LICCER

LICCER Model Case Study Report

Application of the LICCER-model to a Swedish road section between Yxtatorpet and Malmköping

Report Nr 5.1

November 2013

José Potting (coordinator), KTH Royal Institute of Technology, Sweden and Wageningen University, the Netherlands

Helge Brattebø, NTNU, Norway

Harpa Birgisdottir, Harpa Birgisdottir Consulting, Denmark

Kristina Lundberg, Ecoloop, Sweden

This project was initiated by ERA-NET ROAD.

Project Nr. 832625

Project acronym: LICCER

Project title: Life cycle considerations in EIA of road infrastructure

Deliverable Nr 5.1 – LICCER Model Case Study Report

Due date of deliverable: 31.12.2013

Actual submission date: 23.12.2013

Start date of project: 01.01.2012 End date of project: 31.12.2013

Author(s) this deliverable: C. Liljenström (ed.), S. Miliutenko, H. Brattebø, R. O'Born, H. Birgirsdottir, K. Lundberg, S. Toller and J. Potting

Preface

This report takes its basis in the MSc-thesis of Carolina Liljenström, but has been extended with help of inputs from the LICCER-team. The present report serves as the Swedish case study report for the LICCER-project, i.e. Report No. 5.1. Another report, i.e. Report No. 5.2, will include the Norwegian case study. We like to thank Anna Björklund for her constructive input to this report.

Page v

LICCER Model Case Study Report – Contents

List of Figures

List of Tables

1 Introduction

1.1 Project context

Life Cycle Considerations in EIA of Road Infrastructure (LICCER) is a research project of the cross-border funded joint research programme **"ENR2011 ENERGY – Sustainability and Energy Efficient Management of Roads"**

"ENR2011 ENERGY – Sustainability and Energy Efficient Management of Roads" is a trans-national joint research programme that was initiated by "ERA-NET ROAD II – Coordination and Implementation of Road Research in Europe" (ENR2), a Coordination Action in the 7th Framework Programme of the EC. The funding partners of this cross-border funded Joint Research Programme are the National Road Administrations of Germany, Denmark, Ireland, Netherlands, Norway, Sweden and United Kingdom.

The *aim* of the LICCER project was to develop an easy to use model, consisting of a modular framework and guidelines, based on existing tools and methodologies for Life Cycle Assessment of road infrastructure. The developed model does not follow a modular approach, however, but fully integrates modelling of road elements (i.e. road, bridges and tunnels). The model aims on decision-support in the early stage of transport planning. The framework, use and aim of the model are further described in detail in the technical report and the user guideline.

The LICCER project duration: 01/01/2012– 31/12/2013

Coordinator: José Potting, KTH Royal Institute of Technology (Sweden) / Wageningen University (the Netherlands) (previous coordinators: Susanna Toller and Göran Finnveden, KTH Royal Institute of Technology, Sweden)

Other team members: Helge Brattebø, NTNU (Norway), Harpa Birgisdottir, Harpa Birgisdottir Consulting (Denmark), Kristina Lundberg, Ecoloop (Sweden).

1.2 Background to this report

Environmental impacts from the road transport sector are often associated with the vehicles on the road. However construction, operation and maintenance of the road infrastructure should not be neglected. Estimates show that the road infrastructure can stand for up to 22% of the total energy use of a specific road transport system (Jonsson, 2007). However, GHG-emissions and energy consumption from road infrastructure are often not considered in early planning of road infrastructure (Finnveden and Åkerman, 2011; Hilden et al., 2004). By including only impacts directly related to traffic, the basis for decision can be misleading, especially for bigger resource demanding road projects (Öman et al., 2012).

Life cycle assessment (LCA) is a methodology that can be used for quantification of the environmental impacts of a product system throughout the whole life cycle, from extraction of raw materials to waste treatment (Baumann and Tillman, 2004). LCA has been used to evaluate the environmental impacts of road infrastructure since the 1990's (Carlson, 2011), but so far it has not been common to actually include LCA in early planning stages. The LCA is rather performed when location of the road has already been chosen (Kluts and Miliutenko, 2012).

The project LICCER (Life Cycle Considerations in EIA of Road Infrastructure) aims to develop a life cycle model (the LICCER-model) for assessment of GHG-emissions and energy use in early planning of road infrastructure. Early planning is defined as choice of road corridor and choice of construction type, i.e. road element – plain road, tunnel or bridge. The LICCER-model will enable national road agencies and other stakeholders to compare different road corridor alternatives in the decision-making process (Brattebø et al., 2013).

Development of the LICCER-model started in January 2012. A final version of the model is expected to become available in the beginning of 2014. Before finalising the model it is necessary to test its applicability and robustness, in order to evaluate its usability for decision making. The applicability of the model is defined as user friendliness, and relevant content and relevant results for decision making in early planning stages. Robustness of the model is in this report understood as its possibilities to show differences between road corridors, and its sensitivity for assumptions and parameters. Both can be evaluated through identification of assumptions and parameters to which the model output is the most sensitive and the uncertainty in these parameters and assumptions.

This report presents results from a case study performed for a Swedish road, aiming to evaluate applicability and robustness of the LICCER-model. The model is applied to a case study of selection of road corridors in early planning of road infrastructure, and a sensitivity analysis is performed in order to identify parameters and assumptions to which the model output is most sensitive. Note that the case study is performed with version 2.7 of the LICCER-model, available in June 2013. At the time of performing this case study the model was still under development and it has later been modified, partly based on results from this case study.

2 Methodology

2.1 Life cycle assessment

The LICCER-model is based on life cycle assessment methodology following the ISO 14040 standard. Life cycle assessment (LCA) is a framework for assessment of resource use and environmental impacts throughout the life cycle of a product or a service, from acquisition of raw materials via production and use stages to waste management (ISO 14040:2006). An LCA study usually consists of four stages applied in an iterative process (Baumann and Tillman, 2004; ISO 14040:2006). Figure 1 below shows an outline of the LCA procedure.

1. Goal and scope definition. The goal is related to the context of the study, such as why it is performed and who will use the result. The scope of the study is related to choices made in modelling, such as options to model, choice of functional unit, impact categories, system boundaries and data quality requirements.
2. The life cycle inventory (LCI) includes description and quantification of the resources used throughout the life cycle and the resulting emissions.
3. The emissions and resource use are then related to environmental problems in the life cycle impact assessment (LCIA), i.e. environmental loads such as emissions of CO_2 and SO_2 are translated into environmental impacts such as climate change, acidification, etc.
4. Finally the results are evaluated in relation to the goal and scope, in order to reach conclusions and provide recommendations.

