Comparison of Klimatkalkyl, LICCER & SimaPro

Three models to quantify life cycle energy and carbon dioxide in early road infrastructure planning

Jämförelse av Klimatkalkyl, LICCER & SimaPro

Tre modeller för kvantifiering av energianvändning och koldioxidutsläpp ur ett livscykelperspektiv för väginfrastruktur i tidiga planeringsskeden

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Summary

Early environmental assessments provide important information for decision making processes in road construction projects. This report is about a comparative study among different Life Cycle Assessment (LCA) tools used in road construction. These are, KlimatKalkyl, LICCER and SimaPro. KlimatKalkyl was developed by a consultancy firm and used by Trafikverket, LICCER was developed by a collaboration of three universities and used in research studies and SimaPro is used by industry and academia for environmental studies. In this report the results are referring only to primary energy consumption in GJ/year and Global Warming Potential (GWP) in CO_2-eq. kg/year.

The following report includes three cases studies based on different road projects. The results generated from each tool are compared in order to evaluate the tools and present the similarities and differences among them in quantitative and qualitative manner. Variations in the outputs regarding the impact in the environment mainly come from the different input formats and calculation processes that the tools have. Regarding the road type, the three models are generating different results for energy or CO_2 emissions. In the qualitative comparison it is showed that the tools have different input formats and at some cases one has more input details against the other.

Sammanfattning

Tidiga miljöbedömningar ger viktig information vid beslutsfattande i vägbyggnadsprojekt. Denna rapport handlar om en jämförelse av olika verktyg som används för att göra livscykelanalyser (LCA) av vägbyggen. Dessa är KlimatKalkyl, LICCER och SimaPro. KlimatKalkyl har utvecklats av en konsultfirma och används av Trafikverket, LICCER har utvecklats i ett samarbete mellan tre universitet och användas i forskningsstudier och SimaPro används av industrin och i den akademiska världen för miljöstudier. I denna rapport presenteras resultaten i form av primär energianvändning, mätt i GJ/år, och global uppvärmningspotential, mätt i CO2-ekvivalenter/år.

Denna rapport innehåller tre fallstudier baserade på olika vägprojekt. De resultat som erhållits från varje verktyg jämförs för att utvärdera verktygen och presentera likheter och skillnader mellan dem, både kvantitativt och kvalitativt. Skillnader i resultat när det gäller miljöpåverkan beror främst på de olika indata som behövs och de olika beräkningsantaganden som har gjorts i verktygen. När det gäller vägelement ger de tre modellerna olika resultat för energianvändning och CO2-utsläpp. I den kvalitativa jämförelsen visade det sig att verktygen har olika inmatningsformat och i vissa fall kräver ett verktyg mer indata än det andra.

1. Introduction

This study is about the comparison of three tools that assist transportation engineers in producing environmental assessments in the early stages of road infrastructure projects. These are KlimatKalkyl, LICCER and SimaPro.

- KlimatKalkyl is used by the Swedish road administration Trafikverket and calculates the life cycle energy and carbon dioxide emissions of road and rail infrastructure. The model was developed by the consultancy WSP and funded by Trafikverket. KlimatKalkyl uses predefined road and rail elements for its calculations making it simpler for application. The user does not need to have an environmental engineering background. The assessment of the project is produced by inserting the dimensions of the road or rail segments. There are also optional input sections that correspond to construction and operation processes. More details can be found in the next table.
- LICCER calculates the life cycle energy and carbon dioxide emissions for early phases of road infrastructure projects. It roughly estimates in addition life cycle energy and carbon dioxide emissions of traffic. The model was developed by an international consortium coordinated by KTH Royal Institute of Technology and funded by the European ERA-net ROAD. This tool is also simple in use and the user does not need any further environmental knowledge in order to produce assessment results. LICCER has also input sections that correspond to different road types and the user has only to insert the road dimensions and optional details regarding the road construction and operation. Nevertheless the formats of these input sections in LICCER differ from the ones in KlimatKalkyl. In LICCER there is also the ability to insert a zero alternative and up to three more alternatives in order to produce comparative results of projects.
- SimaPro is an LCA software developed by Pré Consultants in the Netherlands. It is used by a wide range of environmental engineers in order to provide assessments based on the life cycle of products and processes in general. SimaPro can be used for a variety of industries since it gives the possibility to build an assessment model from scratch for basically any product system, including road infrastructure. The user is required to have an environmental knowledge of materials and processes in order to create a model and produce environmental assessments. Assessments made in SimaPro need more time than in LICCER and KlimatKalkyl since every process or material has to be modelled and linked with a specific database. The results produced from SimaPro can correspond to different environmental impacts like global warming, eutrophication, acidification, primary energy consumption and water use. It is up to the user to define the most suitable impact category in order to interpret the results. For the purpose of this comparative study the impact categories that were used in SimaPro V8.0.4.30 were Cumulative energy Demand V1.09 and Greenhouse Gas Protocol V1.01 as they are modelled in EcoInvent 2.0 version.

Trafikverket is interested in comparing and evaluating the KlimatKalkyl model outputs with the ones from LICCER and SimaPro. Therefore in this study the tools were compared by the means of:

1. Recalculating the predefined elements from KlimatKalkyl with LICCER
2. Recalculating a Swedish case study in LICCER with KlimatKalkyl
3. Calculating a project in Sweden provided by Trafikverket in KlimatKalkyl, LICCER and SimaPro.

The comparison was performed for the two available versions of KlimatKalkyl (i.e. v2.0 and v3.0), version v1.0 of LICCER and version 8.0 for SimaPro. The study focuses on evaluating the outcomes from all models based on their results mainly, so without concentrating as such on the model structure underlying the calculations. Due to the different inputs required for each model, adjustments were needed in order to align calculations to start from the input values. The input values and the modifications made are explained for each case study.

The structures of the LICCER, KlimatKalkyl v2.0 andv3.0 were also qualitative compared in order to identify their similarities and differences. The table below presents the road elements, inputs and outputs included in LICCER and KlimatKalkyl. These are the ones that can be set and modified in the tools. The elements that are presented as missing, are either not included in the tool, or included with a default value.

Differences between LICCER and KlimatKalkyl Skillnader mellan LICCER och KlimatKalkyl				
Road element		**LIC**	**KK3**	**KK2**
Included road elements / Inkluderade vägelement	New road / Ny väg	V	V	V
	Extended road / Breddad väg	V	V	V
	Bridge / Bro	V	V	V
	Tunnel / Tunnel	V	V	V
	Road under groundwater / Väg under grundvattennivån	V		
	Roundabout / Cirkulationsplats		V	V
	Rest Areas / Trafikplats		V	V
	Cyclists lane / Cykelväg	V	V	V
	Pedestrians walk / Gångväg	V	V	V
	Option for existing roads (calculating only the operation phase) / Alternativ för befintliga vägar (beräkna endast driftsfasen)	V		
Minimal road inputs needed / Nödvändig indata	Number of driving lanes / Antal körfält	V	V	V
	Adjustable lane width / Justerbar körfältsbredd	V		
	Hard / Soft shoulders / Vägren (belagd/obelagd)	V		
	Middle guardrail / Mitträcke	V	V	V
	Side guardrail / Sidoräcke	V	V	V
	Ditch / Dike	V		
	Street lighting / Vägbelysning	V		
	Ventilation for tunnels / Tunnelventilation	V	V	V
Optional road inputs / Valfri indata	Pavement section under guardrail / Mittremsa	V		
	Selection of guardrail material / Val av material i skyddsräcke	V	V	
	Bounded material selection / Bundet bärlager	V		
	Unbounded material selection / Obundet bärlager	V		
	Thickness of bounded base / Tjocklek av bundet bärlager	V	V	
	Thickness of unbounded base / Tjocklek an obundet bärlager	V	V	
	Bridge material selection / Bromaterial	V	V	
	Soil excavation / Jordschakt	V	V	V
	Rock excavation / Bergschakt	V	V	V
	Soil filling / Jordfyllning		V	
	Rock filling / Bergfyllning		V	
	Input for fuel consumption for earthworks / Indata för bränsleförbrukning för markarbeten	V		
	Soil stabilization / Grundförstärkning	V	V	V
Traffic inputs / Indata för trafik	Annual Average Daily Traffic (AADT)/Årsmedeldygnstrafik (ÅDT)	V	V	V
	For maintenance calculations / För beräkning av underhåll		V	V
	For future traffic estimation / För uppskattning av framtida trafikmängder	V		
	Results on Life cycle energy and GWP from traffic / Trafikrelaterad resultat för primär energianvändning och GWP	V		
Results presentations / resultatpresentation	Total project impact / Totalt projektpåverkan		V	V
	Life cycle energy (GJ) / Primär energianvändning (GJ)	V	V	V
	Global Warming Potential (CO_2 –eq.) / Global uppvärmningspotential (CO_2 –ekv.)	V	V	V
	Project impact per year / Projektets påverkan per år	V	V	V
	Impact by life cycle stage / Påverkan fördelat på livscykelfaser	V	V	V
	Impact by road type / Påverkan föredelat på olika vägtyper	V	V	
	Impact by material type / Påverkan fördelat på materialtyper	V		
	Alternative project scenarios / Alternativa projektscenarier	V		

2. Predefined road elements in KlimatKalkyl v3.0

I denna fallstudie omräknades de fördefinierade vägelementen från KlimatKalkyl v3.0 i LICCER och KlimatKalkyl v2.0. En längd på 1 km antogs för alla fördefinierade väg element i KlimatKalkyl v3.0 (ny väg, utbyggd väg, tunnel och bro). Varje vägelement finns tillgängligt i tre versioner baserat på antal filer. Dessa filer har en fix bredd och är kopplade till en viss mängd konstruktionsmaterial och konstruktionsprocesser. Resultaten presenteras som energianvändning, mätt i GJ/år, och global uppvärmningspotential (GWP), mätt i ton CO_2-ekvivalenter/år. Tabeller som visar förhållandet mellan KlimatKalkyl v3.0 och LICCER ingår också i resultatavsnittet. För vägelementen ny väg, utbyggd väg och bro är skillnaderna i resultatvärden små. För tunnlar ger KlimatKalkyl v3.0 högre skattningar än LICCER för energianvändning och GWP under driftsfasen. Detta beror främst på de värden som används i KlimatKalkyl v3.0 och LICCER för att beskriva elanvändning

The inputs from the predefined road elements in KlimatKalkyl v3.0 were used to recalculate these road elements in LICCER and KlimatKalkyl, v2.0. A length of 1 km was assumed for all predefined road elements in KlimatKalkyl v3.0 (new road, extended road, tunnel and bridge). Every road element has one to three lane versions with different widths which are linked with different values of road width. All predefined road elements in KlimatKalkyl v3.0 relate to different amounts of materials and energy used for the construction and operation of the road type. This applies also for each lane version of the specific road element. Processes like soil and rock excavation or use of materials like asphalt and concrete, were to the extent possible inserted as input values in LICCER and KlimatKalkyl v2.0 to recalculate the predefined road elements from KlimatKalkyl v3.0.The amount of excavated rock for tunnels is predefined in LICCER, however, and is calculated by default from the volume of tunnels. These values cannot be modified in LICCER. KlimatKalkyl v3.0 and v2.0 also contain default values for rock excavation, but also offer the possibility to insert user-defined values. The predefined tunnels from KlimatKalkyl v3.0 were therefore first recalculated with the default values for excavated rock (indicated by Tunnel* in the results presentations). Next, the predefined tunnels in KlimatKalkyl v3.0 (and in KlimatKalkyl v2.0 as well) were recalculated after adjusting the default values for excavated rock to the same volume of excavated rock as calculated in LICCER with default values (indicated by Tunnel in the results presentations. Tunnel is considered to be constructed through rock mass and the bridge material is concrete. More details about the different construction values of the road elements can be found in Table A.1 in the appendix.

The preset lane widths for the same road elements can vary between KlimatKalkyl v3.0 and v2.0. Furthermore, the extended road elements in KlimatKalkyl v3.0 are not specified by the number of lanes, but by their absolute number in meters of width extension. Therefore, a combination of different widths from KlimatKalkyl v3.0 are used in order to enable in the best possible way the comparison with the new road elements of one, two and three lanes.

The results from the three tools LICCER (LIC), KlimatKalkyl v3.0 (KK3) and KlimatKalkyl v2.0 (KK2) are per number of lanes presented for the different road elements, and also communicate the breakdown to the various life cycle stages. The results are separately presented and discussed for life cycle energy and global warming potential (GWP).

2.1 Results and discussion

2.1.1 Life cycle energy

Figure 1 presents the results for life cycle energy in GJ/year consumed in every life cycle stage of the various road elements. It is necessary to mention here that KlimatKalkyl v3.0 and v2.0 present the results only in two life cycle phases which are construction and operation/maintenance. One the other hand LICCER provides results for production of materials, construction, operation and end of life phase. For this reason the construction phase in KlimatKalkyl will be compared with the sum of production and construction on LICCER.

The results from KlimatKalkyl v3.0 and LICCER for one and two lanes of new road and extended road are very close to each other only with small differences in the values for the life cycle stages. For the two lanes extended road, however, life cycle energy is more than double in KlimatKalkyl v3.0 compared to LICCER. As it is seen from Table 1, the ratio between KlimatKalkyl v3.0 and LICCER for the rest of the results for new road and extended road is around 1,0 and 1,3. The results for KlimatKalkyl v2.0 are in general higher than for KlimatKalkyl v3.0. The reason for that can be the level of the simplifications and assumptions that took place during the tool development.

