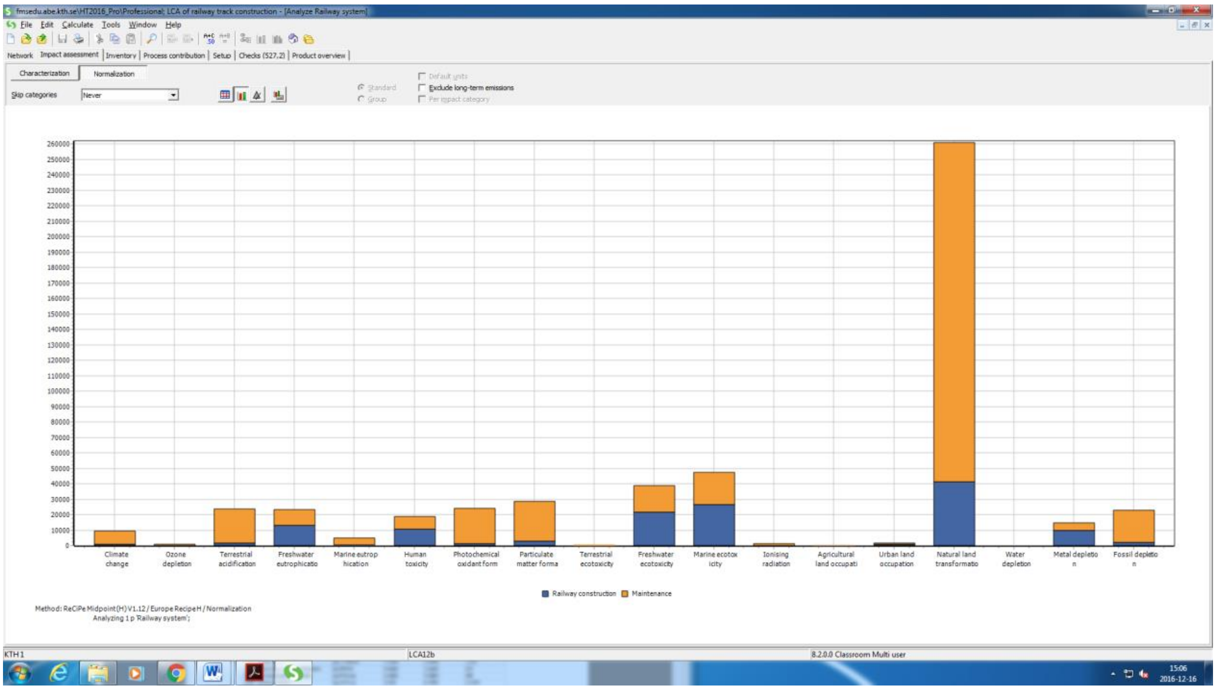


Figure 7 ***Normalization result of product stage of railway system***

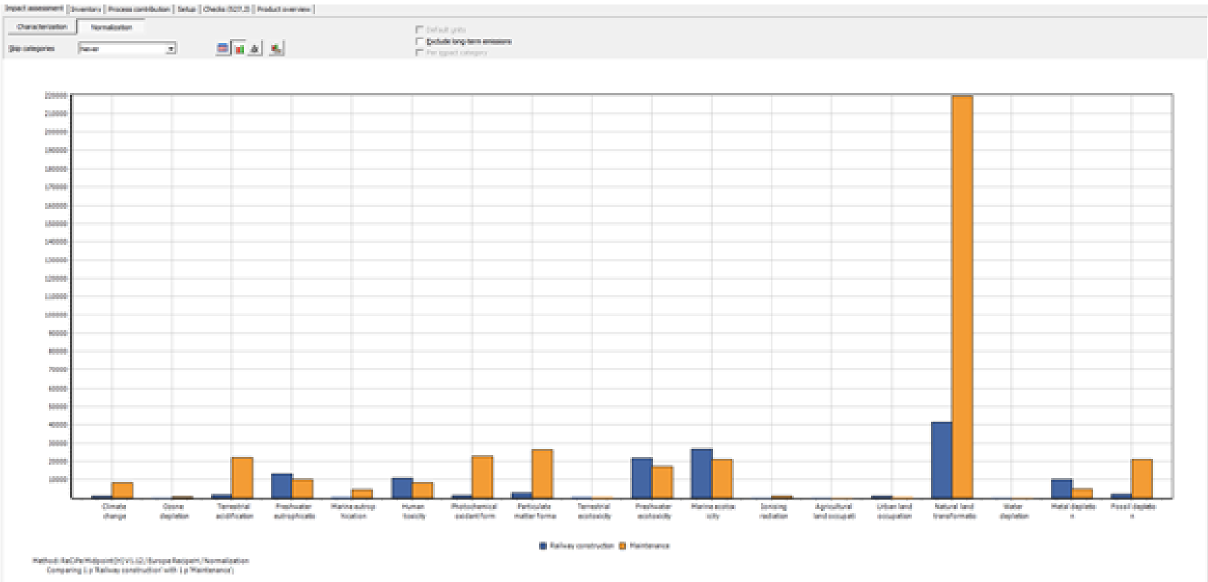


Figure 8 ***Comparison between construction and maintenance***

However, as the focus of the project is to understand which sub-system of the railway has the main impacts, the impact assessment of railway construction stage is conducted. From the figure 9 it is seen that railway track has the dominant contribution to the construction of railway. As the picture shown in figure.10, natural land transformation, marine ecotoxicity and freshwater excotoxicity are the highest environmental impacts of the railway construction stage.