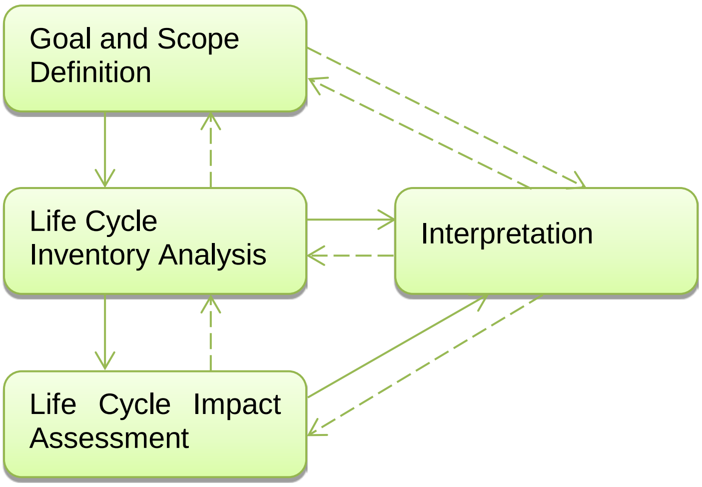


Figure 1: Overview of the LCA-procedure. The arrows indicate the order in which the procedural steps are performed. The broken arrows indicate possible iterations (adapted from Baumann and Tillman, 2004).

2.2 The LICCER-model

The LICCER-model is specifically designed for use in early stages of road infrastructure planning. In this stage, decisions still have to be taken on the exact location of the road in combination with required road elements (e.g. tunnels and bridges). The LICCER-model can thereby be used in the choice of route selection and choice between construction types (e.g. road, bridge or tunnel). A brief overview of the model is provided below. The model is described in detail by Brattebø et al. (2013).

The LICCER-model is developed as an MS-Excel tool that should be easy to use and transparent in terms of background data and calculations. With the LICCER-model it is possible to quantify energy use (cumulative energy demand) and GHG-emissions (CO_2-equivalents) in all life cycle stages of the road, from material production to demolition. Additionally also impacts from traffic on the road are taken into account. Different types of roads, bridges and tunnels are included in the model, as well as supporting road furniture such as guardrails and road lighting.

The methodological choices in the case study are limited by the choices already made in the development of the LICCER-model. This implies that the functional unit, system boundaries, background data and the environmental impacts assessed are the same as in the LICCER-model.

The functional unit in the LICCER-model is "road infrastructure enabling annual transport from “A” to “B” over an analysis time horizon of a defined number of years” (Brattebø et al., 2013). The LICCER-model calculates the annual GHG-emissions and energy consumption as the average values per year for the analysis time horizon. As the yearly traffic on the road is increasing with time it was decided to use the average annual impacts in the LICCER-model and not the value over the whole analysis period. All calculations are adjusted to the service life of the road elements. In this case study an analysis period of 20 years is chosen, as it is the common dimensioning period for roads in Sweden. The service life of road elements in Sweden is recommended to be 60 years for roads and 100 years for bridges and tunnels, hence these values are used in the case study.

Figure 2 below provides an overview of the LICCER-model’s system boundaries. The main life cycle stages included are the following:

- **Production**: includes production of bitumen and aggregates, as well as other materials needed for road construction. The inventory data for the production stage includes excavation of raw material, transportation of materials and processing of these materials to construction components. This constitutes background data in the model and is gathered from databases and the LCA-literature.
- **Construction**: is in the LICCER-model taken into account by transportation of materials to the construction site, in addition to diesel consumption for earthworks and construction of tunnels.
- **Operation**: includes maintenance of the road surface by reasphaltation (including production of materials and transportation of these materials to the construction site), and operational activities such as road lighting, ventilation of tunnels and pumping of water from tunnels.
- **End-of-life**: includes demolition of the road superstructure, bridges and guardrails, earthworks necessary to restore the land area back to natural conditions and transportation of materials to landfill and depots. Recycling and reuse of materials in the end-of-life stage is left outside the system boundary of the analysis.
- **Traffic**: includes consumption of gasoline, diesel, biofuel and electricity in light and heavy vehicles on the road.

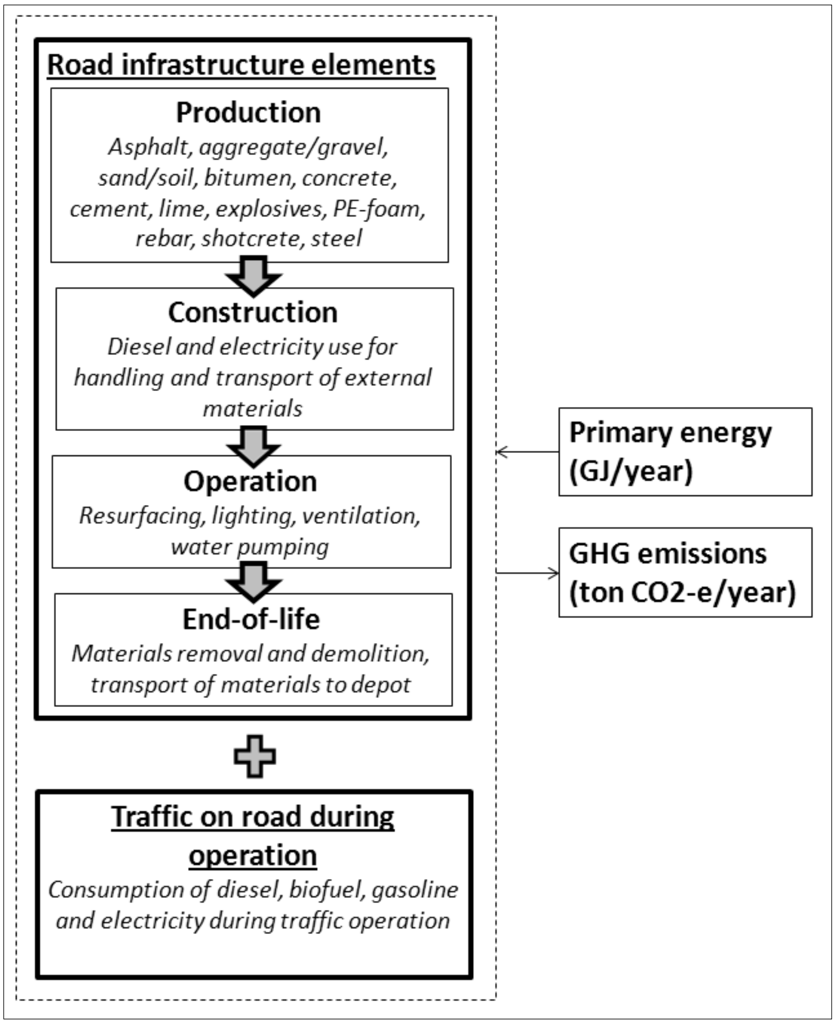


Figure 2: Simplified system boundaries in the LICCER model (Brattebø et al., 2013).

The LICCER-model includes a set of default data used to calculate environmental impacts based on the data inserted by the user. This default data include transportation distances, specific material, electricity and fuel consumption, and emission and energy factors. At the time of performing the case study, not all default data had yet been gathered specifically for Sweden. In that case Norwegian default data has been used. Swedish data is used specifically for fuel consumption in the traffic use stage, material consumption for bridges and for different types of soil stabilisation. Emission and energy factors are mainly the same as in the model Klimatkalkyl developed for the Swedish Road Administration, which in turn has gathered most of these factors from Ecoinvent 2.2. Swedish electricity mix is used.