Table 1: Ratio between KlimatKalkyl v3.0 and LICCER as calculated for the life cycle energy of the different road elements

Tabell 1: Kvoten mellan KlimatKalkyl v3.0 och LICCER beräknad för primär energianvändning för de olika vägelementen

Life cycle energy KK3/LIC Livscykelenergi KK3 / LIC			
	1-lane	2-lanes	3-lanes
New Road / Ny väg	1.03	1.10	1.31
Extended Road / Breddning väg	1.03	2.43	1.12
Tunnel / Tunnel	7.44	10.02	10.46
Bridge / Bro	1.03	0.75	0.69

The life cycle energy results for the tunnels are very different between KlimatKalkyl v3.0 and LICCER. Especially the operation and maintenance phase for both KlimatKalkyl v3.0 and v2.0 seems to be extremely high compared to LICCER. This phase includes processes like tunnel lighting and ventilation. One explanation for this difference is that LICCER and KlimatKalkyl use data from different sources regarding the electricity demand for the tunnel and the impact factors that are linked with processes of electricity consumption. Table 3 in the next section presents the values that each tool uses for this purpose.

Bridges are considered as a complicated construction works with many aspects that should be considered during the road design phase. This creates the necessity to take into considerations assumptions that can help for the life cycle impact estimations. Additionally this increases the uncertainty of the model hence it is difficult to make conclusions. Nevertheless LICCER and KlimatKalkyl v3.0 present almost similar values of life cycle energy for the one lane bridge. In bridge width of two and three lanes the differences increase with LICCER having the higher values.

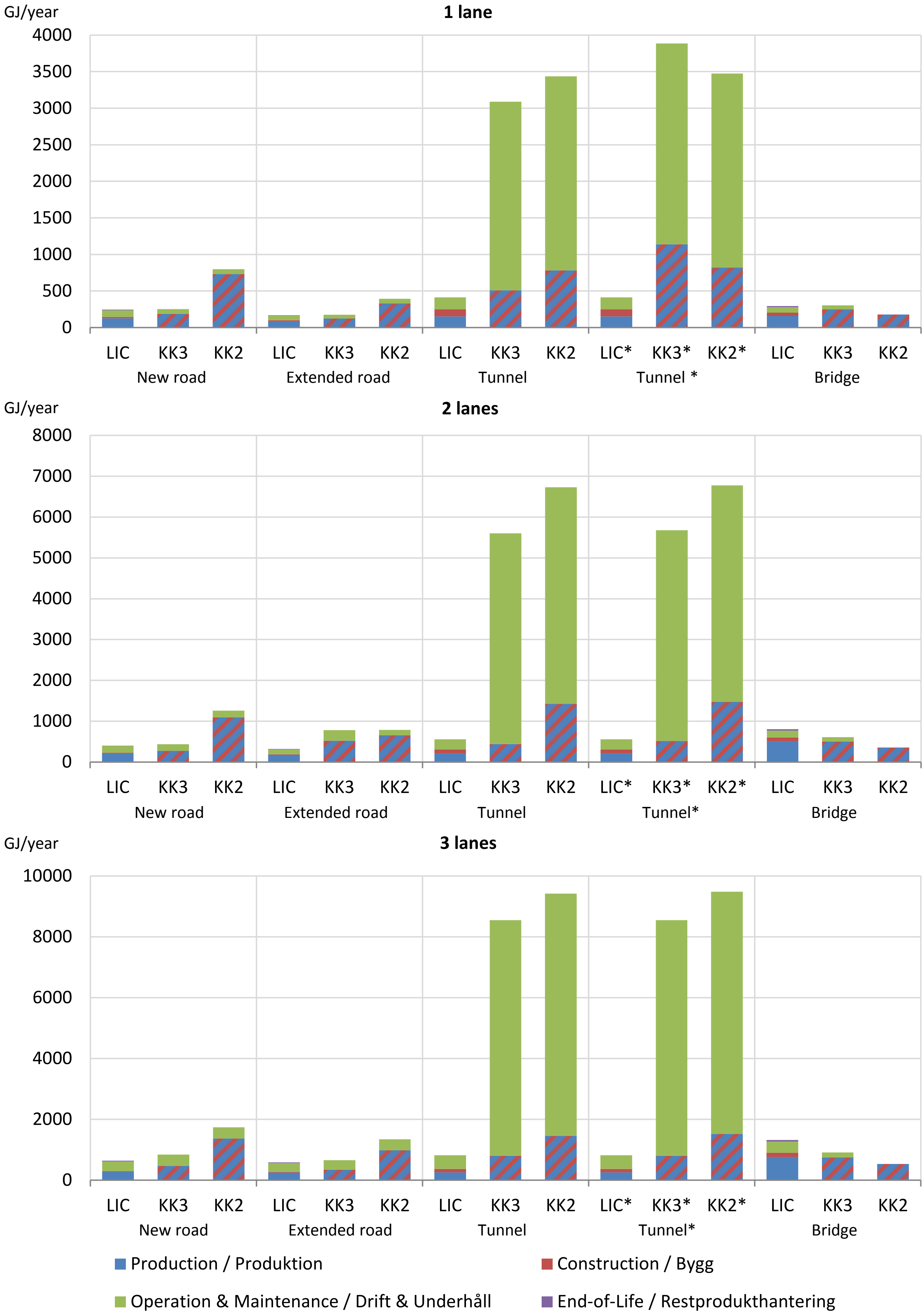


Figure 1: Yearly life cycle energy as calculated with LICCER (LIC), KlimatKalkyl v3.0 (KK3) and v2.0 (KK2) for the different road elements per number of lanes.

Figur 1: Årlig livscykelenergi beräknat med LICCER (LIC), KlimatKalkyl v3.0 (KK3) och v2.0 (KK2) för de olika vägelementen per antal körfält.

2.1.2 Life cycle Global Warming Potential (GWP)

Figure 2 presents the life cycle GWP results, expressed in CO_2 -eq. emissions for the different life cycle stages of the road elements. The results for life cycle GWP follow the results for life cycle energy for the new roads and the extended roads for all models. Also life cycle GWP results are close for LICCER and KlimatKalkyl v3.0, except for the case of 3 lanes new road that in KlimatKalkyl v3.0 is higher than in LICCER. The ratio between KlimatKalkyl v3.0 and LICCER for the new road and extended road is between 1,1 and 1,86 as it can be seen in Table 2.

Compared to LICCER and KlimatKalkyl v2.0, KlimatKalkyl v3.0 shows for the tunnels a peak in GWP that comes from high values in the operation phase. The operation phase is higher than construction phase, something that is not happening in the values for KlimatKalkyl v2.0. Life cycle GWP for the production and construction phase of the tunnel is in LICCER higher than in KlimatKalkyl v3.0.

Table 2: Ratio between KlimatKalkyl v3.0 and LICCER as calculated for the life cycle Global Warming Potential (GWP) of the different road elements

Tabell 2: Kvoten mellan KlimatKalkyl v3.0 och LICCER beräknad för global uppvärmningspotential (GWP) för de olika vägelementen

Global Warming Potential KK3/LIC Klimatgasutsläpp KK3/LIC			
	1-lane	2-lanes	3-lanes
New Road / Ny väg	1.14	1.21	1.86
Extended Road / Breddning väg	1.10	1.17	1.37
Tunnel / Tunnel	2.80	3,92	4.31
Bridge / Bro	0.95	0.91	0.88

Regarding the bridge section in LICCER and KlimatKalkyl v3.0 the values of GWP are close to each other with small differences. The gap between the two tools increases as the width of the bridge increases. As in life cycle energy LICCER also here produces the highest value among the other models, for the different bridge widths.

By investigating the reason of this big difference in the tunnel operation among the tools, it was found that the values that correspond in the electricity consumption and impact factors have significant differences.

Table 3 below presents the energy demand for lighting and ventilation during the operation of 1km tunnel with 1 lane. Also this table includes the CO_2 emissions and primary energy consumption factors for the electricity consumption in Sweden and Norway as well as the Nordic mix which is a combination of the emission factors from the different Nordic countries. The values were taken from the parameter values in LICCER, KlimatKalkyl v3.0 and v2.0. Emission factors from the SimaPro EcoInvent v2.0 database were taken for comparison purposes. The cells for energy demand in grey color represent the values in the specific unit the each tools uses. The emission and energy factors in grey represent the default values in LICCER.

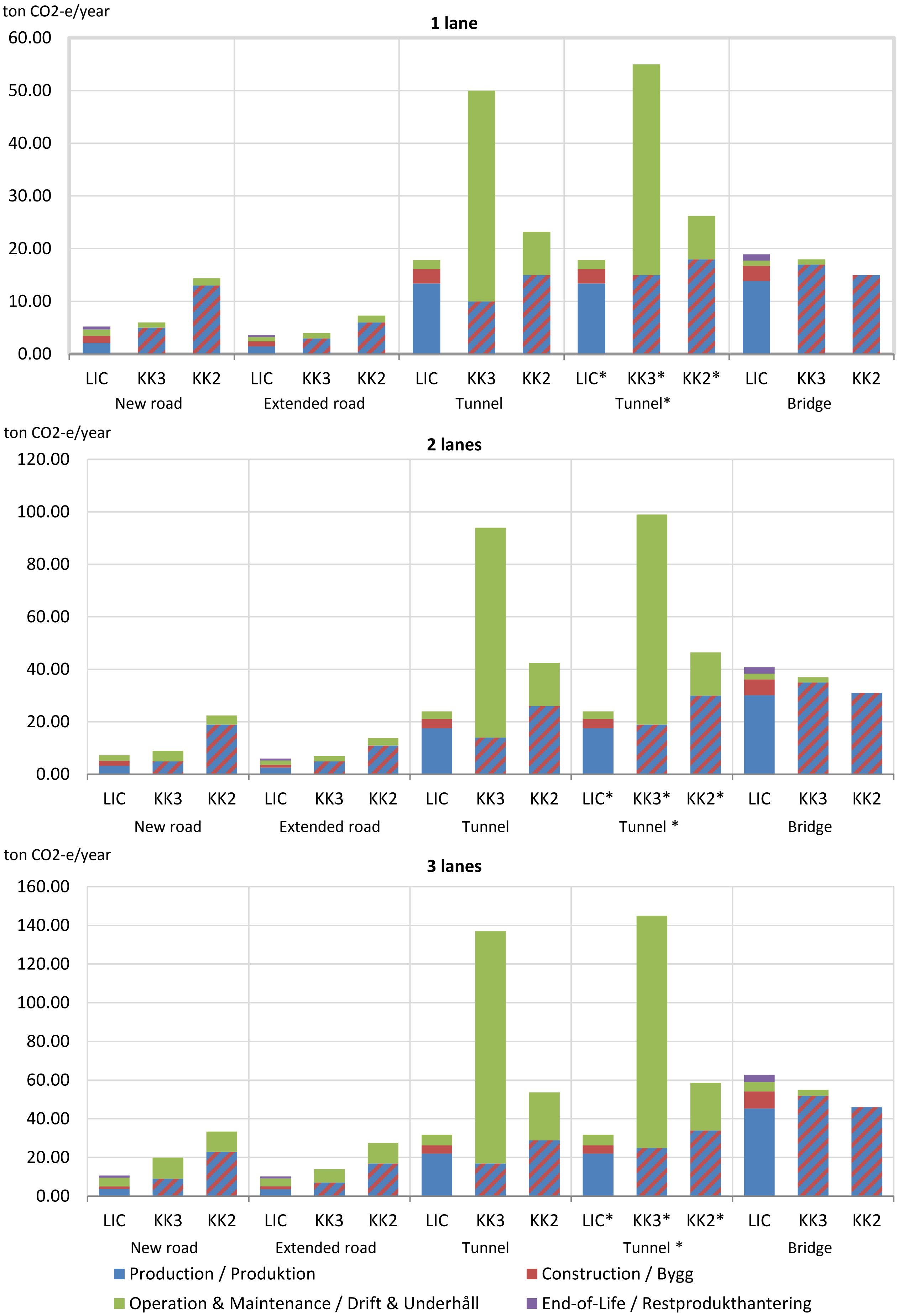


Figure 2: Yearly emissions in tons of CO_2 –eq/year for the different road elements in proportion to the number of lanes.

Figur 2: Årliga utsläpp i ton CO_2-ekvivalente/år för de olika vägelementen i förhållande till antalet körfält.

As it is observed from the table the estimated tunnel energy demand in KlimatKalkyl has higher values than in LICCER. This leads to higher primary energy consumption and CO_2 –eq. emissions

Table 3: Energy demand, emission and primary energy factors as were taken from LICCER, KlimatKalkyl v3.0, v2.0 and SimaPro. The cells in grey correspond to the original values from the tools and for comparison purposes the energy values were recalculated in MJ or kWh (3.6 MJ = 1 kWh).

Tabell 3: Energibehovet och emissions- och primärenergifaktorer som togs från LICCER, KlimatKalkyl v3.0, v2.0 och SimaPro. Cellerna i grått motsvarar de ursprungliga värdena från verktygen och för jämförelseändamål räknades värdena om i MJ eller kWh (3,6 MJ = 1 kWh).