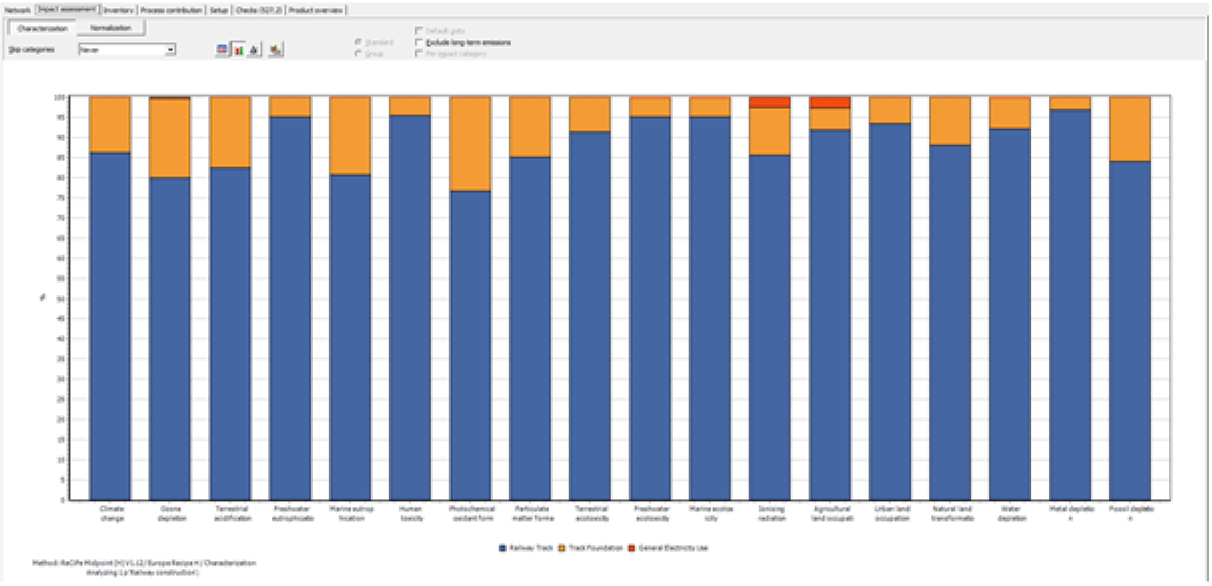


Figure 9 ***Characterization of railway construction***

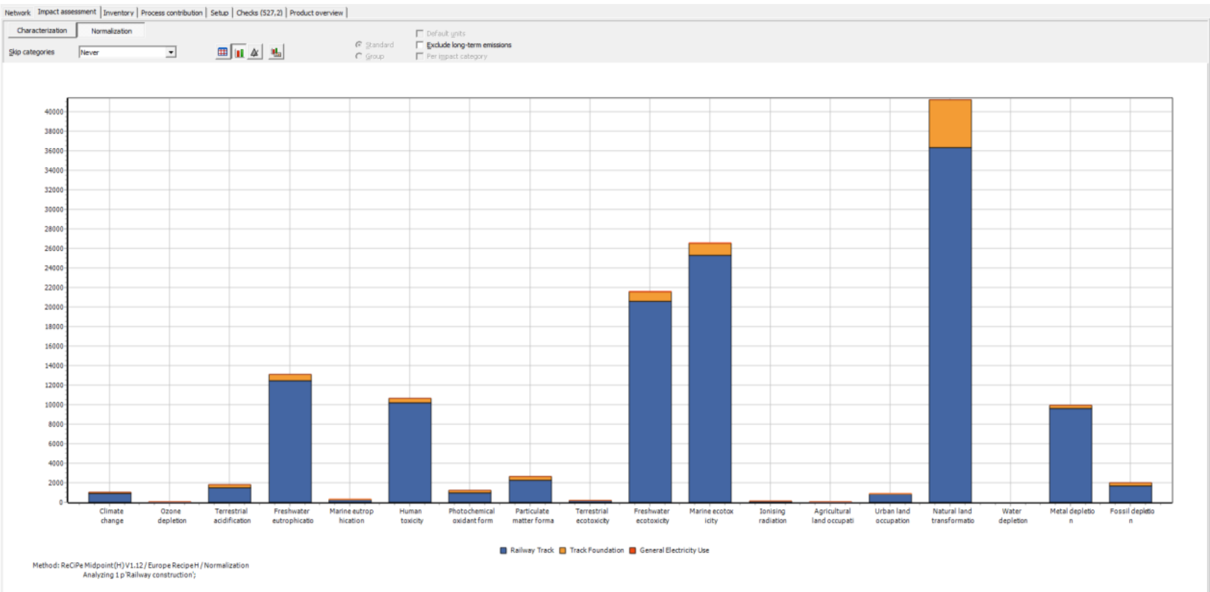


Figure 10 ***Normalization result of railway construction***

5.2 ASSEMBLY RESULTS

In order to assess the impacts from each components of the railway system, impact assessment of each sub system: railway track and railway foundation is conducted.

5.1.1 ASSEMBLY OF RAILWAY TRACK

In the assessment of the railway track assembly, the normalization result (figure 11) indicates that natural land transformation, freshwater ecotoxicity and marine ecotoxicity are the highest environmental burdens. In figure 12, the comparison result between subassemblies of railway track- rail, sleeper and superstructure ballast is presented. It is seen that superstructure ballast has the highest contribution to the natural land transformation, while in other impact categories, rails that the most contributor. The reason that ballast has high burden on natural land transformation may because that ballast used in our project is transported from other area and are not produced on site as mostly are forest. Hence, gravel, which is the main material for ballast, has to be extracted from another places and which will have a big impact on the production land. Rail is the most contributors to other impact categories is mainly due to the production of steel.