2.3 Description of the case

The project chosen for the case study is the on-going reconstruction project on road 55, between Yxtatorpet and Malmköping in south-eastern Sweden. This project is chosen as it includes both widening of an existing road and construction of new road sections and bridges, which allows for testing many of the features in the LICCER-model. The project has also been evaluated previously by Shamoon (2012) who used the road LCA-model JOULESAVE to evaluate energy consumption for the road corridors in terms of material production, construction and operation of traffic. This case study therefore also provides an opportunity to compare results from the case studies performed with JOULESAVE and the LICCER-model.

Road 55 is located in the south-east of Sweden, between Norrköping and Uppsala. The part of the road that is analysed in this case study is an approximately 7 km long road section located between Yxtatorpet and Malmköping, see Figure 3. Road 55 has a strategic role in the transport system in Mälardalen but its low standard has had a negative impact on its usability. To meet the demands on technical standard it was decided to widen the road from 9 to 14m and adjust its plan and profile geometry. Once the reconstruction is finished the whole road section will have a reference speed of 100 km/h and the standard of a 2+1 road (Swedish Road Administration, 2006). A 2+1-road is a specific category of roads with three driving lanes. The road has two lanes in one direction, and one lane in the other direction, alternating every few kilometres. The lanes are separated with a centre guardrail located in the central reserve.

Figure 3: Location of road 55 between Norrköping and Uppsala (Swedish Road Administration, 2006).

The feasibility study was performed in 2004-2005 (Swedish Road Administration, 2006). Construction started in spring 2012 and the road is planned to open for use in the end of 2014. Three different road corridors were analysed in the feasibility study, as well as the zero-alternative. The zero-alternative is a reference alternative to which the other alternatives are compared. It includes those changes to the transport system which are predicted to take place if no bigger investments or reconstruction projects are taking place (Swedish Road Administration, 2006).

Below follows a brief description of the road corridors that were assessed in the feasibility study. A map showing the locations of the road corridors is presented in Figure 4.

Alternative 1, Improvement (Förbättringsalternativet, Alt. 1): Involves reconstruction of the existing road by widening and straightening the road and making adjustments to the road profile. The length of the road is approximately 7.5 km.

Alternative 2, Middle (Alternativ Mitt, Alt. 2): The beginning and the end of the road section follows the original road and involves extending the road in the same way as in Alternative Improvement (Alt. 1). In between the extended road sections a new road is constructed with length 2.6 km. A bridge is constructed over the valley at Ålkärr, 3.0km from Yxtatorpet. The total length of the planned road within the road corridor is approximately 6.9 km.

Alternative 3, West (Alternativ Väst, Alt. 3): This is the road corridor that was chosen after the feasibility study and where the new road is now constructed. It was chosen mainly because it is shorter than the other alternatives as it was concluded that there is no big difference in environmental impacts between the road corridors (Swedish Road Administration, 2006). Construction involves a 3.0 km long new road section with a bridge over the valley at

Ålkärr, just as in Alternative Middle (Alt. 2). The beginning and the end of the road is reconstructed in the same way as described for Alternative Improvement (Alt. 1). The total length of the road will be around 6.6 km.

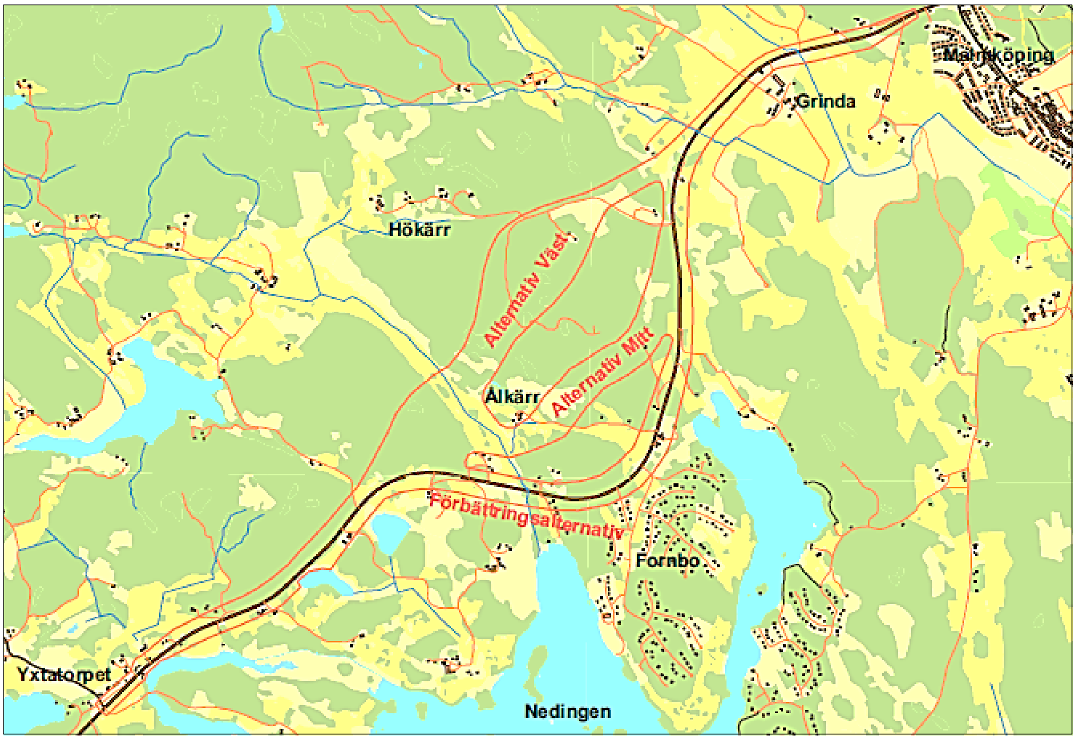


Figure 4: Map showing the location of the different road corridors analysed in the case study (Swedish Road Administration, 2006).

2.4 Data inventory

Project specific data that was gathered for the case study include amount of earthworks needed, area of soil stabilisation, width of roads and bridges, share length with side and centre guardrails, height and type of layers in the road superstructure, amount of traffic in start year of analysis and share of vehicles and fuels. This data was as far as possible gathered from the feasibility study in order to provide a realistic case of using the LICCER-model in early planning. This will help to show the applicability of the model, i.e. relevant content at this stage of the planning process. Input data which was not available in the feasibility study was obtained with help from Englund (2013), who was involved in the performance of the feasibility study for the road construction project which is evaluated in the case study.

The length of the road elements are presented in Table 1. The roads all share the same width and height of pavement layers. All road elements (including the bridge) are 14m wide. The road superstructure consists of a sub-base (420mm), a base course (150mm), and a pavement layer (80mm). In general there are good conditions for construction. It is mainly around Ålkärr in Alternative Middle (Alt. 2) and West (Alt. 3) that soil stabilisation is needed. The soil stabilisation method used is concrete piles for stabilisation of the bridge, and lime/cement columns for stabilisation of other areas. Big quantities of rock are excavated, particularly in Alternative West (Alt. 3), were 500 000 m^3 of rock are excavated. There is a predicted annual average daily traffic (AADT) of 4894 vehicles in 2014 with a 1% yearly increase in traffic. The share of heavy vehicles is 12%. For more details on how this data was sourced, see Liljenström (2013).

Table 1: Length of road elements for the three road corridor alternatives.