	KK3 (lightning & ventilation)	**KK2** (lightning & ventilation)	**LICCER** (lightning & ventilation)	**SimaPro** (only ventilation)
Electricity demand (kWh/km-year)	411,766	411,766	34,000	58,400
Electricity demand (MJ/km-year)	1,482,360	1,482,360	122,400	210,240
Primary energy use (kWh/kWh) – Nordic mix	1.74			
Primary energy use (MJ/MJ) – Sweden		1.79		
Primary energy use (MJ/kWh)	6.624	6.44		
Primary energy use (MJ/kWh) – Sweden			7.56	10.56
Total primary energy use (MJ/km-year)	2,579,306	2,653,424	257,040	615,974
GHG emissions (kg CO_2-eq./kWh) – Nordic mix	0.097		0.036	
GHG emissions (kg CO_2-eq./kWh) – Sweden		0.02	0.04	0.24
Total GHG emissions (kg CO_2-eq./kWh)	40,065	8,235	1,224	3,850

2.2 Conclusions

Recalculating the predefined road elements from KlimatKalkyl v3.0 in LICCER and KlimatKalkyl v2.0 is a first attempt to compare these three models.

- LICCER and KlimatKalkyl v3.0 provide similar results with a comparison ratio between 0,7 to 1,3 for energy consumption for the new road and extended road, and the bridges. For CO_2 emissions the same factor is from 0,9 to 1,3.
- In tunnel operation great differences occur. The ration between KlimatKalkyl and LICCER is up to 10 times for energy consumption and 4 times for CO_2 emissions.
- It is found that LICCER and KlimatKalkyl v3.0 retrieve data from different sources regarding the energy demand estimations for the tunnel operation. For the same reason the emission and primary energy factors that are used in the environmental assessment are not the same between the two tools. This leads to peak values in tunnel operation in KlimatKalkyl 3.0
- The fact above can be the reason also for the differences in the other road types but on a smaller magnitude.

3. Swedish case study

Den här fallstudien är en del av LICCER-projektet, som finansierades av europeiska ERA-NET ROAD. Den handlar om väg 55 som ligger i den sydöstra delen av Sverige, mellan Norrköping och Uppsala. Den del av vägen som analyseras är en ca 7 km lång vägsträcka belägen mellan Yxtratorpet och Malmköping. Fyra alternativa vägkorridorer jämfördes (Figur 3). Ett alternativ, nollalternativet, representerade en situation där ingen förändring görs. Ett annat alternativ innebar breddning av befintlig väginfrastruktur. De andra två alternativen inkluderade båda konstruktion av nya vägavsnitt och broar. Dessa alternativ har redan utvärderats i LICCER för ett tidigare projekt. De ingångsvärden som tidigare användes i LICCER-modellen tillämpades nu i modellerna KlimatKalkyl v3.0 och v2.0. Resultaten presenteras i form av årlig energianvändning och global uppvärmningspotential (GWP) för alla fyra alternativ. Skillnaderna i de uppskattade värdena som förekommer mellan de tre verktygen beror främst på att KlimatKalkyl v3.0 och v2.0 kräver annan typ av indata än LICCER. Detta beror på att olika vägbredder är fördefinierade i de olika versionerna av KlimatKalkyl och på att det inte är möjligt att införa samma mängd markarbete i KlimatKalkyl och LICCER. Trots detta är kvoten mellan KlimatKalkyl och LICCER på samma nivå som i den första fallstudien.

As part of the LICCER-project, funded by European road-ERA-net, two case studies were analyzed. One case study involved a Swedish case study. The Swedish case study involved Road 55 located in the south-east of Sweden, between Norrköping and Uppsala. The part of the road analyzed is an approximately 7 km long road section located between Yxtratorpet and Malmköping. Four road infrastructure corridor alternatives were compared (Figure 3). One alternative, the zero alternative, represented the unchanged situation. Another alternative embodied widening of the existing road infrastructure. The other two alternatives both involved construction of new road sections and concrete bridges. These alternatives were already evaluated in LICCER for a previous project. The input values in the LICCER model were applied in KlimatKalkyl v3.0 and v2.0 models.

KlimatKalkyl v3.0 and 2.0 both have preset values for the road width. The best fitting preset widths in KlimatKalkyl have been applied according the specific value for each alternative from LICCER. The applied values can be seen from Table 4 to Table 7. This should be taken into consideration in the result comparison.

The results are presented first for the zero alternative and then the alternatives 1, 2 and 3 are presented together in order to make easier the comparison and interpretation.

Further details about the impact values can be found in the Appendix in A.2.Swedish case study

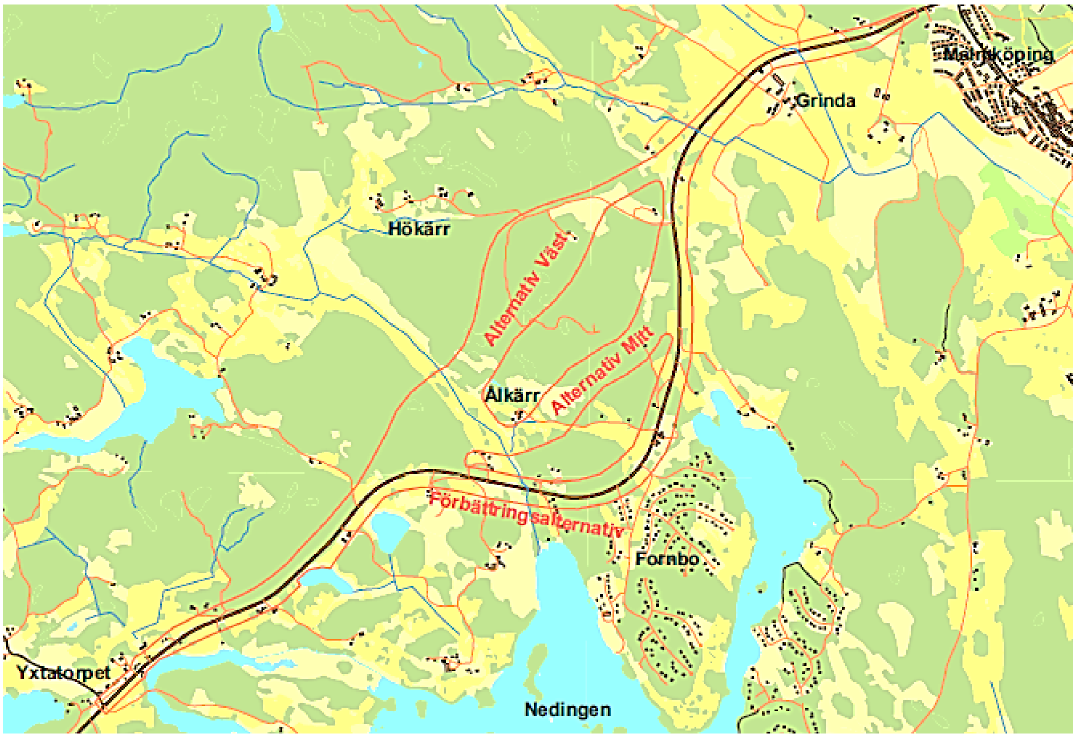


Figure 3: Schematic representation of road corridor alternatives for a section of Road 55 between Yxtatorpet and Malmköping

Figur 3: Schematisk bild av alternativa vägkorridorer till ett avsnitt av väg 55 mellan Yxtatorpet och Malmköping.

3.1 Zero alternative

This alternative includes no construction of new road or extension, just only the operation of the existing road. KlimatKalkyl does not have the option of assessing the environmental impact of an existing road. For this reason a hypothetical scenario of a new road was applied and the values for operation and maintenance were extracted in order to be compared with LICCER results.

Table 4: Dimensions and details of zero alternative road section

Tabell 4: Mått och uppgifter om vägsträckan i nollalternativet.

	LICCER	**KlimatKalkyl v3.0**	**KlimatKalkyl v2.0**
extended road / breddad väg (km)	7.574	7.574	7.574
Number of lanes / Antal körfält	2	2	2
Total road width / Totalt vägbredd (m)	9.0	8.0	8.0
Aver. An. Daily Traf. (AADT) (veh/day)	4894	4894	4894

The following results present the environmental impacts in terms of life cycle energy in GJ per year and Global Warming Potential (GWP) in tons of CO_2 emissions per year. The comparison between the three models (LICCER and KlimatKalkyl v3.0 and v2.0) is presented regarding the total amount of impacts as well as the life cycle stages of the project.

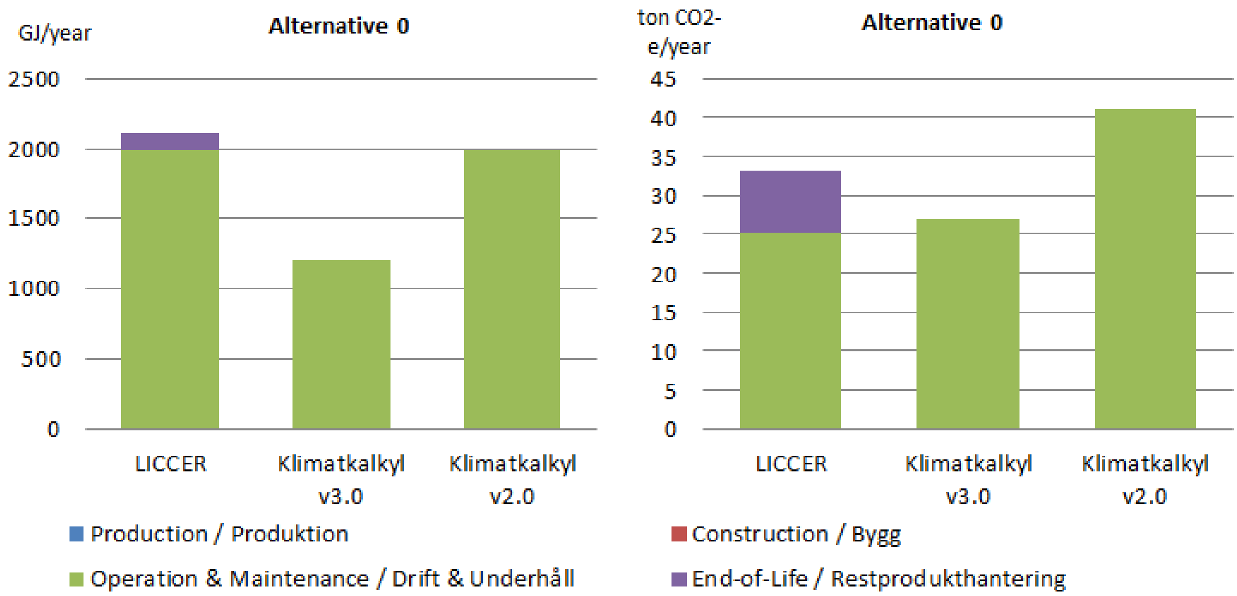


Figure 4: Yearly life cycle energy and CO_2 emissions as calculated for LICCER, KlimatKalkyl v3.0 and KlimatKalkyl v2.0 for the zero alternative.

Figur 4: Årlig energianvändning och CO_2-utsläpp beräknat med LICCER, KlimatKalkyl v3.0 och KlimatKalkyl v2.0 för nollalternativet.

In the graphs above the values for GWP in operation of this road is almost equal between LICCER and KlimatKalkyl v3.0. On the other hand in life cycle energy LICCER has similar values with KlimatKalkyl v2.0. In both graphs we can observe as well that KlimatKalkyl v2.0 provides different results than KlimatKalkyl v3.0. The impacts that come from the operation are mainly for street lighting and processes for road maintenance. In LICCER there is also consideration of the end of life phase, something that is not included in KlimatKalkyl results.

3.2 Alternative 1, 2 and 3 inputs

3.2.1 Alternative 1

This alternative investigates the scenario of extending the existing road corridor. The assessment involves material production, construction of the project, operation, maintenance and end of life. These life cycle phases are included in LICCER but KlimatKalkyl on the other hand aggregates the life cycle phases to construction and operation/maintenance.

Another thing that should be mentioned here is that the case study data acquired from LICCER have details about the road width together with the hard shoulders width and the area of the road that is below the middle guardrails. Since KlimatKalkyl has no inputs fields about these details, hard shoulders and the area below the middle guardrail were included in the total road width. Therefore in the tables below (Table 5 to Table 7) the total road width is referred to the sum of width of road, hard shoulders and area below middle guardrail.

Table 5: Dimensions and details of alternative 1

Tabell 5: Mått och information om alternativ 1.

	LICCER		KlimatKalkyl v3.0	KlimatKalkyl v2.0
extended road / breddning av väg (km)	7.574		7.574	7.574
Number of lanes / Antal körfält	2		2	2
Total road width (incl. hard shoulders) Totalt vägbredd (inkl. vägren) (m)	8.0		8.5	7.0
Hard shoulders (m)/ Vägren (asfalterad) (m)	Included (2m)		Not included	Not included
Lighting / Belysning (km)	13.2%	1.000	Not included	1.000
side guardrail / Sidoräcke (km)	15.8%	1.197	1.197	1.197
Soft shoulders / Vägren (ej asfalterad)	Included		Not included	Not included
Road ditch / Vägdike (m)	1		Not included	Not included
Aver. An. Daily Traf. (AADT) (veh/day)	4894		4894	4894

3.2.2 Alternative 2

This alternative investigates the scenario of constructing a new road, widening of an existing road and constructing a bridge section.

Table 6: Dimensions and details of alternative 2

Tabell 6: Mått och uppgifter om alternativ 2.