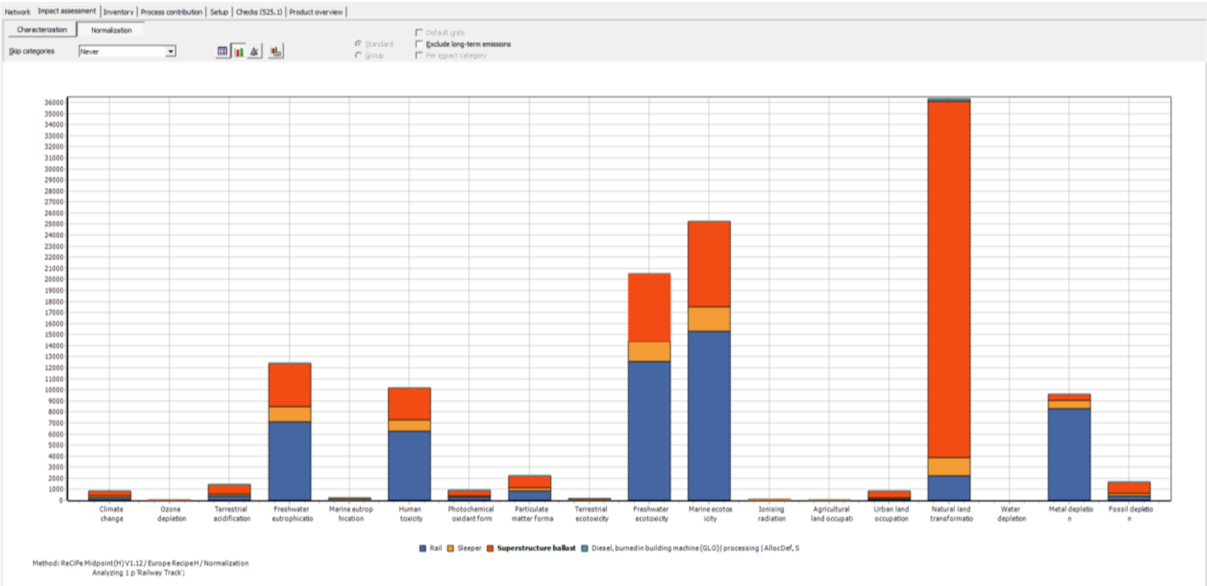


Figure 11 *Normalization result of railway track*

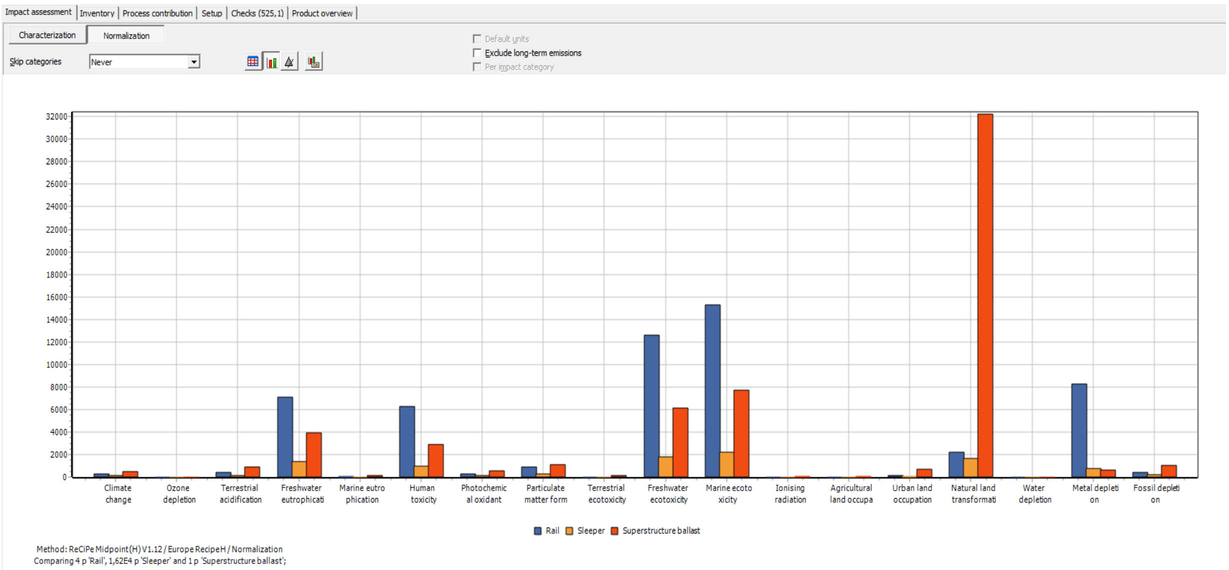


Figure 12 *Comparison between rail, sleeper and superstructure ballast*

When considering sleeper, the character action result is shown in figure 13 that transportation and concrete block are the main contributors. Figure 14 show that marine ecotoxicity is the highest impact of the sleeper.