Length of road elements (m)	*Improvement*	*Middle*	*West*
New road	n/a	2580	2980
Extended road	7500	4330	3620
Concrete bridge	n/a	20	20

3 Results

3.1 Resulting material, electricity and fuel consumption

The LICCER-model quantifies material, electricity and fuel consumption based on the inventory data gathered for the case study and default values included in the LICCER-model. This default data includes transportation distances of materials, fuel and material consumption for construction, fuel consumption for operation of vehicles, and energy and emission factors. The default values used for the case study are presented in Appendix I. Note that these default values are not necessarily the same as the default data that will be included in the final version of the model. The resulting consumption of materials, fuel and electricity calculated by the LICCER-model based on the inventory data is presented in Table 2.

Table 2: Resulting material, electricity and fuel consumption for the different life cycle stages and road corridors.

	Unit	*Improvement*	*Middle*	*West*	*0-alternative*
PRODUCTION					
Asphalt membrane	tonne/year	-	0.1	0.1	-
Aggregate	tonne/year	1573.7	2111.8	2151.4	-
Bitumen	tonne/year	37.2	35.2	33.7	-
Concrete, bridge	tonne/year	-	5.2	5.2	-
Concrete, concrete piles	tonne/year	-	1.2	1.2	-
Cement, LC-columns	tonne/year	2.4	14.5	19.4	-
Lime, LC-columns	tonne/year	2.4	14.5	19.4	-
Explosives	tonne/year	0.6	2.6	6.4	-
Rebar, bridge	tonne/year	-	0.4	0.4	-
Steel, guardrails	tonne/year	3.5	3.5	3.9	-
Steel, concrete piles	tonne/year	-	0.1	0.1	-
CONSTRUCTION					
Diesel for excavation	m^3/year	1.1	4.1	8.5	-
Diesel for transportation of masses	m^3/year	0.5	1.4	1.6	-
OPERATION					
Aggregate, resurfacing	tonne/year	691.6	638.2	609.5	444.6
Bitumen, resurfacing	tonne/year	31.0	28.6	27.3	19.9
END-OF-LIFE					
Diesel, removal of road superstructure	m^3/year	0.7	1.1	1.1	0.7
Diesel, demolition of concrete structures	m^3/year	-	0.01	0.01	-
Diesel, earthworks	m^3/year	4.5	4.1	3.9	2.3
TRAFFIC ON ROAD DURING OPERATION STAGE					
Electricity, transport by light vehicle	MWh/year	35264.8	32584.7	31127.1	35264.8
Total diesel, traffic use stage	m^3/year	520.0	480.5	459.0	520.0
Total biofuel, traffic use stage	m^3/year	390.6	360.9	344.8	390.6
Total gasoline, traffic use stage	m^3/year	651.9	602.3	575.4	651.9

3.2 Annual GHG-emissions and energy consumption

Results from the case study shows that the total GHG-emissions amounts to around 3500-4000 tonne CO_2-eq./year and the energy consumption to 250 000 - 274 000 GJ/year, depending on road corridor. One of the specific features of the LICCER-model is the possibility to evaluate a road corridor in relation to the reference or the zero-alternative. The alternative with the lowest GHG-emissions and energy consumption is the alternative with the smallest Δ, where Δ=Alt.X-Alt.0. Figure 5 shows the total annual GHG-emissions and energy consumption relative to the reference alternative. It can be seen that Alternative West (Alt. 3) is the road corridor with the lowest GHG-emissions and energy consumption relative to the reference alternative.

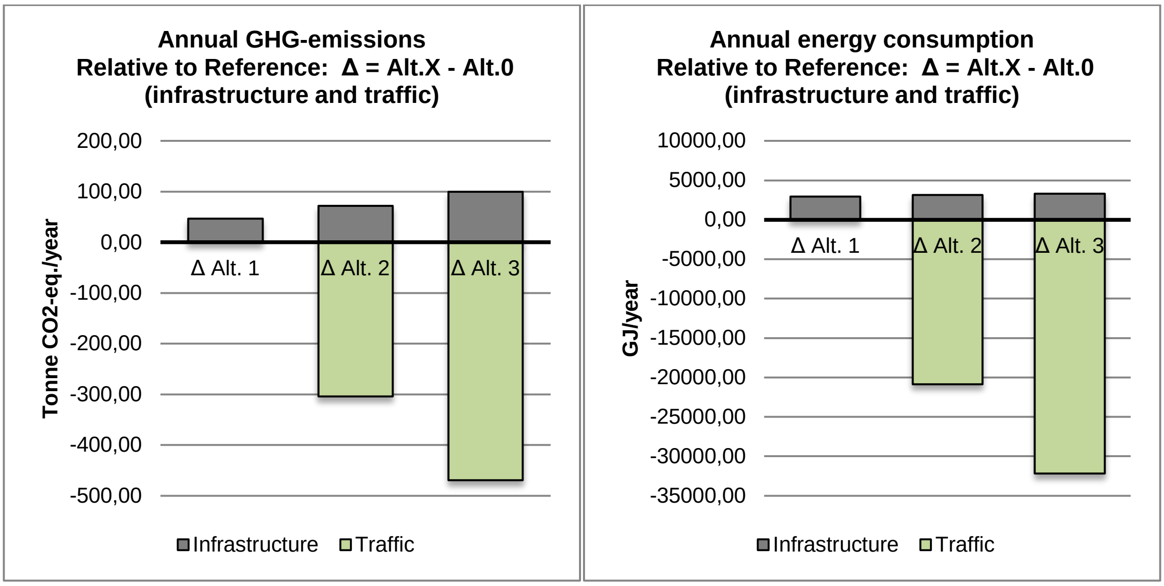


Figure 5: Annual GHG-emissions and energy consumption for the three road corridors relative to the reference alternative (infrastructure and traffic).

A few things can be especially noted. First, Alternative Improvement (Alt. 1) does not show any impacts from traffic in Figure 5, as the length of the road and the traffic scenario is the same as in the zero-alternative, hence Δ=0. Secondly, the energy consumption and GHG-emissions are not negative for Alternative Middle (Alt. 2) and West (Alt. 3). The negative bars in Figure 5 mean that the traffic related impacts are smaller than those in the reference alternative, as the new road alternatives (Alt.2-3) are shorter than in the zero-alternative. This causes a negative net total result, i.e. Δ<0. When analysing infrastructure related impacts alone, it is seen that Alternative West (Alt.3) stands for the highest GHG-emissions and energy consumption, see Figure 6.