	LICCER		KlimatKalkyl v3.0	KlimatKalkyl v2.0
new road (km) / ny väg	2.579		2.579	2.579
Number of lanes / Antal körfält	3		3	3
Total road width (incl. hard shoulders) / Total vägbredd (inkl. vägren) (m)	13.95		14	11.5
Hard shoulders / Vägren (asfalterad)	Included (2m)		Not included	Not included
Center guardrail / Mitträcke (km)	100.0%	2.579	2.579	2.579
Side guardrail / Sidoräcke(km)	40.7%	1.050	1.050	1.050
Soft shoulders / Vägren (ej asfalterad)	Included		Not included	Not included
Road ditch / Vägdike(m)	1		Not included	Not included
extended road (km) / breddad väg	4.434		4.434	4.434
Number of lanes / Antal körfält	2		2	2
Total road width (incl. hard shoulders) / Total vägbredd (inkl. vägren) (m)	8.0		7.0	7.0
Hard shoulders / Vägren (asfalterad)	Included (2m)		Not included	Not included
Center guardrail / Mitträcke (km)	100.0%	4.434	4.434	4.434
Side guardrail / Sidoräcke(km)	11.3%	0.501	0.501	0.501
Soft shoulders / Vägren (ej asfalterad)	Included		Not included	Not included
Road ditch / Vägdike(m)	1		Not included	Not included
concrete bridge / Betongbro(km)	0.021		0.021	0.021
Number of lanes / Antal körfält	3		3	3
Total road width / Totalt vägbredd (m)	11.95		11.95	11.95
Center area of guardrail / Mittremsa	Included		Included	Included
Total bridge road surface / Total broyta (m2)	-		250.95	250.95
Aver. An. Daily Traf. (AADT) (veh/day)	4894		4894	4894

3.2.3 Alternative 3

Alternative 3 includes a construction of a new road, a widening of an existing road and a construction of a bridge section. The difference with alternative 2 is that the new and extended road have different lengths. Also there are some small changes in the use of side and middle guardrails.

Table 7: Dimensions and details of alternative 3

Tabell 7: Mått och uppgifter om alternativ 3.

	LICCER		**KlimatKalkyl v3.0**	**KlimatKalkyl v2.0**
new road (km) / ny väg	2.979		2.979	2.979
Number of lanes / Antal körfält	3		3	3
Total road width (incl. hard shoulders) / Total vägbredd (inkl. vägren) (m)	13.95		14	11.5
Hard shoulders / Vägren (asfalterad)	Included (2m)		Not included	Not included
Center guardrail / Mitträcke(km)	64.0%	1.907	1.907	1.907
Side guardrail / Sidoräcke(km)	64.0%	1.907	1.907	1.907
Soft shoulders / Vägren (ej asfalterad)	Included		Not included	Not included
Road ditch / Vägdike(m)	1		Not included	Not included
extended road (km) / breddad väg	3.794		3.794	3.794
Number of lanes / Antal körfält	2		2	2
Total road width / total vägbredd (m)	8.0		7.0	7.0
Hard shoulders / Vägren (asfalterad)	Included (2m)		Not included	Not included
Center guardrail / Mitträcke (km)	11.0%	0.417	0.417	0.417
Side guardrail / Sidoräcke(km)	11.0%	0.417	0.417	0.417
Soft shoulders / Vägren (ej asfalterad)	Included		Not included	Not included
Road ditch / Vägdike(m)	1		Not included	Not included
concrete bridge / Betongbro (km)	0.021		0.021	0.021
Number of lanes / Antal körfält	3		3	3
Total road width / Total vägbredd (m)	11.95		11.95	11.95
Center area of guardrail / Mittremsa	Included		Included	Included
Total bridge road surface / Broyta (m2)	-		250.95	250.95
Aver. An. Daily Traf. (AADT) (veh/day)	4894		4894	4894

3.3 Results alternative 1, 2 and 3

The following results show that KlimatKalkyl v3.0 is insensitive for the changes of the scenario inputs, which obviously follows from working with predefined elements. LICCER on the other hand, needs more user-specific data for input than KlimatKalkyl v3.0 and (v2.0) thus is more sensitive in the scenario changes. LICCER provides results with lower values compared to KlimatKalkyl v3.0 but also with small variations among the alternatives. It is also noticeable that in LICCER the life cycle energy for the operation phase is higher than the other life cycle phases. The operation phase includes also maintenance of the road surface and layers. LICCER divides the bounded base into two sections while KlimatKalkyl has only one section. Therefore in the maintenance part more processes are included in LICCER. KlimatKalkyl values in life cycle energy are also 1.25 times higher than the ones from LICCER.

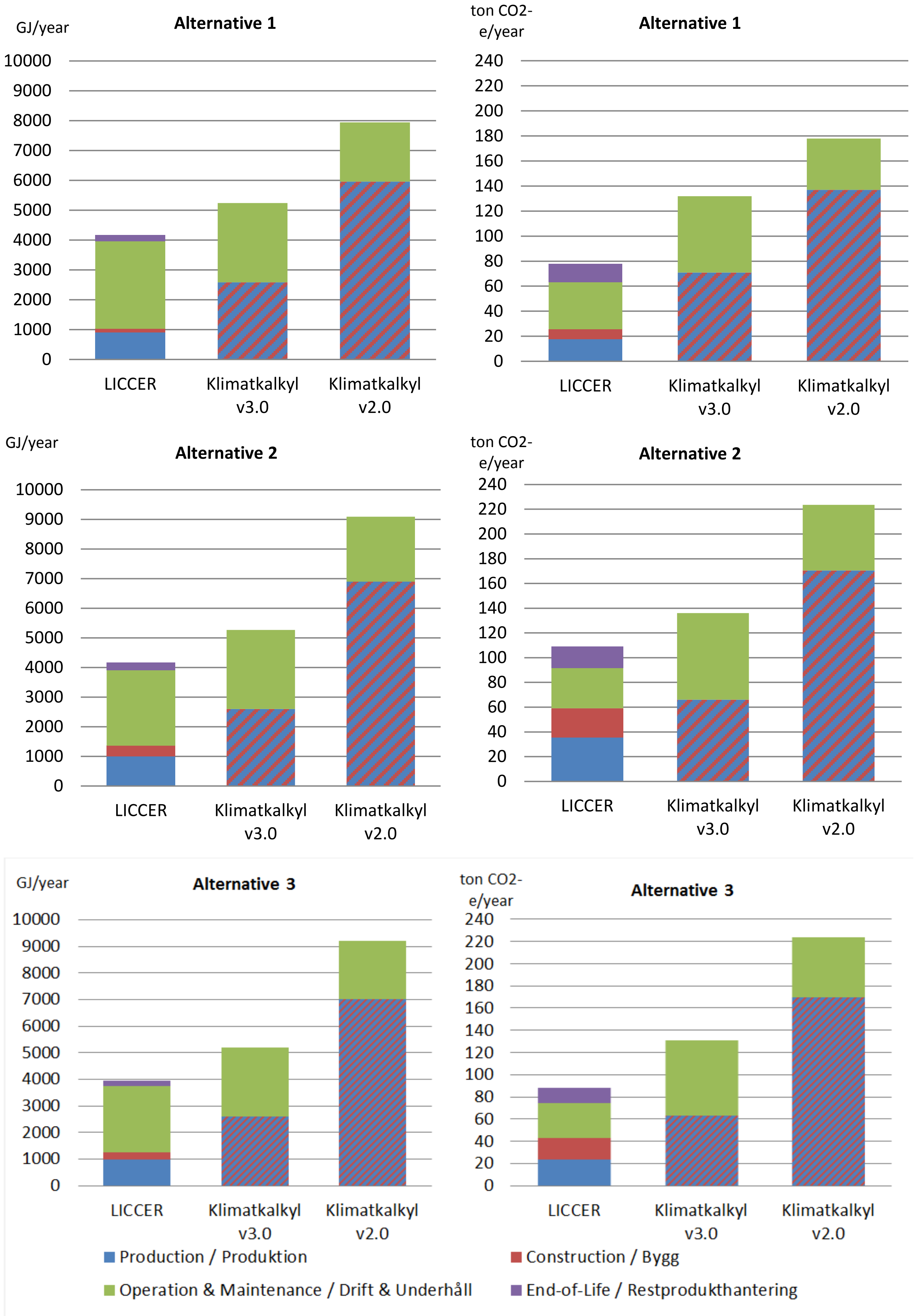


Figure 5: Yearly life cycle energy and CO_2 emissions for alternatives 1, 2 and3

Figur 5: Årlig primär energianvändning och CO_2-utsläpp för alternativ 1, 2 och3, This pattern is the same for all three alternatives. There are no big differences in the values of life cycle energy or GWP among the three alternatives. Especially the life cycle energy seems to be stable around 5200 GJ/year for KlimatKalkyl v3.0.

The next series of graphs present the distribution of yearly life cycle energy for the different road sections and bridge for alternatives 2 and 3

Figure 6 shows that the biggest energy consumption comes from the new road construction and road extension. The bridge construction has very low amount of energy consumption for the project life cycle due to short length. It is also observed that life cycle energy consumption in Kllimatkalkyl v3.0 is around 1.25 times higher than in LICCER for the results of the new and extended road. In LICCER the amount of energy consumed for the operation phase of the new and extended road is higher than the rest of the phases.

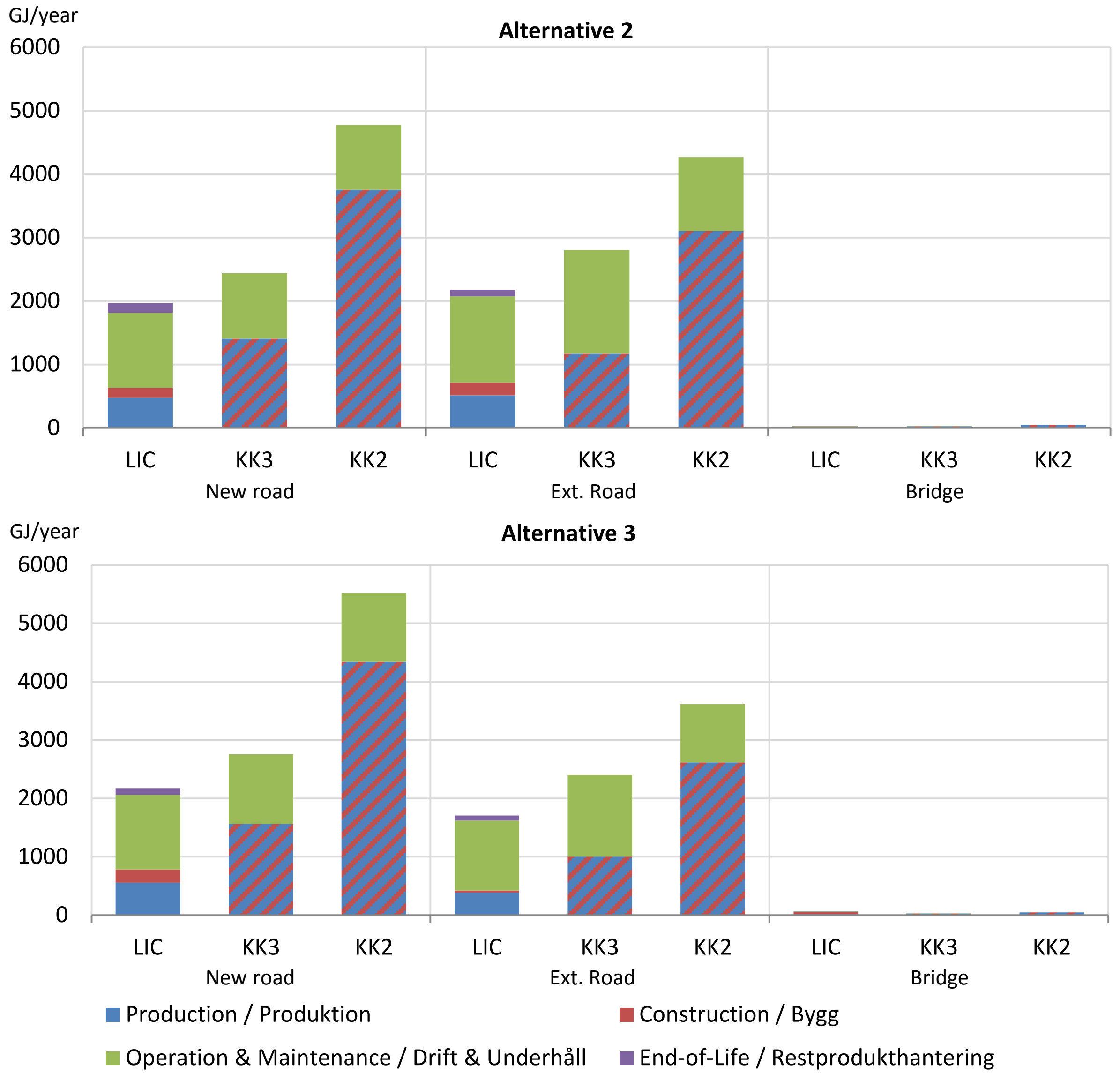


Figure 6: Life cycle energy for the various road sections in alternative 2 and 3

Figur 6 Energianvändning för de olika vägsträckorna i alternativ 2 och 3

The following set of results presents the yearly life cycle amount of GWP for the various road elements. LICCER and KlimatKalkyl v3.0 present almost the same values for the new road in both alternatives. On the other hand there is a significant change for extended road values between alternative 2 and 3. This is caused mainly because of the decrease in length on the extended road.