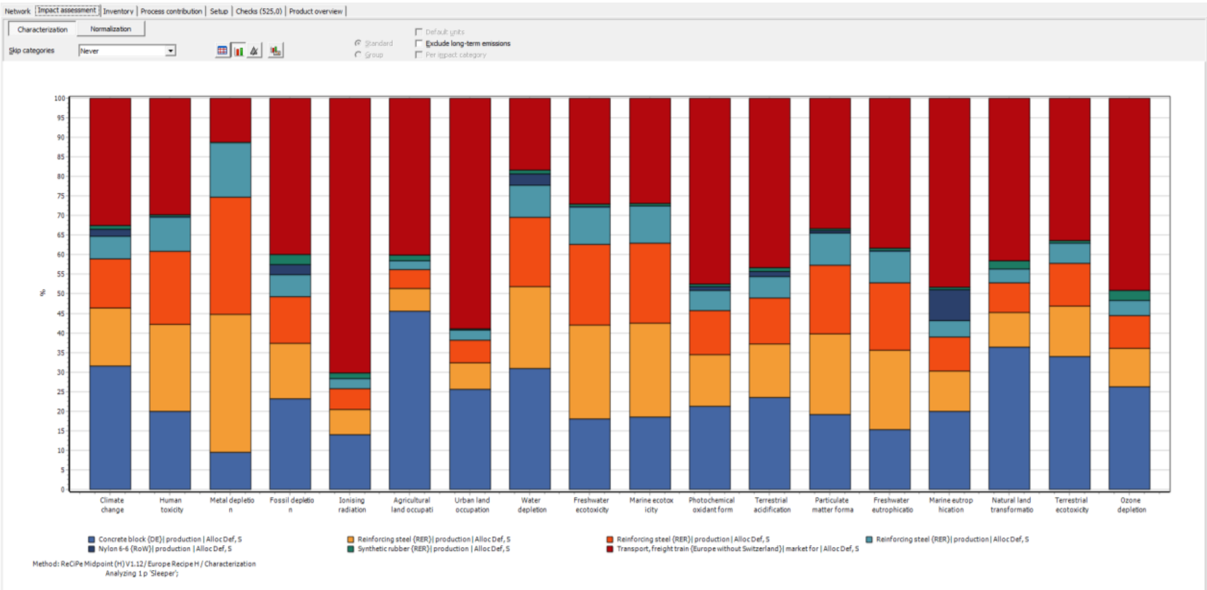


Figure *13Characterization result of sleeper*

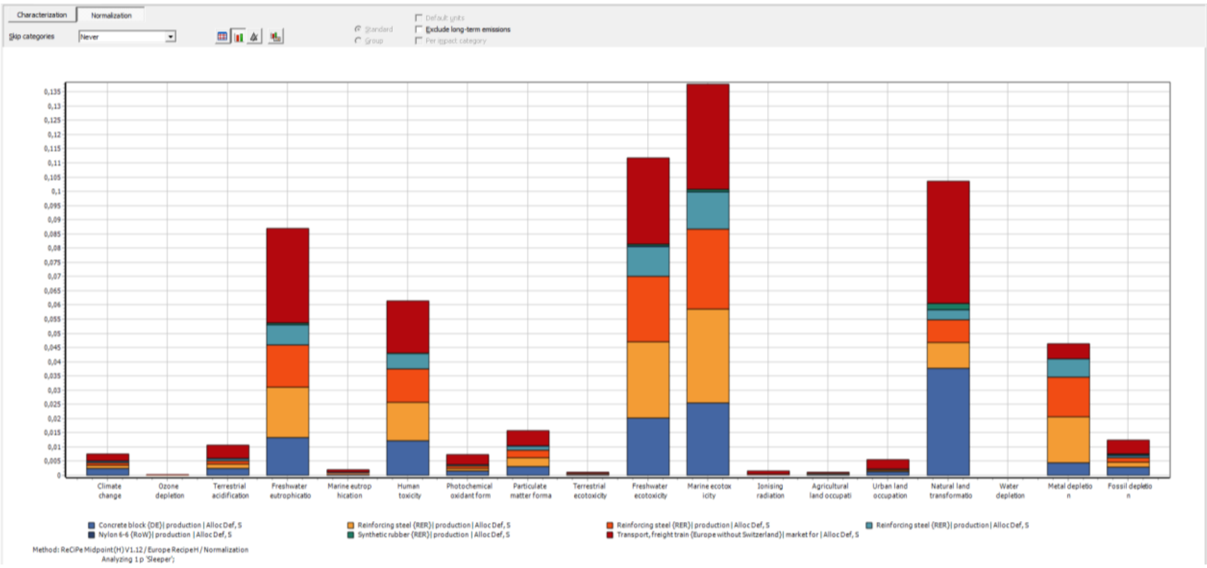


Figure 14 *Normalization result of sleeper*

5.1.2 ASSEMBLY OF RAILWAY

Although track foundation seems do not have much impact compared to railway track, it is still interesting to have a deeper look at the components contribution to the environmental impacts. Figure 15 is the normalization result of track foundation. From the figure it is seen that natural land transformation is the highest impact with the reason of deforestation, which is illustrated in the previous subchapter. From the figure, it is also shown that underground ballast is the main contributor, followed by ground stabilization. In this result, only concrete stabilization is considered. However, as there are another alternative of lie/cement stabilization that could replace