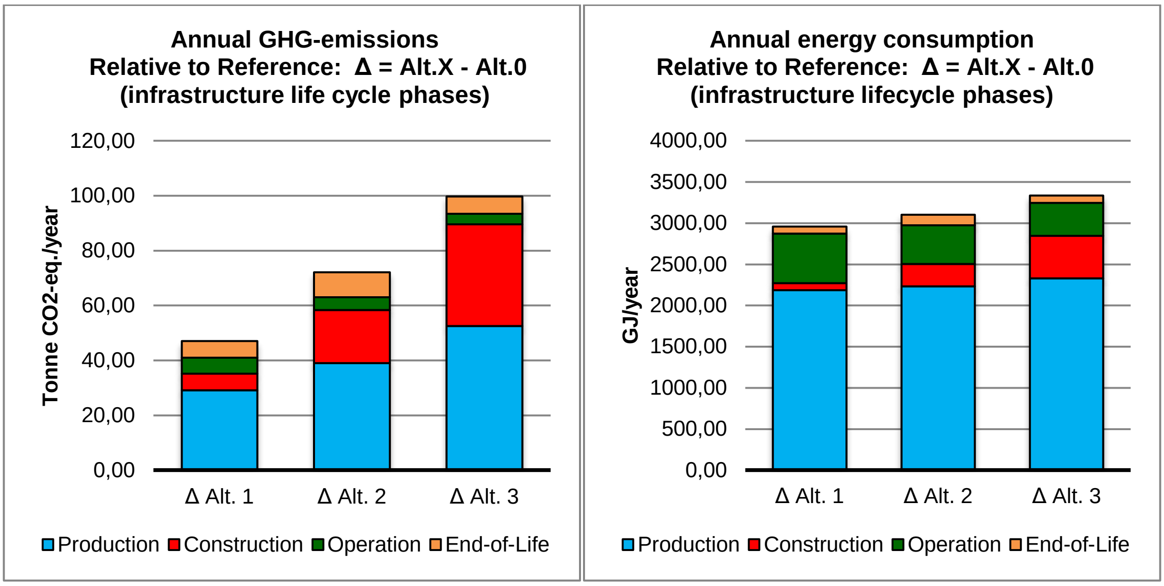


Figure 6: Annual GHG-emissions and energy consumption for the three road corridors relative to the reference alternative (infrastructure components).

Figure 6 shows the results of Alt. 1-3 relative to the reference alternative (0-alternative). It should be kept in mind that no impacts from production or construction are related to the 0-alternative, but only impacts from operation and end-of-life. Operation and end-of-life in Alt. 1-3 appear in Figure 6 to have a low share of GHG emissions. The end-of-life stage also appears to have low energy consumption. But considering each alternative on itself (i.e. not relative to the reference alternative), these stages have a much higher contribution to impacts. For each alternative, the operation phase has a particularly high contribution to energy consumption, around 30%, while the end-of-life has a high contribution to emissions of GHG, around 20% of the total emissions

For all alternatives it is however the production stage that stands for the biggest share of GHG-emissions and energy use, mainly due to production of aggregates and bitumen. It can be noted that also production of explosives has a high share of GHG-emissions, especially for Alternative West (Alt. 3), where big amounts of rock are excavated (see section 2.4). Impacts in the construction stage are mainly related to use of construction machinery for excavation and transportation of excavated materials. Also in the operation stage it is the production of aggregates and bitumen needed for resurfacing that has a big impact. Surprisingly the end-of-life stage contributes relatively much to the GHG-emissions. The LICCER-model takes into account removal of basically all materials that were once brought into the system. Additionally the model includes fuel to break down the pavement, upload the material to trucks before disposal and restore the whole road area back to its natural conditions.

3.3 Sensitivity analysis

An initial sensitivity analysis is performed in order to evaluate the change in GHG-emissions and energy consumption for a certain increase in foreground and background parameters. All parameters in the LICCER-model are increased with 20%. Table 3 below displays the result for infrastructure related impacts and Table 4 traffic related impacts. Only parameters that contribute with a change higher than 2% for at least one alternative and impact category are displayed.

Table 3: Relative change in infrastructure related GHG-emissions and energy consumption for changes in foreground and background parameters. Displayed are only parameters that contribute with a change higher than 2% for at least one alternative and impact category.

	GHG-emissions				Energy consumption			
Parameter	**0-Alt.**	**Alt. 1**	**Alt. 2**	**Alt. 3**	**0-Alt.**	**Alt.1**	**Alt. 2**	**Alt. 3**
AADT	1,06	1,05	1,03	1,02	1,10	1,09	1,07	1,06
Length of road	1,20	1,16	1,09	1,06	1,20	1,19	1,16	1,14
Volume of excavated rock	1,00	1,02	1,06	1,10	1,00	1,00	1,02	1,04
Area of stabilised soil	1,00	1,01	1,03	1,03	1,00	1,00	1,01	1,01
Analysis period	1,06	1,05	1,03	1,02	1,10	1,09	1,07	1,06
Width of road	1,00	1,22	1,14	1,09	1,00	1,27	1,24	1,22
Service life, roads	0,93	0,91	0,88	0,86	0,98	0,96	0,94	0,93
Reasphaltation frequency	0,90	0,92	0,96	0,97	0,85	0,87	0,89	0,91
Depth of reasphaltation	1,12	1,08	1,04	1,03	1,18	1,14	1,11	1,10
Cement, LC-columns	1,00	1,01	1,03	1,02	1,00	1,00	1,00	1,00
Diesel, excavation of rock	1,00	1,01	1,03	1,05	1,00	1,00	1,01	1,02
Diesel, earthworks at end-of-life	1,06	1,02	1,01	1,01	1,01	1,01	1,00	1,00
Explosives	1,00	1,01	1,02	1,04	1,00	1,00	1,01	1,02
Emission factor: bitumen	1,00	1,07	1,04	1,03	1,00	1,00	1,00	1,00
Emission factor: bitumen, reasphaltation	1,09	1,02	1,01	1,01	1,00	1,00	1,00	1,00
Emission factor: diesel	1,08	1,04	1,06	1,07	1,00	1,00	1,00	1,00
Emission factor: explosives	1,00	1,01	1,02	1,04	1,00	1,00	1,00	1,00
Emission factor: cement	1,00	1,01	1,03	1,02	1,00	1,00	1,00	1,00
Energy factor: bitumen	1,00	1,00	1,00	1,00	1,17	1,17	1,14	1,12
Energy factor: diesel	1,00	1,00	1,00	1,00	1,02	1,01	1,02	1,03

Table 4: Relative change in traffic related GHG-emissions and energy consumption for changes in foreground and background parameters. Displayed are only parameters that contribute with a change of more than 2% for at least one alternative and impact category.

Parameter	GHG-emissions				Energy consumption			
	0-Alt.	**Alt. 1**	**Alt. 2**	**Alt. 3**	**0-Alt.**	**Alt. 1**	**Alt. 2**	**Alt. 3**
AADT	1,20	1,20	1,20	1,20	1,20	1,20	1,20	1,20
Share of heavy traffic	1,04	1,04	1,04	1,04	0,99	0,99	0,99	0,99
Share of biofuel in end year	0,97	0,97	0,97	0,97	0,99	0,99	0,99	0,99
Share of electric vehicles in end year	1,03	1,03	1,03	1,03	1,14	1,14	1,14	1,14
Length of road	1,20	1,20	1,20	1,20	1,20	1,20	1,20	1,20
Diesel fuel, trucks with trailer	1,03	1,03	1,03	1,03	1,01	1,01	1,01	1,01
Gasoline, light vehicles	1,09	1,09	1,09	1,09	1,03	1,03	1,03	1,03
Electricity, light vehicles	1,04	1,04	1,04	1,04	1,15	1,15	1,15	1,15
Emission factor: diesel	1,07	1,07	1,07	1,07	1,00	1,00	1,00	1,00
Emission factor: electricity	1,04	1,04	1,04	1,04	1,00	1,00	1,00	1,00
Emission factor: gasoline	1,08	1,08	1,08	1,08	1,00	1,00	1,00	1,00
Energy factor: gasoline	1,00	1,00	1,00	1,00	1,03	1,03	1,03	1,03