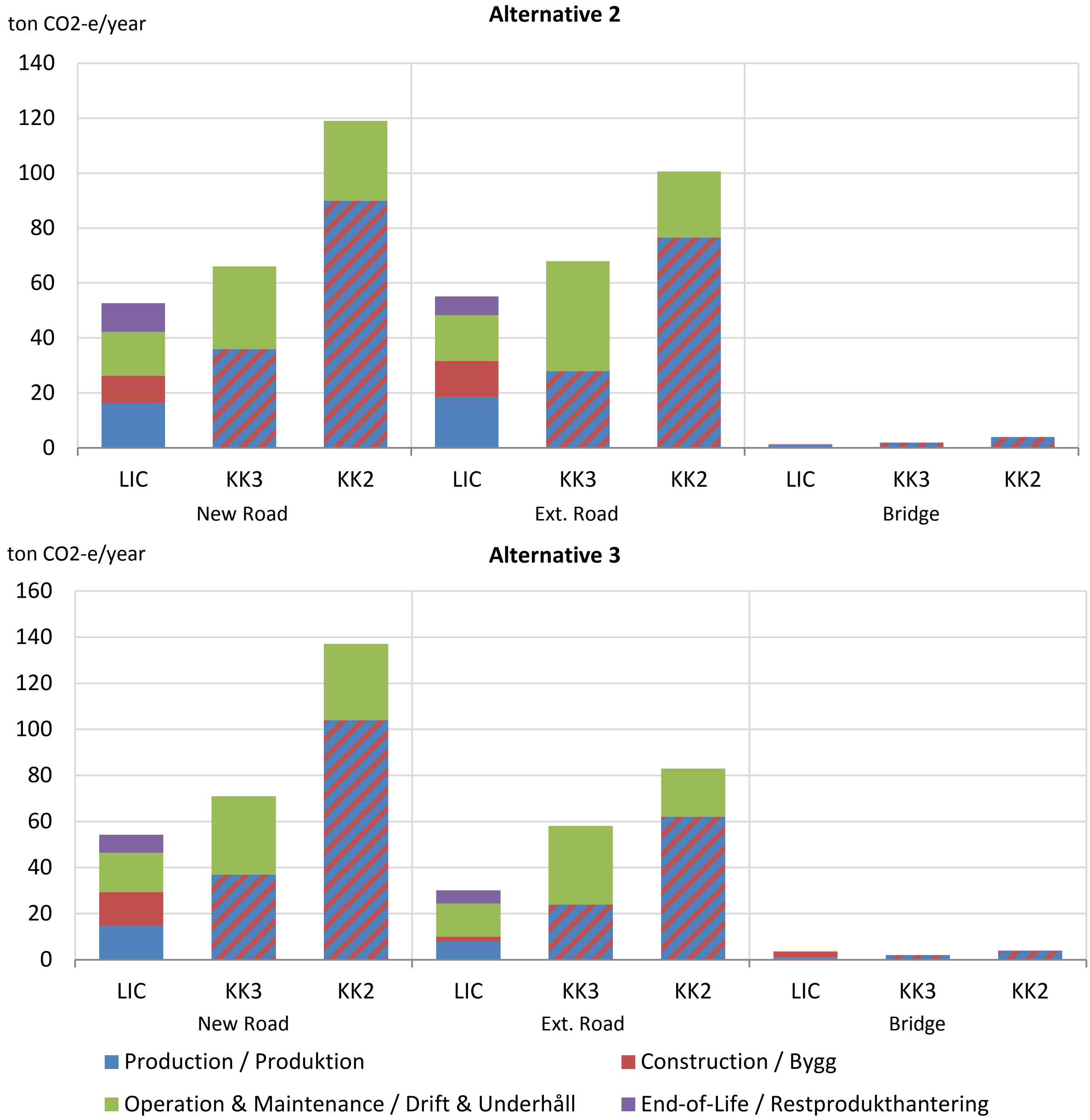


Figure 7: GWP for the various road sections in alternative 2 and 3

Figur 7: GWP för de olika vägsträckorna i alternativ 2 och 3.

3.4 Discussion

Comparing this case study with the previous example of the predefined elements we can observe that KlimatKalkyl V3.0 continues to provide similar results with LICCER, but these results are less similar than reproducing predefined KlimatKalkyl road elements with LICCER. The Swedish case study included the elements of new road, road extension and bridge. These elements when they were studied in the “predefined elements” case study they had similar impacts in LICCER and KlimatKalkyl v3.0. That was basically because as it was mentioned previously, KlimatKalkyl has predefined dimensions for the road types.

In this case study where we reproduce previous case studies from LICCER with KlimatKalkyl, it should be mentioned that the input data for the above alternatives in LICCER deviate from the data underlying the predefined elements in KlimatKalkyl v3.0 and v2.0. So the recalculations with KlimatKalkyl were not exactly the same. Thus if a road of 3 lanes and 12.2 m width is from the Swedish case study in LICCER is to be evaluated, then in KlimatKalkyl v3.0 these 3 lanes will have to be approximated with a width of 14 m. This creates confusion in the result interpretation since the differences in material amount can be large.

In LICCER the amount of earthworks can be defined with the amount of fuel consumed. This cannot be applied in KlimatKalkyl. Therefore the selection of earthworks in KlimatKalkyl v3.0 was set in default. In case which the amount of excavated soil or rock was known the results might be different.

The results that LICCER and KlimatKalkyl v3.0 provide have the same pattern of changes among the different scenario alternatives. The ratio between KlimatKalkyl v3.0 and LICCER for the life cycle of the projects was most of the times around 1.25. Also from the comparison of the alternatives it was shown that both tools are stable in small changes in the inputs

3.5 Conclusion

In this case study four alternatives of a project were chosen in order to check and demonstrate the comparison of LICCER and KlimatKalkyl v3.0. The main purpose of all the alternatives is to connect point A with point B.

- LICCER and KlimatKalkyl provided similar results for all the alternatives with small variations in some life cycle phases.
- Construction phase has differences between LICCER and KlimatKalkyl v3.0 and this is due to:
    - different input formats between the two tools
    - fixed predefined values in KlimatKalkyl for road width
    - the fact that LICCER has more detailed inputs for the earthwork processes

- In the operation and maintenance phase, LICCER has greater values for energy and emissions. Bounded and unbounded base is more detailed in LICCER than in KlimatKalkyl therefore this lead to more described processes for maintenance in LICCER.
- LICCER divides the outcomes in more life cycle categories that KlimatKalkyl. This helps to understand the distribution of impacts and whether these come from the materials or the construction phase.
- KlimatKalkyl includes only two life cycle phases of construction and operation/maintenance. It is not considering the end of life phase.
- KlimatKalkyl gives in most of the cases higher values than the construction phase in LICCER. This can be due to different calculation methods for construction processes, or different connections to environmental impact data.
- KlimatKalkyl v3.0, as it is mentioned, has predefined road elements that were developed and based on the needs of Trafikverket for road and railway projects in Sweden. Therefore this tool has low level of flexibility and application in projects that are handled outside of Trafikverket.

4. Trafikverket LCA case study

Den följande bedömningen handlar om ett hypotetiskt projekt från Trafikverket som innehåller tre alternativ (A, B och C) för en vägförbindelse antagningsvis i Sverige. Dessa alternativ inkluderar olika vägelement såsom byggandet av ny väg, bro, l cut-and-cover tunnel, och de sekundära vägar som tjänar huvudvägen. Trafikverket bistod med projektdetaljer och vägdimensioner och data tillämpades sedan för en jämförelse i LICCER, KlimatKalkyl v3.0 och SimaPro. Alternativ A består av en ny väg, ett brosegment och de sekundära vägarna. De sekundära vägarna är främst de delar som förbinder huvudvägen med omkringliggande områden. Gång- och cykelvägar är också inkluderade i de sekundära vägarna. Alternativ B består av en ny väg, bro, cut-and-cover tunnel och de sekundära vägarna. Alternativ C har samma geografiska läge som alternativ B, men i stället för cut-and-cover tunnel finns ett öppet vägavsnitt. Ändringar inträffade för alternativ B därför kallas det för gamla alternativ B i resultatdelen. De resultat som presenteras för energianvändning och GWP indikerar att skillnaderna är små mellan resultat från LICCER och KlimatKalkyl v3.0. SimaPro däremot ger resultat med högre värden jämfört med de andra verktygen för alla alternativ. Detta beror på att SimaPro kan anpassas och kan kombinera alla de processer som ingår i ett vägbygge. LICCER och KlimatKalkyl är begränsade på så sätt att det finns processer och effekter som inte ingår i dessa verktyg.

I avsnitt 4.4 finns en trafikbedömning beräknad i LICCER för alternativ A och B. Trafikvärden tillhandahölls av Trafikverket. Resultaten ger uppskattningar på trafikens totala miljöpåverkan mätt i primär energianvändning och GWP för 40 års användning av vägen och en årlig trafikökning på 0 % och 1,5 %.

The following assessment is about a hypothetical project provided by Trafikverket that includes three alternatives (A, B and C) for a road connection assumingly in Sweden.

Alternative A consists of a new road, a bridge segment and the secondary roads. The secondary roads are mainly the sections that connect the main road with the surrounding areas. Pedestrian and cyclists lanes are also included in the secondary roads. Alternative B consists of a new road, bridge, a cut and cover tunnel and the secondary roads as well. Alternative C has the same geographical position of alternative B but in the place of the cut and cover tunnel in B there is an open road section.

The set of data for the above alternatives were provided by Trafikverket. All the dimensions of the road sections as well the material amounts are described in the appendix section.

The alternatives were set for comparison in LICCER, KlimatKalkyl and SimaPro. The impact categories that were used in SimaPro were Cumulative Energy Demand and Greenhouse Gas Protocol as they are modelled and described in the EcoInvent V2.2 database.

The following is a list of the materials and processes that are included in SimaPro calculations for alternatives B and C. More details as well the specific amounts can be found in the excel files appended with this report.

- Main road
  - Excavation & transportation of excavated soil/rock
  - Filling & transportation of filled soil/rock
  - Unbounded base (aggregates)
  - Bounded base (aggregates & asphaltic mix)
  - Concrete & steel for pipes
  - Steel for guardrails
  - Excavation for plants
- Tunnel (cut & cover) (not in Alternative C)
  - Excavation & transportation of excavated soil/rock
  - Filling & transportation of filled soil/rock
  - Bounded base (aggregates & asphaltic mix)
  - Concrete & steel for the cut & cover construction
  - Transportation of concrete & steel
- Bridge
  - Excavation & transportation of excavated soil/rock
  - Filling & transportation of filled soil/rock
  - Bounded base (aggregates & asphaltic mix)
  - Concrete & steel for the bridge construction
  - Transportation of concrete & steel
  - Steel for guardrails
- Secondary roads, pedestrians and cyclists lane
  - Excavation & transportation of excavated soil/rock
  - Filling & transportation of filled soil/rock
  - Unbounded base (aggregates)
  - Bounded base (aggregates & asphaltic mix)
  - Steel for guardrails
  - Excavation for plants

Figure 8: Schematic representation of the two alternatives for a road project in Sweden.

Figur 8: Schematisk bild av de två alternativen för ett vägprojekt i Sverige.

4.1 Results for Life cycle energy (GJ per year)

Figure 9 below presents the yearly life cycle energy consumption for the three alternatives as calculated in LICCER, SimaPro and KlimatKalkyl v3.0. The LCA report that was provided from Trafikverket presented the life cycle energy results in the units of MWh for the entire project (40 years). In order the report values to be compared with the results from LICCER and KlimatKalkyl were converted into GJ/year. During this study, changes were applied in alternative B and a new set of data was available. For this reason the following table includes both new and old version of alternative B.

In order to check the functionality of KlimatKalkyl calculation processes, the following tables include the defaults input values (KK3d) for the earthworks and general construction processes of the road elements as they have been set from KlimatKalkyl, The KK3 columns include the adjusted ones as they have been calculated in the project's bill of materials

It is observed that SimaPro produces higher results on energy consumption than LICCER and KlimatKalkyl v3.0. Also the proportion of construction in the total life cycle in SimaPro is higher than in the other tools. The processes that are selected in SimaPro for each model have a network of secondary processes that are connected with. SimaPro also calculates the impacts from the secondary processes and therefore gives higher impact assessment result values. For example the production and use of materials like concrete, as it is modelled in SimaPro, is linked with other processes like electricity consumption or use of secondary materials or resources. This increases the final impact factor of concrete production and as a result the outcomes from SimaPro can be higher than from LICCER or KlimatKalkyl. On the other hand, tools like LICCER and KlimatKalkyl use a specific value for each material or process that is acquired from a reference that describes the concrete production in a different way. It is not sure which processes are included and how they were estimated, unless someone traces back the source. Therefore the final impact factor may aggregate different values or processes.

LICCER and KlimatKalkyl v3.0 seem to have more similar life cycle energy consumption values for all of the three alternatives. The main difference is spotted in the fact that the construction phase in KlimatKalkyl v3.0 appears to be greater than the construction phase in LICCER for all alternatives. This is something that was observed in the previous case studies as well. The main processes that take part in the construction phase of a road project are the earthworks like soil/rock digging or filling and the laying of the different road base layers which can be the unbound base with aggregates and the bounded base with aggregates and asphaltic materials. Processes like soil or rock filling are not included in LICCER and according to the bill of materials there is a significant amount of soil filled for this project. Due to this the final impact in construction will be higher in KlimatKalkyl than in LICCER.