concrete stabilization, hence the comparison is done as a small part for sensitivity analysis is then conducted for these two alternatives.

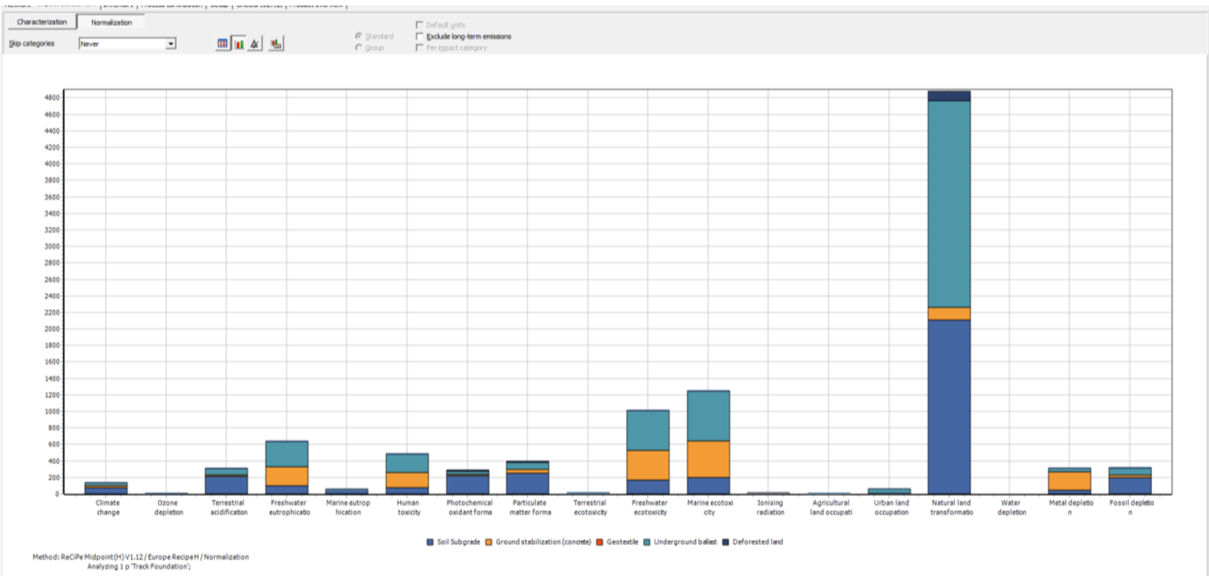


Figure 15 ***Normalization result of track foundation***

5.2 SENSITIVITY ANALYSIS

Because of the time limitation, a strict sensitivity analysis is not conducted in our project. However, there are two ground stabilization are discussed as a simplified part for sensitivity analysis. Figure 16 is the comparison between concrete ground stabilization and lime/cement ground stabilization. From the comparison, it is shown that lime/cement ground stabilization has much lower impact in each category then the concrete one. This result give us a recommendation on the selection of lime/cement ground stabilization for the railway foundation, if both of the alternatives are have similar functional properties.