Even though this sensitivity analysis provides an indication of which parameters has the biggest possibilities to change the output, it is not necessarily so that an increase with 20% is realistic. With the method used for the sensitivity analysis above it is also not possible to analyse combinations of different parameters and scenarios (such as choice of soil stabilisation method). A more extensive sensitivity analysis is therefore made analysing specific scenarios within the categories

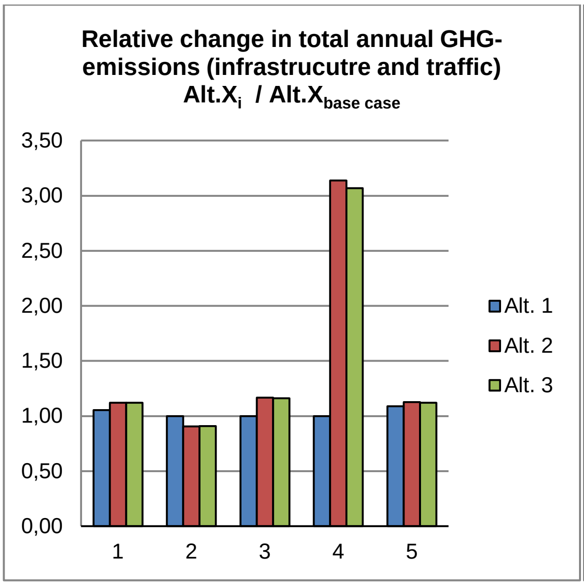
- Earthworks and soil stabilisation
- Material consumption for construction of roads and bridges
- Traffic and fuels
- Energy and emission factors for selected materials and fuels

Possible realistic ranges are gathered from Shamoon (2012), from other road LCA literature, through comparison with background data in JOULESAVE and from information provided by the Swedish Transport Administration. For more details, see Liljenström (2013).

The five scenarios which give the biggest change in output for total GHG-emissions and energy consumption respectively, i.e. in total results for both infrastructure and traffic, are the following as presented below in Figure 7:

1. 10% higher AADT
2. Fuel scenario for end of analysis period: 48% biofuel and 7% electric vehicles
3. Fuel scenario for end of analysis period: 23% biofuel and 17% electric vehicles
4. Electricity mix NORDEL in the operation stage
5. Ecoinvent database for diesel

It can be noted that these are all scenarios which are related to the traffic on the road. As the traffic related impacts are dominating, changes made in infrastructure parameters do not have a big influence on the total impacts. These scenarios also lead to the same results in all three alternatives; hence they do not have an influence on the ranking of alternatives.



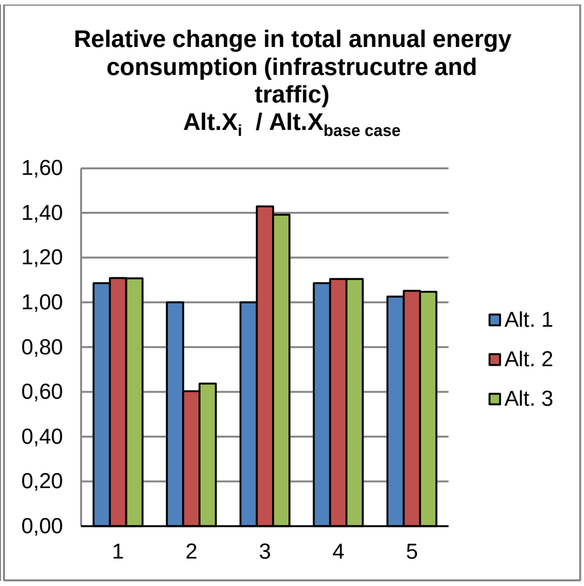


Figure 7: The five scenarios that give the biggest change in total GHG-emissions and energy consumption (infrastructure and traffic). The relative change from the base case scenario is displayed: $Alt.X_i$ / $Alt.X_{base\ case}$, where $Alt.X_i$ is the GHG-emissions or energy consumption for scenario i, where i = 1-5 corresponding to the scenarios on page 16, and $Alt.X_{base\ case}$ is the GHG-emissions or the energy consumption in the base case scenario.

For total impacts it was the same five scenarios which gave the biggest change for both GHG-emissions and energy consumption. For infrastructure related impacts however, the scenarios differ in both impact categories, see Table 5. Resulting change in output is seen in Figure 8.

Table 5: The five scenarios which have the highest influence on infrastructure related GHG-emissions and energy consumption respectively.

	GHG-emissions	*Energy consumption*
1	Background data for earthworks are gathered from JOULESAVE	Background data for earthworks are gathered from JOULESAVE
2	30% increase in excavated volumes of rock	Embankments are so high that concrete piles are necessary
3	Embankments are so high that concrete piles are necessary	Increased road length with 2.5%
4	Concrete bridge is increased to 200m, increased material consumption	Road width decreased to 12.75m
5	Idemat database for aggregates	German database for bitumen

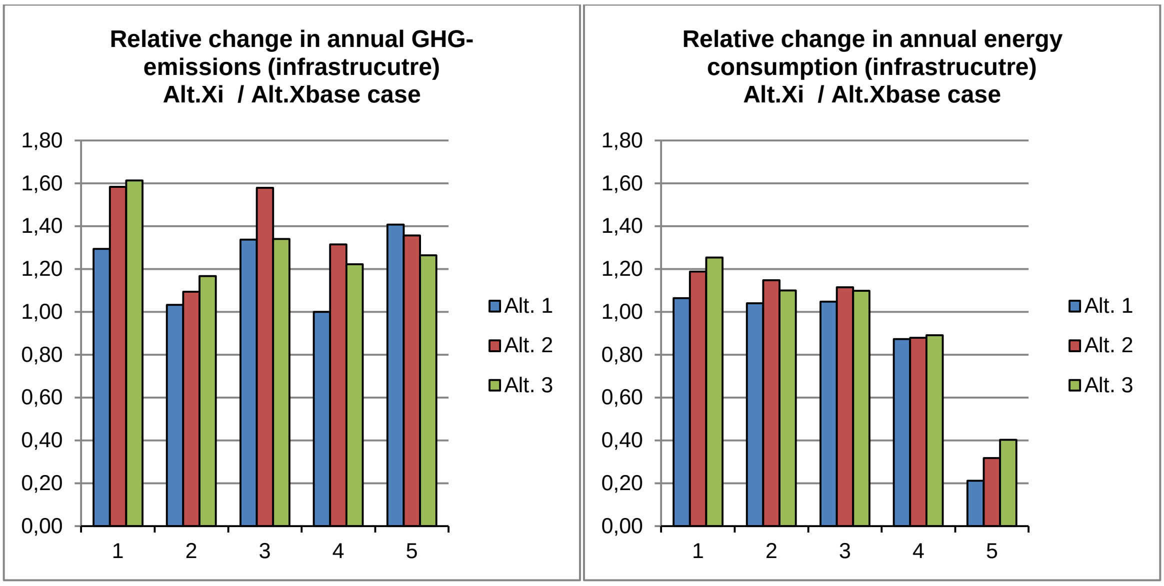


Figure 8: The five scenarios that give the biggest change in infrastructure related GHG-emissions and energy consumption. The relative change from the base case scenario is displayed: $Alt.X_i$ / $Alt.X_{base\ case}$, where $Alt.X_i$ is the GHG-emissions or energy consumption for scenario i, where i = 1-5 corresponding to the scenarios in Table 5, and $Alt.X_{base\ case}$ is the GHG-emissions or the energy consumption in the base case scenario.