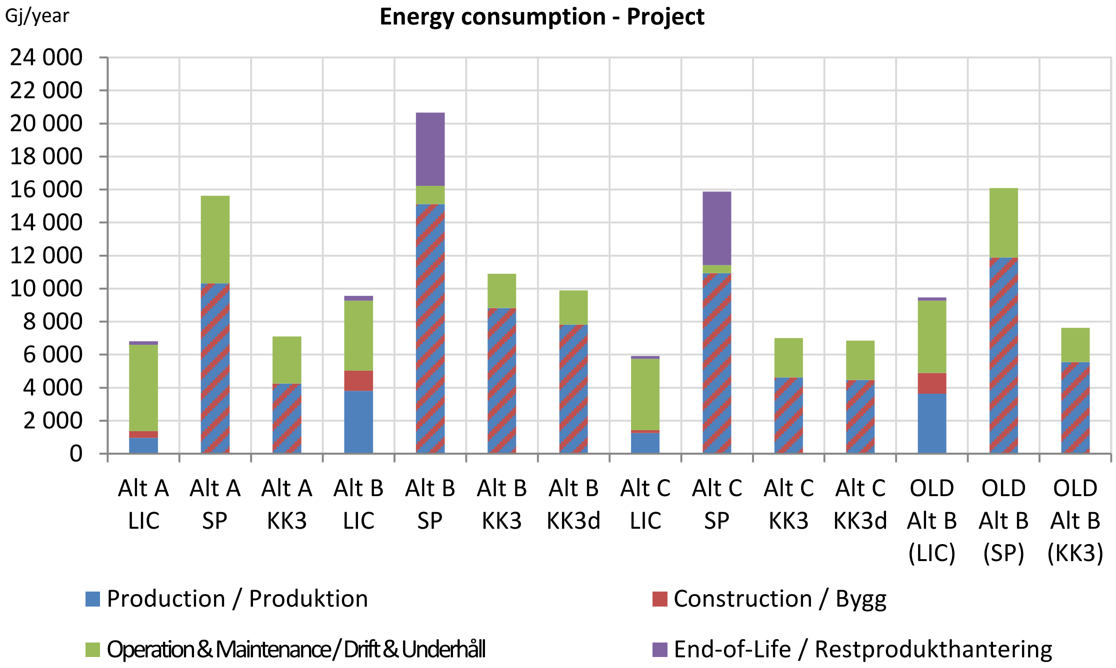


Figure 9: Yearly life cycle energy for alternative A B and C as calculated in LICCER (LIC), SimaPro (SP), KlimatKalkyl v3.0 (KK3), and default values in KlimatKalkyl v3.0 (KK3d).

Figur 9: Årlig livscykelenergi för alternativ A, B och C beräknat med LICCER (LIC), SimaPro (SP), KlimatKalkyl v3.0 (KK3), och standardvärden i KlimatKalkyl v3.0 (KK3d).

Table 8 below presents the ratio of the three tools in pairs for the results in life cycle energy consumption. It is observed that results from LICCER and KlimatKalkyl have a ratio of almost 1 while SimaPro provides outcomes that have almost 2 times higher values in comparison with LICCER and KlimatKalkyl v3.0.

Table 8: Ratio of the life cycle energy for alternative A, B and C as calculated from the results in SimaPro, LICCER and KlimatKalkyl v3.0

Tabell 8: Kvoten mellan livscykelenergi för alternativ A, B och C beräknat från resultaten i SimaPro, LICCER och KlimatKalkyl v3.0.

Ratio in Energy	SP/LIC	KK3/LIC	SP/KK3
Alt A	2.29	1.04	2.20
Alt B (new values)	2.16	1.14	1.89
Alt C	2.68	1.18	2.27

4.2 Results for Global Warming Potential (CO_2-eq. emissions per year)

Figure 10 presents the yearly Global Warming Potential (GWP) for the life cycle of the three alternatives as calculated in LICCER, SimaPro and KlimatKalkyl v3.0. The results for GWP acquired from Trafikverket report were presented in CO_2 -eq. emissions for the entire lifetime of the project (40 years) therefore they needed to be calculated for the yearly values so that they can be compared with the results from the rest tools.

It is observed that SimaPro has also the highest values for CO_2 emissions in comparison with the other tools. The reason for that is the same as in the energy results. Also alternative B is the one that has the highest impact compared with the other alternatives. This is mainly due to the tunnel section that is included in alternative B.

KlimatKalkyl most of the times provides results with an average ratio of 1,7 in comparison with LICCER. On the other hand, according to Table 9 SimaPro has lower ratio when it is compared with KlimatKalkyl v3.0 than with LICCER.

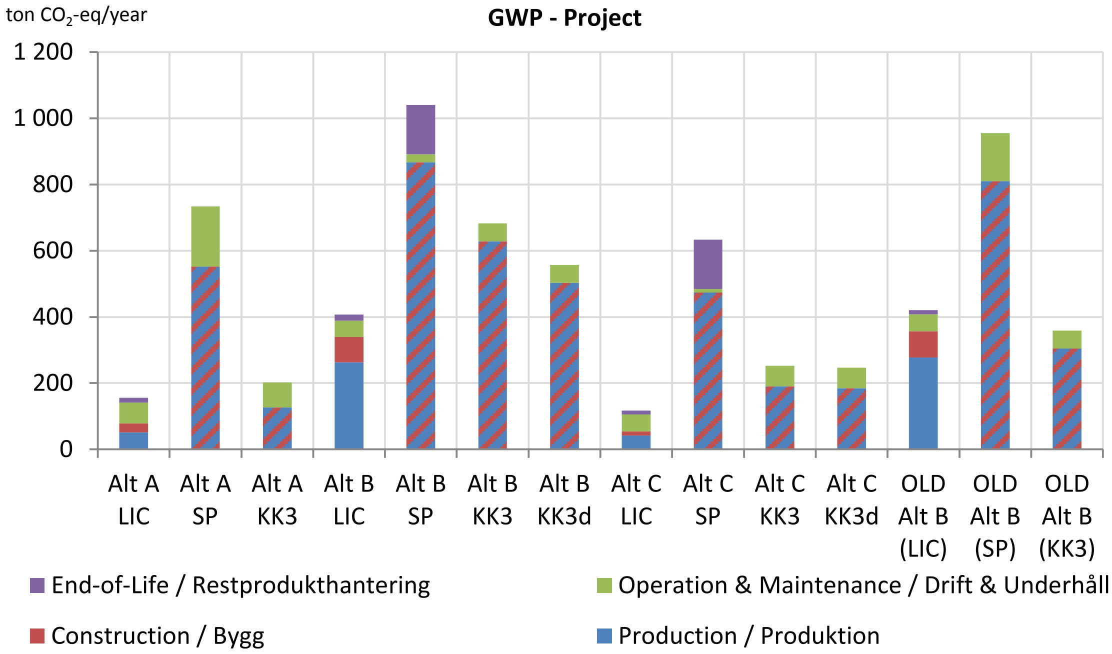


Figure 10: Yearly GWP for alternative A, B and C as calculated in LICCER (LIC), SimaPro (SP), KlimatKalkyl v3.0 (KK3), and default values in KlimatKalkyl v3.0 (KK3d)

Figur 10: Årlig GWP för alternativ A, B och C beräknat med LICCER (LIC), SimaPro (SP), KlimatKalkyl v3.0 (KK3), och standardvärden i KlimatKalkyl v3.0 (KK3d).

Table 9: Ratio of the life cycle GWP for alternative A, B and C as calculated from the results in SimaPro, LICCER and KlimatKalkyl v3.0

Tabell 9: Kvoten mellan GWP för alternativ A, B och C beräknat från resultaten i SimaPro, LICCER och KlimatKalkyl v3.0.

Ratio in GWP	SP/LIC	KK3/LIC	SP/KK3
Alt A	4.70	1.29	3.63
Alt B (new values)	2.55	1.67	1.52
Alt C	5.41	2.16	2.51

4.3 Results for the different road segments.

Separating the impacts in the different road sections can help in focusing and understanding the way that each tool models every road type.

The following graphs represent the impacts in life cycle energy and GWP only for the production/construction phase of the different road sections in alternatives A, B and C. This is because the alternatives were modeled in SimaPro in a way that the operation data and results refer to the entire life cycle and cannot be broken down into road sections.

Figure 11 presents the yearly life cycle energy consumption for the different road sections of alternatives A, B and C as calculated in LICCER, SimaPro and KlimatKalkyl v3.0. It is understood from the values that the construction of tunnel has big impact in the energy consumption and it is something that all tools agree with that. It should be mentioned as well that the tunnel has a length of 590m while the total length of alternative B is 4300 m.

The high impact of the tunnel can be understood also from the comparison of alternative B and C. In alternative C the tunnel was replaced by an open road section. Due to this, the length of new road in alternative C is bigger than in alternative B, but the final construction impact for alternative C is decreased.

Regarding the tool comparison it is observed that LICCER provides the lowest estimations for the construction phase of the road elements. It is also noticeable that the energy consumption estimations for tunnel construction are very close for all of the three tools.

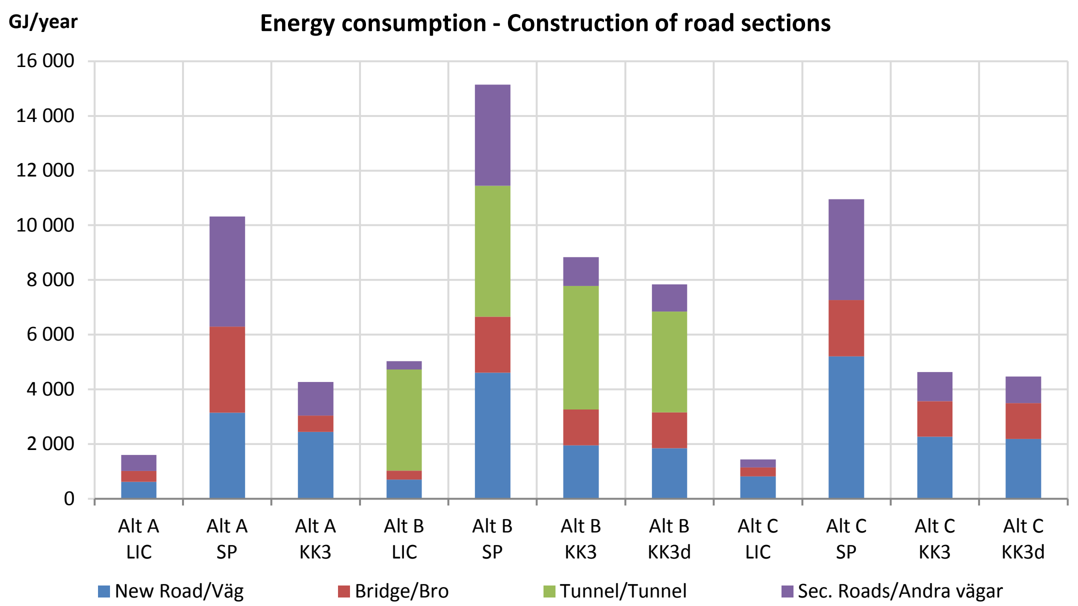


Figure 11: Yearly life cycle energy excluding operation phase for the different road sections in alternative A, B and C as calculated in LICCER (LIC), SimaPro (SP), and KlimatKalkyl v3.0 (KK3).

Figur 11: Årlig livscykelenergi exklusive driftfasen för de olika vägsträckorna i alternativ A, B och C beräknat med LICCER (LIC), SimaPro (SP), och KlimatKalkyl v3.0 (KK3).

Table 10 presents the ratio of energy consumption for the construction of the different road sections. For a better interpretation the ratio values in the table below are lower than 1,5 were colored with green and the values that are greater than 5 with red.

From Table 10 it is also observed that there a big difference in the values between SimaPro and LICCER for alternative A, B and C. On the other hand the ratio between KlimatKalkyl v3.0 and LICCER or SimaPro and KlimatKalkyl v3.0 are between 1 and 4. Tunnel section in alternative B seems to have low ratio values for all the tool combinations.

The secondary roads in alternative B and C appear to have high ratio between SimaPro and LICCER and this is due to the soil filling operations that occur during the road construction. As it is mentioned previously, soil filling is not included in LICCER therefore in the construction phase the impact is smaller than in KlimatKalkyl v3.0.

Table 10: Ratio of the different road sections for life cycle energy results excluding operation phase. The values over 5 are marked with red color and the values below 1.5 are marked with green color.

Tabell 10: Förhållandet mellan de olika vägavsnittenför livscykelenergiexklusive driftsfasen. Värden över 5 är markerade med röd färg och värden under 1,5 är markerade med grön färg.

GJ/year	**Alternative A**			**Alternative B**			**Alternative C**		
Ratio	SP/LIC	KK3/LIC	SP/KK3	SP/LIC	KK3/LIC	SP/KK3	SP/LIC	KK3/LIC	SP/KK3
New Road/Väg	5.06	3.93	1.29	6.54	2.77	2.36	6.37	2.77	2.30
Bridge/Bro	7.86	1.49	5.27	6.29	4.01	1.57	6.29	4.01	1.57
Tunnel/Tunnel	-	-	-	1.29	1.22	1.06	-	-	-
Sec. Roads/ Andra vägar	6.89	2.10	3.29	12.27	3.50	3.50	12.27	3.51	3.50
Total	**6.42**	**2.66**	**2.42**	**3.01**	**1.75**	**1.71**	**7.58**	**3.20**	**2.37**

Figure 12 presents the yearly Global Warming Potential (GWP) for the construction phase of the different road sections. It can be seen that the results for the tunnel in alternative B give again high values for all tools compared with the other road sections. Results from SimaPro give higher values than the other tools especially for alternatives A and C.

In the Table 11 it is observed that the ratio between SimaPro and LICCER is also high, from 5 to 15 for all three alternatives. The ratio values in alternative B and C between SimaPro and LICCER are high due to the soil filling processes as explained above.