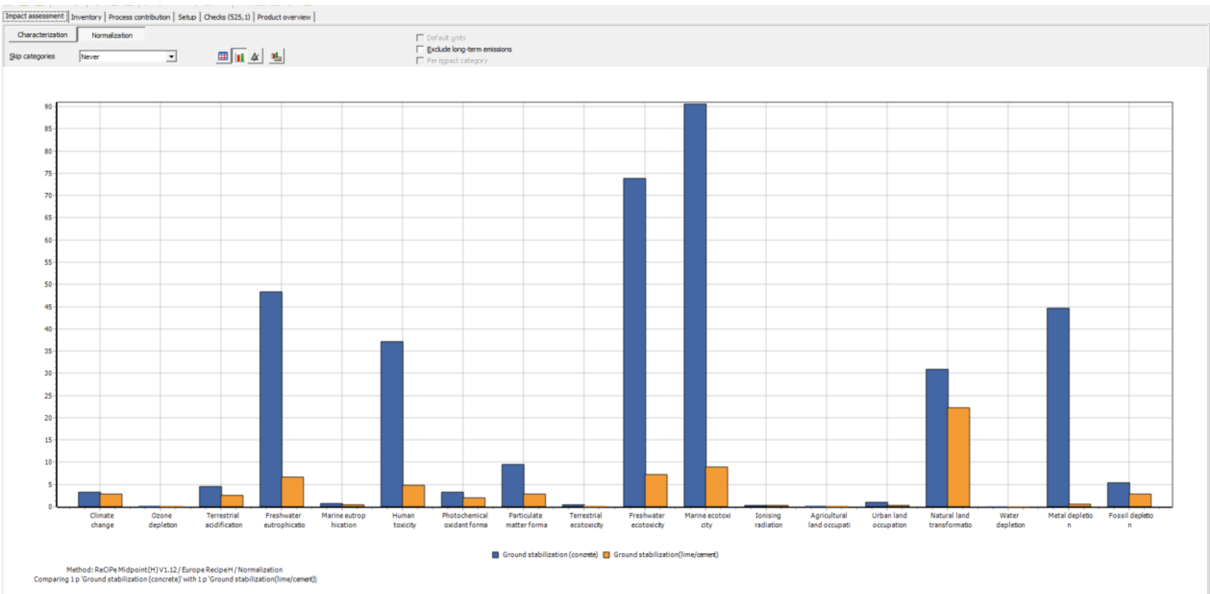


Figure 16 ***Normalization result of the comparison between concrete ground stabilization and lime/cement ground stabilization***

6. CONCLUSIONS AND RECOMMENDATIONS

The goal of the study is to understand the hotspots of the life cycle of the railway system. The results exist many differences from our expectations. The most significant difference is that maintenance stage of the railway track has the highest impact to the entire life cycle of the railway system. In the maintenance stage, only milling process is considered. Under the circumstance that the operation of the rail and the track is not considered in our model, it is predicted that the use phase of the railway system may have the higher impact than construction, which is opposite to our assumption.

Besides, the railway ballast have more impact than the production of rail and track, which is another result that is not the same as our prediction. However, it is understandable that the ballast production needs the extraction of raw material of gravel, which brings many impact on land transformation. Besides, as track line passes through mainly forest area, it gives less local material for foundation. From literature review, we know that concrete could replace ballast in the foundation, hence, it is highly suggested that a comparative LCA between ballast foundation and concrete foundation could be conducted in the future in help to seek a more environmentally friendly material for foundation construction.

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APPENDIX A ASSUMPTIONS OF RAILWAY SYSTEM

Rail	
Steel	Galvanized zinc steel is not accssible in the Ecoinvent database, so this type steel is selected and assumed has the same function as galvanized zinc steel.
Transport Freight, rail	Assuming the rails are transported to Skutskär from rail mode UIC 60 manufacturer ArcelorMittal Europe which is located in Gijon, Spain. The distance is calculated through Googel Map.
Sleeper	
Transport Freight, rail	Assuming all the sleeper materials are transported to Skutskär from Vigier rail Factory which is located in Swithzerland. The distance is calculated through Googel Map.
Others	
Diesel	Excavating, transporting gravel to construction site, laying track etc .will only consider the impact of diesel use during the operation of machines. The impacts due to production of machines are excluded.
Soil clearing	
Vegetation	All vegetation will be used as filling substance in foundation.
Soil excavation	
Soil	Removed soil will be recycled use in filling foundation. The extracted soil is assumed used in other construction site.
Maintenance	

Diesel	Assume all components have lifetime larger than 50 years which means there will be no requirement of material change during the defined life span study. The only process included is diesel use for milling rails.
Waste treatment	
Recycling	The recycling materials of steel and concrete do not include the impact due to transporting to recycling site.

APPENDIX B NETWORK OF THE SIMAPRO MODEL OF RAILWAY SYSTEM LIFE CYCLE