It is seen that the changes can be quite significant, but these changes does not translate into big changes in the net total result, as traffic has such a high share of impacts. Many of the scenarios are the same in all alternatives, and changes made will thus not affect the ranking of alternatives. However, earthworks are one of the major differences between the road corridors and also a parameter connected to high uncertainty. It can therefore be assumed that changes in excavated volumes could reverse the ranking between alternatives. For example if it would be possible to decrease the excavated volumes of rock in Alternative West (Alt. 3), but not in the other alternatives. For instance, a decrease in excavated rock with 30% in Alternative West (Alt. 3) reversed the ranking between Alternative Middle (Alt. 2) and West (Alt. 3) in terms of infrastructure related energy consumption (Liljenström, 2013).

4 Discussion and conclusions

Results from the case study comply well with results from previous road LCAs. Shamoon (2012) performed a case study for the same road corridors that were analysed in this case study, but with the road LCA-model JOULESAVE. The ranking of alternatives is the same in the two case studies, both for total results and for infrastructure related energy consumption, despite the many differences between JOULESAVE and the LICCER-model. In both studies it was the excavation work that caused the highest construction related impacts. The share between traffic related and infrastructure related impacts are also in line with results from Shamoon (2012) where 96% of the impacts were related to operation of traffic.

The sensitivity analysis showed that the result is very sensitive to changes in input parameters and scenarios related to traffic. The result is less sensitive to changes in infrastructure parameters. Total GHG-emissions and energy consumption is particularly sensitive to assumptions of future fuels and electricity mix. Infrastructure related output is mainly sensitive to changes in fuel consumption for excavation, choice of soil stabilisation method, changes that affects bitumen and aggregate consumption, and choice of background data for bitumen and aggregates.

Many of the input parameters are the same for all alternatives. All alternatives have for example the same height of layers in the road superstructure, the same emission and energy factors, the same traffic scenario, etc. Consequentially, changes in these parameters and scenarios will likely not affect the ranking between alternatives. From the scenarios analysed in the sensitivity analysis it was seen that it is particularly assumptions in relation to excavated volumes of rock that has a possibility to change the ranking between Alternative Middle (Alt. 2) and West (Alt. 3). If it is possible to reduce the volumes of excavated rock in Alternative West, but the volumes increase or are the same for a road constructed in Alternative Middle, Alternative West (Alt. 3) could in fact have lower infrastructure related impacts than Alternative Middle (Alt. 2).

Before conclusions are drawn from this case study it should however be noted that the uncertainty in parameters and scenarios has not been assessed. It is therefore not known whether the changes applied in the sensitivity analysis are actually realistic for the case study road, and what could be the total uncertainty in the output (i.e. what is the likelihood that Alternative West (Alt. 3) have the highest infrastructure related impact). Additionally, not all possible combinations of parameters and scenarios have been analysed. It could for example be assumed that a combination of increase/decrease in rock with excavation of soil, changed fuel consumption, etc. could have an influence on conclusions regarding ranking of alternatives.

Care should also be taken if conclusions from this case study are transferred to other road construction projects. This project should essentially be seen as a special case where the three road corridors are relatively similar in terms of length and type of construction, and where the alternatives are relatively similar to the reference alternative. It should also be noted that many of the conclusions from this study are related to the big rock cuts made, especially in Alternative West (Alt. 3). Before general conclusions on the robustness of the LICCER-model are drawn it is necessary to perform additional case studies for other types of road construction projects, including projects with tunnels, and to evaluate the uncertainty in the input parameters.

Applicability of the model was earlier defined as user friendliness and relevant content and relevant results for decision making. The model has many benefits in terms of user friendliness, such as transparency when it comes to background data and calculations, and possibilities to add project specific data. The main drawback with the model version 2.7 was difficulties navigating the model due to the many route alternatives and road elements displayed on each sheet in the Excel-file. This problem was fixed in later stages of the model development.

The content of the model was well suited to the information available in the feasibility study. While quantitative data was scarce, the qualitative data presented could be used to make reasonable estimations without much extra work. As the case study was not performed as part of the actual planning process it is difficult to evaluate whether the generated results are useful for decision making. It is therefore necessary to perform additional case studies, and to apply the LICCER-model in the planning process. This will also help to further evaluate the relevance of the model content and the model's user friendliness.

5 References

Baumann, H. and Tillman, A.M. (2004): *The Hitch Hiker's Guide to LCA. An orientation in life cycle assessment methodology and application.* Studentlitteratur AB, Lund (Sweden).

Brattebø, H., O'Born, R., Miliutenko, S., Birgisdóttir, H., Lundberg, K., Toller, S. and Potting, J. (2013): *LICCER Model Technical Report – Account of technical backgrounds of the LICCER model* Report. *Report no 4.2.* ERA-NET ROAD, Stockholm (Sweden).

Carlson, A. (2011): *Life cycle assessments of roads and pavements. Studies made in Europe. VTI rapport 736A.* The Swedish National Road and Transport Research Institute (VTI), Linköping (Sweden).

Englund, J. (2013): Personal communication, 9 August 2013.

Finnveden, G., Åkerman, J. (2011): Not planning a sustainable transport system - two Swedish case studies., *World Renewable Energy Congress*, Linköping.

Hilden, M., Furman, E., Kaljonen, M. (2004): Views on planning and expactations of SEA: the case of transport planning. *Environment Impact Assessment Review* 24, 519-536.

ISO 14040 (2006): ISO 14040 *International Standard. Environmental management — Life cycle assessment – Principles and framework.* International Organization for Standardization, Geneva (Switzerland).

Jonsson, D.K. (2007): Indirect energy associated with Swedish road transport. *European Journal of Transport and Infrastructure Research* 7(3), 183-200.

Kluts, I. and Miliutenko, S. (2012): Overview of road infrastructure planning process and the use of Environmental Assessments in the Netherlands and Sweden. Internship report. TRITA-INFRA-FMS 2012:6. ISSN 1652-5442. Environmental Strategies Research (fms) division, KTH Royal Institute of Technology, Stockholm (Sweden).

Liljenström, C. (2013): *Life cycle assessment in early planning of road infrastructure – application of the LICCER-model.* KTH Royal Institute of Technology, Stockholm (Sweden).

Shamoon, H. (2012): *Energieffektiv vägdesign.* Master thesis. KTH Royal Institute of Technology, Stockholm (Sweden).

Swedish Road Administration (2006): Väg 55, delen Yxtatorpet-Malmköping. Vägutredning. Samrådshandling 2006-01-25. Objekt nr 10898.