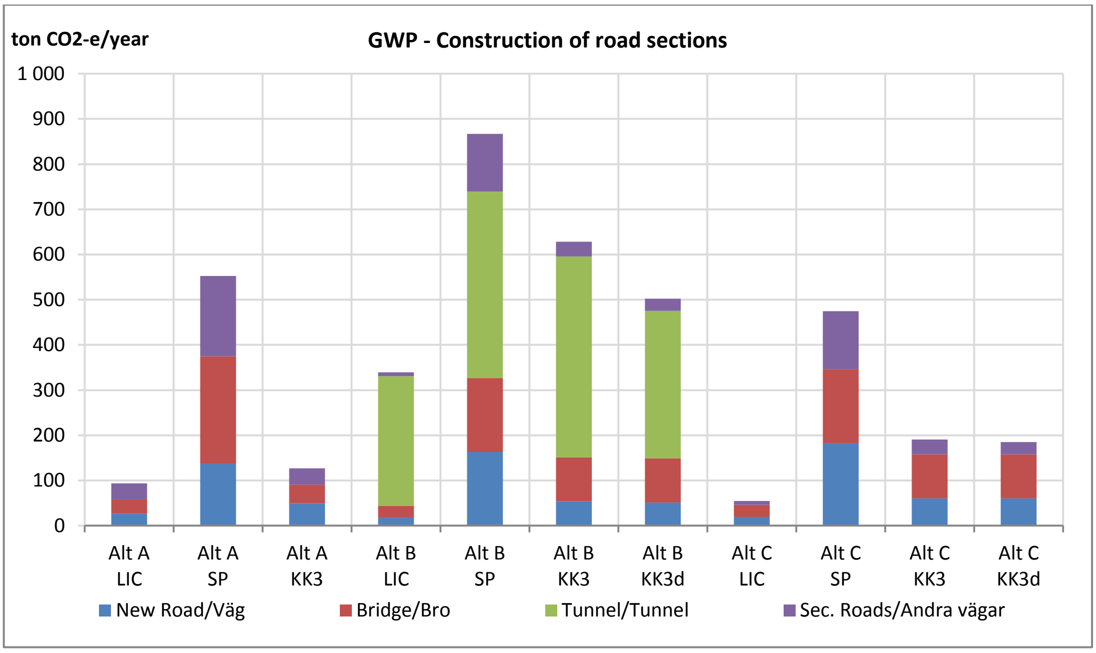


Figure 12: Yearly life cycle GWP excluding operation phase for the different road sections in alternative A, B and C as calculated in LICCER (LIC), SimaPro (SP), and KlimatKalkyl v3.0 (KK3).

Figur 12: Årlig GWP exklusive driftfasen för de olika vägsträckorna i alternativ A, B och C beräknat med LICCER (LIC), SimaPro (SP), och KlimatKalkyl v3.0 (KK3).

Table 11: Ratio of the different road sections for GWP results excluding operation phase. The values over 5 are marked with red color and the values below 1.5 are marked with green color.

Tabell 11: Förhållandet mellan de olika vägavsnitten för GWP exklusive driftsfasen. Värden över 5 är markerade med röd färg och värden under 1,5 är markerade med grön färg.

ton CO_2-eq/year	**Alternative A**			**Alternative B**			**Alternative C**		
Ratio	SP/LIC	KK3/LIC	SP/KK3	SP/LIC	KK3/LIC	SP/KK3	SP/LIC	KK3/LIC	SP/KK3
New Road/Väg	5.18	1.88	2.75	9.36	3.09	3.03	9.34	3.10	3.01
Bridge/Bro	7.34	1.27	5.79	6.16	3.66	1.68	6.16	3.66	1.68
Tunnel/Tunnel	-	-	-	1.44	1.55	0.93	-	-	-
Sec. Roads/ Andra vägar	5.10	1.03	4.93	14.90	3.83	3.89	14.90	3.83	3.89
Total	**5.90**	**1.36**	**4.35**	**2.55**	**1.85**	**1.38**	**8.67**	**3.49**	**2.48**

4.4 Traffic Assessment

Additionally to life cycle assessment, LICCER has also the ability to estimate the environmental impact of traffic during the years of road operation. The results from the traffic assessment can also be compared with the life cycle impact of the road project. In order to elaborate this, Trafikverket provided two traffic scenarios based on alternatives A and B. The assessment included the number of cars in Annual Average Daily Traffic (AADT) that will circulate on alternative A and B for the entire life time of the project (40 years). The alternative C is not included in this assessment since it has the same length and route as alternative B. The start year is 2020 and the end year is 2060. Every alternative has different number of cars in the start year and regarding the scenario, there is an annual increase of 0% or 1.5%. The calculations were made in LICCER model since KlimatKalkyl v3.0 does not have the option of traffic calculation and the report from Trafikverket does not include any calculation regarding the traffic impacts.

The table below presents the amount of Annually Average Daily Traffic (AADT) in the beginning of the road operation in 2020 and the estimated number of cars 40 years later.

Table 12: Annual Average Daily Traffic (AADT) on every alternative for start and end year.

Tabell 12: Årsmedeldygnstrafik (ÅDT) för varje alternativ för start- och slutår.

AADT	2020	2060	
Yearly Increase / Årlig ökning	0%	0%	1.5%
Alt A	7400	7400	13424
Alt B	8800	8800	15963

Below are presented the results in life cycle energy per year and GWP as calculated in LICCER model after applying the above values. Together with the traffic impact, infrastructure impact is presented so that comparisons can be made. The first two columns are for the zero increase and the third and fourth are for the 1.5% of annual increase.

Table 13: Yearly life cycle energy for the traffic scenarios as calculated in LICCER

Tabell 13: Årlig energianvändning för trafikscenarier beräknat med LICCER

Energy	Alt A 0%	Alt B 0%	Alt A 1.5%	Alt B 1.5%
Infrastructure / Infrastruktur	4481	7765	4933	8110
Traffic / Trafik	76735	71530	107967	100585
Ratio (Infrastructure/Traffic)	**17**	**9**	**22**	**12**

Table 14: Yearly GWP for the traffic scenarios as calculated in LICCER

Tabell 14: Årlig GWP för trafikscenarier beräknat med LICCER

GWP	Alt A 0%	Alt B 0%	Alt A 1.5%	Alt B 1.5%
Infrastructure / Infrastruktur	102.84	396.90	108.91	401.70
Traffic / Trafik	4827.38	4499.00	6792.16	6327.80
Ratio (Infrastructure/Traffic)	**47**	**11**	**62**	**16**

As we can observe although the alternative B serves higher number of cars, due to the fact that is shorter in length it has lower emissions of CO_2 and life cycle energy than alternative A. Also the impacts from infrastructure in Alternative B are higher than alternative A. Nevertheless in both scenarios alternative B has the lowest total impact in yearly CO_2 emissions and life cycle energy.

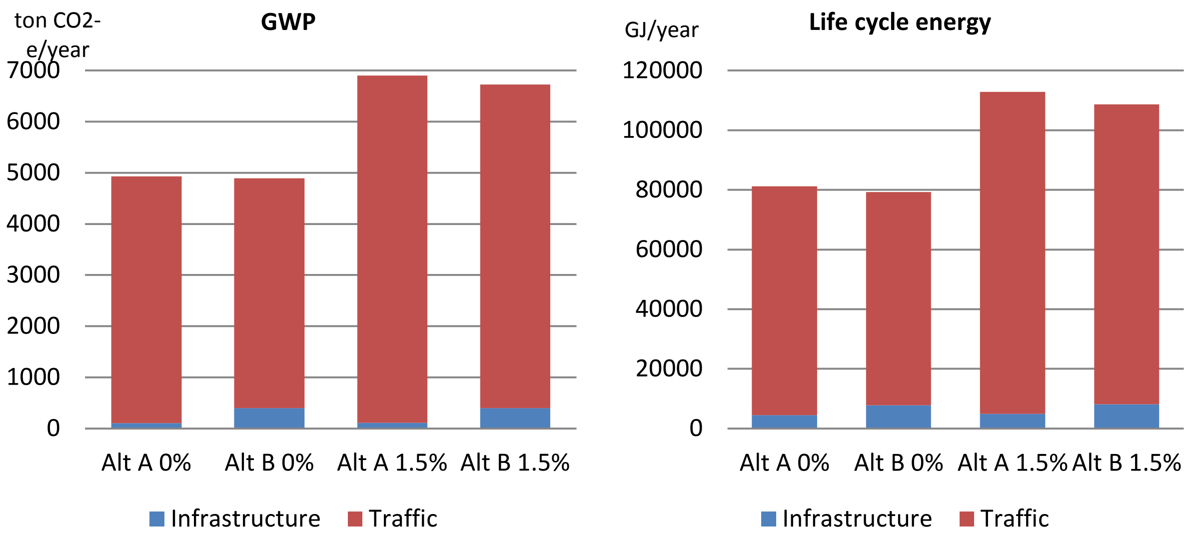


Figure 13: Yearly life cycle energy and GWP results as calculated in LICCER model for the different future traffic increase scenarios

Figur 13: Årlig energianvändning och GWP beräknat med LICCER-modellen för de olika framtida trafikscenarierna

4.5 Discussion

In this case study there is an extra output result for comparison that comes from a model used in SimaPro. The projects' specifications are the same but SimaPro has the ability to include more processes since it is more open to customizations in comparison with LICCER or KlimatKalkyl.

- SimaPro appears to have greater values for the investigated environmental impacts of energy consumption and Global Warming Potential.
- The outcomes from the tools seem to follow the same trend but the values are on a different scale.
- The ratio between KlimatKalkyl and LICCER for the different alternatives varies between 1,75 - 3,20 for energy consumption and 1,36 - 3,49 for CO_2 emissions.
- The ration between SimaPro and KlimatKalkyl reach up to 7,58 for the primary energy consumption and 8,67 for CO_2 emissions
- LICCER provided results for total life cycle that are close to the ones from KlimatKalkyl v3.0.
- Variations in the results, between the two models, were noticed for the different life cycle phases.

5. Overalls conclusions

The purpose of an LCA tool is to assist the designer or the environmental engineer having a preliminary environmental assessment of the under design project. Therefore each LCA tool is constructed and operated in the way that it provides valuable outcomes for the designer and helps in the decision making processes.

KlimatKalkyl v2.0 and v3.0 were explicitly developed for the needs of Swedish road and railroad projects conducted by Trafikverket. For this reason KlimatKalkyl has specific input sections, predefined road elements and calculation procedures that follow Trafikverket projects and Swedish road planning regulations. Due to this it is rather difficult to apply KlimatKalkyl in projects outside Sweden. This should be taken also into consideration in case of KlimatKalkyl result comparison with other models.

On the other hand LICCER is the result of collaboration among three international universities and thus it is more open to modifications and alterations. The input format of LICCER can support different road projects and can also provide the option of alternatives comparison. The traffic assessment that LICCER includes in the calculations can give a holistic approach on the environmental impacts of a road life cycle.

SimaPro is a tool that follows a different approach than KlimatKalkyl and LICCER. The investigated projects should be modelled from scratch and this is a task for someone who has knowledge of the software as well as an environmental background. It is used from industry and academia for studies in the life cycle environmental impacts. It can model a variety of processes therefore it can provide impact assessments with less assumptions and modifications than the other two tools. Due to this reason in the case studies SimaPro had always the highest result values. SimaPro can help in early assessments but the modelling takes more time and in some cases the results interpretation is more complex than in KlimatKalkyl or LICCER.

The comparison of LICCER and KlimatKalkyl has shown that both tools can provide important environmental assessment results for one or more alternatives. Although both are specified for road construction projects, it can be seen that the format of the input data varies between the two models. This is one of the reasons that the tools generate different environmental impact estimations for the same projects. Additionally, the numerical differences in the outcomes point to the fact that each tool is linked with a different set of impact factors. As it is presented in the case studies in some cases the numerical gap is considerable but in general KlimatKalkyl v3.0 follows the same trends with LICCER but on a higher scale.

To sum up, regarding the need, all three tools can provide environmental impact estimations and sufficient outcomes to help the decision making processes in road construction projects.