Swedish Transport Administration (2013): *Modellverktyg Klimatkalkyl (2013-06-12).* [Excel-file] Avaialble at: http://www.trafikverket.se/Foretag/Planera-och-utreda/Planerings--och-analysmetoder/Samhallsekonomisk-analys-och-trafikanalys/Prognos--och-analysverktyg/Fliksida---verktyg/Klimatkalkyl---Infrastrukturens-klimatpaverkan-i-ett-livscykelperspektiv/ [Accessed 29 July 2013].

Öman, A., Andersson, M. and Uppenberg, S. (2012): *Förstudie livscykelanalys i planering och projektering. Prepared by WSP Environmental for The Swedish Transport Administration. Publication number 2012:182.* The Swedish Transport Administration, Borlänge (Sweden).

APPENDIX I – Background data in the LICCER-model

This appendix includes tables presenting the background data included in the LICCER-model (version 2.7) and that were used for the case study presented in this report. Other background data may be used in the final version of the LICCER-model.

Table 6: Emission factors used in the case study, data included in LICCER-model version 2.7.

Material	*GHG-emissions*	*Unit*	*Reference*
Aggregate	3.76	kg/tonne	EFFEKT
Bitumen	430.00	kg/tonne	Swedish Transport Administration (2013)
Asphalt membrane	209.00	kg/tonne	Ecoinvent 2.2
Aggregate in reasphaltation	3.76	kg/tonne	EFFEKT
Bitumen in reasphaltation	430.00	kg/tonne	Ecoinvent 2.2
Concrete	367	kg/m^3	Swedish Transport Administration (2013)
Diesel	2 540	kg/m^3	Swedish Transport Administration (2013)
Biofuel	825	kg/m^3	30% of the value for gasoline in Ecoinvent 2.2
Electricity	0.020	kg/kWh	Swedish Transport Administration (2013)
Explosives	2 520	kg/tonne	Ecoinvent 2.2
Gasoline	2 530	kg/m^3	Ecoinvent 2.2
Rebar (reinforcement steel)	1 200	kg/tonne	Swedish Transport Administration (2013)
Steel	1 500	kg/tonne	Swedish Transport Administration (2013)
Lime	2	kg/tonne	Swedish Transport Administration (2013)
Cement	715	kg/tonne	Swedish Transport Administration (2013)
Transport work	0.120	kg/tonnekm	Ecoinvent 2.2

Table 7: Energy factors used in the case study, data included in the LICCER-model version 2.7.

Material	*Energy*	*Unit*	
Aggregate	103.0	MJ/tonne	EFFEKT
Bitumen	51 900	MJ/tonne	Swedish Transport Administration (2013)
Asphalt membrane	7 040	MJ/tonne	Ecoinvent 2.2
Aggregate in reasphaltation	103.0	MJ/tonne	EFFEKT
Bitumen in reasphaltation	51 900	MJ/tonne	Ecoinvent 2.2
Concrete	2 472	MJ/m^3	Swedish Transport Administration (2013)
Diesel	35 280	MJ/m^3	Swedish Transport Administration (2013)
Biofuel	4785	MJ/m^3	30% of the value for gasoline in Ecoinvent 2.2
Electricity	6,44	MJ/kWh	Swedish Transport Administration (2013)
Explosives	29 465	MJ/tonne	Ecoinvent 2.2
Gasoline	41 528	MJ/m^3	Ecoinvent 2.2
Rebar (reinforcement steel)	19 300	MJ/tonne	Swedish Transport Administration (2013)
Steel	20 100	MJ/tonne	Swedish Transport Administration (2013)
Lime in soil stabilization	28	MJ/tonne	Swedish Transport Administration (2013)
Cement	4 135	MJ/tonne	Swedish Transport Administration (2013)
Transport work	1.80	MJ/tonnekm	Ecoinvent 2.2

Table 8: Specific material consumption used in the case study, data included in the LICCER-model version 2.7.

Material	*Material consumption*	*Unit*	*Reference*
Bitumen Asphalt	Consumption of these materials is calculated based on cross section geometry data.		
Asphalt, replaced in repaving	0.050	m thickness	EFFEKT
Asphalt membrane, bridge	26.04	kg/m^2 surface area	EFFEKT
Concrete, bridge	0.78	m^3/m^2 surface area	Olofsson et al. (2010)
Concrete, concrete piles	1.17	tonne/m^2 stabilised soil	Swedish Transport Administration (2013); Rydberg and Andersson (2003)
Cement, LC-columns	0.08	tonne/m^2 stabilised soil	Rydberg and Andersson (2003)
Lime, LC-columns	0.08	tonne/m^2 stabilised soil	Rydberg and Andersson (2003)
Diesel, transportation of masses in earthwork	0.035	litre/tonnekm mass transport	EFFEKT
Diesel, machinery for earthwork in road construction	0.80	litre/m^3 loose materials	EFFEKT
Diesel, earthworks, blasted rock	0.80	litre/m^3 loose materials	EFFEKT
Diesel, earthworks, simple soil excavation	0.09	litre/m^3 loose materials	Stripple (2001)
Diesel, end-of-life pavement removal	0.80	litre/m^3 loose materials	EFFEKT
Diesel, end-of-life base & sub-base removal	0.80	litre/m^3 loose materials	EFFEKT
Diesel, end-of-life concrete structures demolition	5.00	litre/m^3 concrete structure	EFFEKT
Diesel, end-of-life earthworks	2.00	litre/m^2 total road area	EFFEKT
Explosives	1.00	kg/m^3 rock in situ	EFFEKT
Rebar, bridge	0.13	tonne/m^2 surface area	Olofsson et al. (2010)
Steel, guardrails	0.021	tonne/m guardrail	EFFEKT
Steel, concrete piles	0.047	tonne/m^2 stabilized soil	Swedish Transport Administration (2013); Rydberg and Andersson (2003)

Table 9: Fuel consumption of vehicles, data included in LICCER-model version 2.7.

Type of fuel	*Fuel consumption*	*Unit*	*Reference*
Diesel fuel, trucks, no trailer	2.32	litre/10km	Swedish Transport Administration
Diesel fuel, trucks, with trailer	4.09	litre/10km	Swedish Transport Administration
Diesel fuel, light vehicles	0.67	litre/10km	Swedish Transport Administration
Gasoline fuel, light vehicles	0.87	litre/10km	Swedish Transport Administration
Electricity, light vehicles	1.61	MJ/km	Norwegian Transport Administration

Table 10: Distance of materials to the construction site, data included in LICCER-model version 2.7.

Material	*Transport distance (km)*
Aggregate/gravel, all usage except pavement asphalt	5
Asphalt membrane	500
Asphalt, pavement (incl. bitumen and aggregate)	5
Concrete, bridges	300
Concrete piles	50
Cement, soil stabilization	100
Lime from lime pillars, soil stabilization	300
Explosives	100
Rebar, bridges	500
Steel, guardrails	500
Internal transportation masses from earthwork	2
Pavement materials to depot at end-of-life	10
Base & sub-base materials to depot at end-of-life	10
Concrete materials to depot at end-of-life	10
Rebar materials to depot at end-of-life	10
Steel materials to depot at end-of-life	10