A. Appendix

A.1 Predefined KlimatKalkyl elements

A.1.1 Input values for road elements with 1 lane

		LICCER	KlimatKalkyl v3.0	KlimatKalkyl v2.0
new road (km)		**1.0**	**1**	**1.0**
	number of lanes	1	1	1
	total road width (m)	5.0	5.0	4.5
	soil excavation (m3/km)	16941	16941	16941
	rock excavation (m3/km)	15722	15722	15722
	soil filling	Not included	0	0
	rock filling	Not included	0	0
	kc pilling	Not included	0	0
	asphalt base bounded (m)	0.180	0.180	0.180
	unbounded base	0.000	0.000	not specified
	Aver. An. Daily Traf. (AADT)	456	456	456
	operation years	40	40	40
extended road (km)		**1.0**	**1.0**	**1.0**
	number of lanes	1	1	1
	total road width (m)	3.5	3.5	3.5
	soil excavation (m3/km)	11859	11859	11859
	rock excavation (m3/km)	11005	11005	11005
	soil filling	Not included	0	0
	rock filling	Not included	0	0
	kc pilling	Not included	0	0
	asphalt base bounded (m)	0.180	0.180	0.180
	unbounded base	0.000	0.000	not specified
	Aver. An. Daily Traf. (AADT)	355	355	355
	operation years	40	40	40
tunnel (km)		**1.0**	**1.0**	**1.0**
	number of lanes	1	1	1
	total road width (m)	6.0	6.0	4.0
	rock excavation (m3/km)	44820	44820	44820
	rock excavation (m3/km)*	44820*	160566*	160566*
	fuel use for excavation (l/km)	0	Not included	Not included
	shotcrete	Not included	Not included	Not included
	guardrail (km)	1.0	Not included	Not included
	lighting (km)	1.0	Included	Included
	asphalt base bounded (m)	0.180	0.180	0.180
	unbounded base	0.000	0.000	not specified
	Aver. An. Daily Traf. (AADT)	456	not specified	not specified
	operation years	40	40	40
bridge (km)		**1.0**	**1**	**1.0**
	number of lanes	1	1	1
	total road width (m)	4.0	4	4.0
	asphalt base bounded (m)	0.090	0.18	0.180
	reinforcement	0	0	0
	steel beam elements	0	0	0
	concrete works	not specified	1 m3/m2	1 m3/m2
	Aver. An. Daily Traf. (AADT)	456	456	not specified

A.1.2 Input values for road elements with 2 lanes

	LICCER	KlimatKalkyl v3.0	KlimatKalkyl v2.0
new road (km)	**1.0**	**1.0**	**1.0**
number of lanes	2	2	2
total road width (m)	8.0	8.0	8.0
soil excavation (m3/km)	13753	13753	13753
rock excavation (m3/km)	22609	22609	22609
soil filling	Not included	0	0
rock filling	Not included	0	0
kc pilling	Not included	0	0
asphalt base bounded (m)	0.180	0.180	0.180
unbounded base	0.000	0.000	not specified
Aver. An. Daily Traf. (AADT)	912	912	912
operation years	40	40	40
extended road (km)	**1.0**	**2**	**1.0**
number of lanes	2	-	2
total road width (m)	7.0	3.5	7.0
soil excavation (m3/km)	11859	11859	11859
rock excavation (m3/km)	11002	11002	11002
soil filling	Not included	0	0
rock filling	Not included	0	0
kc pilling	Not included	0	0
asphalt base bounded (m)	0.180	0.180	0.180
unbounded base	0.000	0.000	not specified
Aver. An. Daily Traf. (AADT)	912	912	912
operation years	40	40	40
tunnel (km)	**1.0**	**1.0**	**1.0**
number of lanes	2	2	2
total road width (m)	9.4	9.4	8.0
rock excavation (m3/km)	72088	72088	72088
rock excavation (m3/km)*	72088*	206135*	206135*
fuel use for excavation (l/km)	0	Not included	Not included
shotcrete	Not included	Not included	Not included
guardrail (km)	1.0	Not included	Not included
lighting (km)	1.0	1.0	1.0
asphalt base bounded (m)	0.180	0.180	0.180
unbounded base	0.000	0.000	not specified
Aver. An. Daily Traf. (AADT)	912	not specified	not specified
operation years	40	40	40
bridge (km)	**1.0**	**1**	**1.0**
number of lanes	2	2	2
total road width (m)	8.0	8	8.0
asphalt base bounded (m)	0.180	0.180	0.180
reinforcement	Not included	0	0
steel beam elements	Not included	0	0
concrete works	Not included	1 m3/m2	1 m3/m2
Aver. An. Daily Traf. (AADT)	912	912	Not defined

A.1.3 Input values for road elements with 3 lanes

	LICCER	KlimatKalkyl v3.0	KlimatKalkyl v2.0
new road (km)	**1.0**	**1.0**	**1.0**
number of lanes	3	3	3
total road width (m)	14.0	14.0	11.5
soil excavation (m3/km)	35210	35210	35210
rock excavation (m3/km)	14012	14012	14012
soil filling	Not included	0	0
rock filling	Not included	0	0
kc pilling	Not included	0	0
asphalt base bounded (m)	0.180	0.180	0.180
unbounded base	0.000	not specified	0.000
Aver. An. Daily Traf. (AADT)	3842	3842	3842
operation years	40	40	40
extended road (km)	**1.0**	**2**	**1.0**
number of lanes	3	-	3
total road width (m)	10.0	10	10.5
soil excavation (m3/km)	16941	16941	16941
rock excavation (m3/km)	15722	15722	15722
soil filling	Not included	0	0
rock filling	Not included	0	0
kc pilling	Not included	0	0
asphalt base bounded (m)	0.180	0.180	0.180
unbounded base	0.000	not specified	0.000
Aver. An. Daily Traf. (AADT)	3842	3842	3842
operation years	40	40	40
tunnel (km)	**1.0**	**1.0**	**1.0**
number of lanes	3	3	3
total road width (m)	12.0	13.0	12.0
rock excavation (m3/km)	100880	100880	100880
rock excavation (m3/km)*	100880*	280081*	280081*
fuel use for excavation (l/km)	0	Not included	Not included
shotcrete	Not included	Not included	Not included
guardrail (km)	1.0	Not included	Not included
lighting (km)	1.0	1.0	1.0
asphalt base bounded (m)	0.180	0.180	0.180
unbounded base	0.000	0	not specified
Aver. An. Daily Traf. (AADT)	3842	not specified	not specified
operation years	40	40	40
bridge (km)	**1.0**	**1**	**1.0**
number of lanes	3	3	3
total road width (m)	12.0	12	12.0
asphalt base bounded (m)	0.180	0.18	0.090
reinforcement	Not included	0	0
steel beam elements	Not included	0	0
concrete works	Not specified	1 m3/m2	1 m3/m2
Aver. An. Daily Traf. (AADT)	3842	3842	not specified

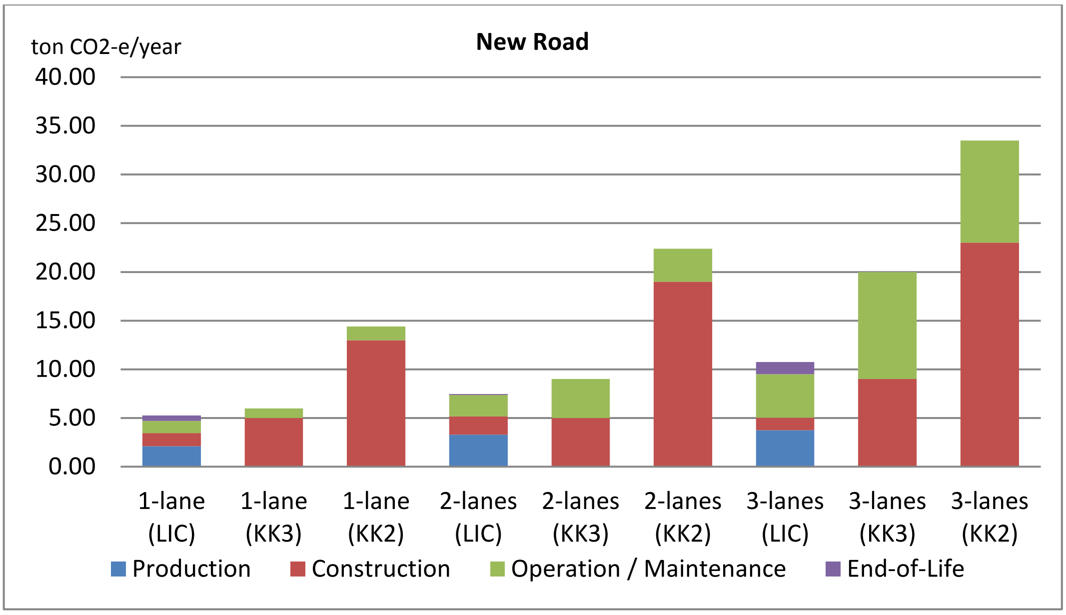
A.1.4 Results regarding the road type element

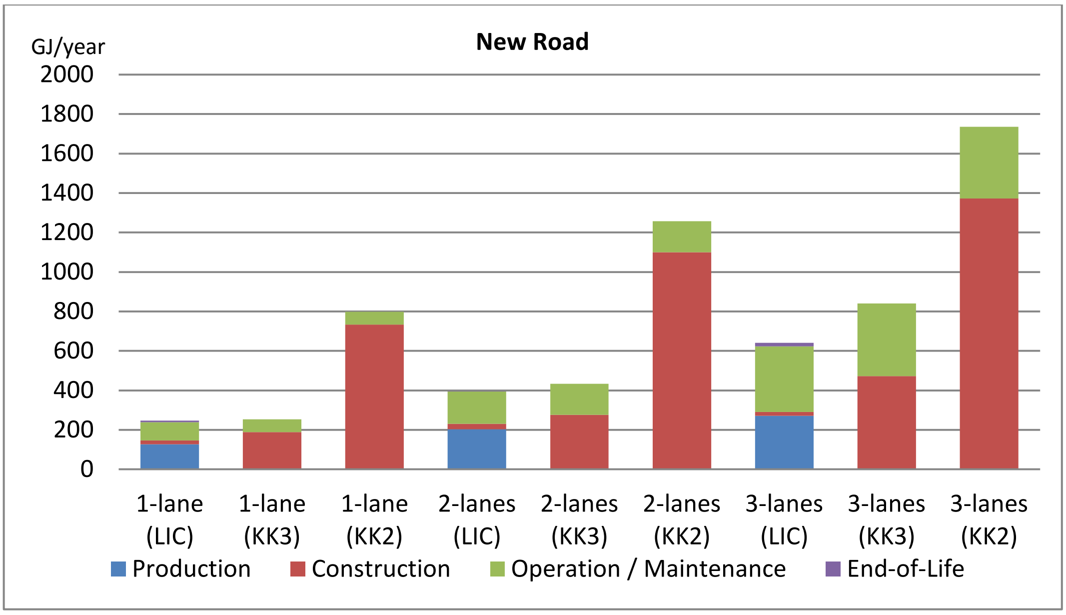
A.1.1.1 New road (1 km)

ton CO_2-e/year	New road								
	1-lane (LIC)	**1-lane (KK3)**	**1-lane (KK2)**	**2-lanes (LIC)**	**2-lanes (KK3)**	**2-lanes (KK2)**	**3-lanes (LIC)**	**3-lanes (KK3)**	**3-lanes (KK2)**
Production	2.11	0.00	0.00	3.28	0.00	0.00	3.76	0.00	0.00
Construction	1.35	5.00	13.00	1.89	5.00	19.00	1.29	9.00	23.00
Operation / Maintenance	1.23	1.00	1.40	2.21	4.00	3.40	4.45	11.00	10.50
End-of-Life	0.56	0.00	0.00	0.08	0.00	0.00	1.25	0.00	0.00

GJ/year	New road								
	1-lane (LIC)	**1-lane (KK3)**	**1-lane (KK2)**	**2-lanes (LIC)**	**2-lanes (KK3)**	**2-lanes (KK2)**	**3-lanes (LIC)**	**3-lanes (KK3)**	**3-lanes (KK2)**
Production	127.00	0.00	0.00	203.00	0.00	0.00	272.00	0.00	0.00
Construction	20.10	189.00	733.00	28.20	276.00	1100.01	19.40	473.00	1372.00
Operation / Maintenance	91.10	65.00	65.00	164.00	158.00	156.50	331.00	367.00	363.40
End-of-Life	8.30	0.00	0.00	1.13	0.00	0.00	18.40	0.00	0.00

Ratio KK3/LIC	1-lane	2-lanes	3-lanes
GWP	1.14	1.21	1.86
Prim. Energ.	1.03	1.10	1.31



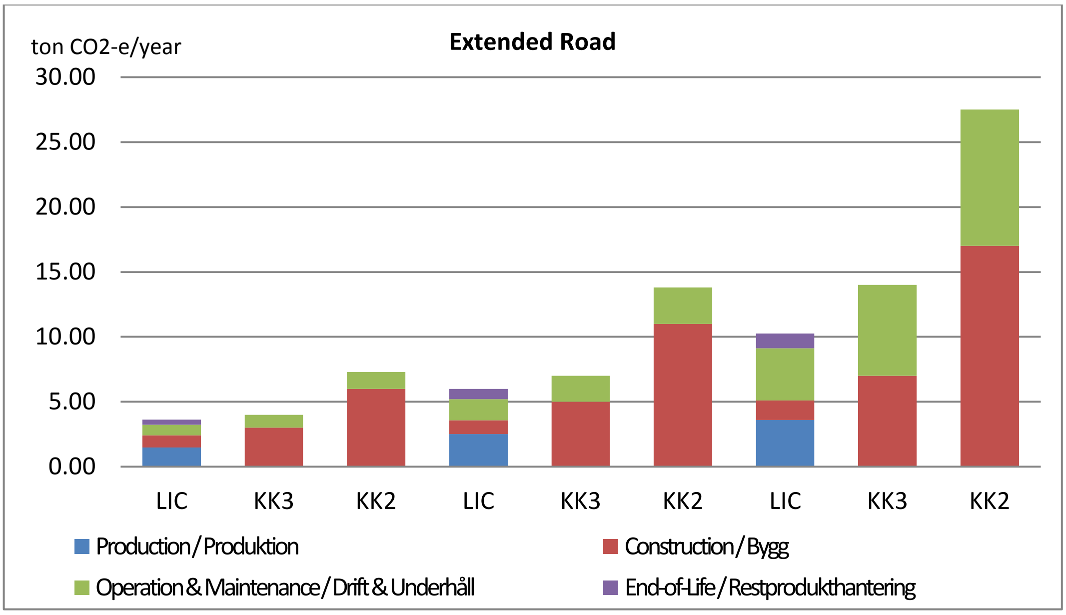


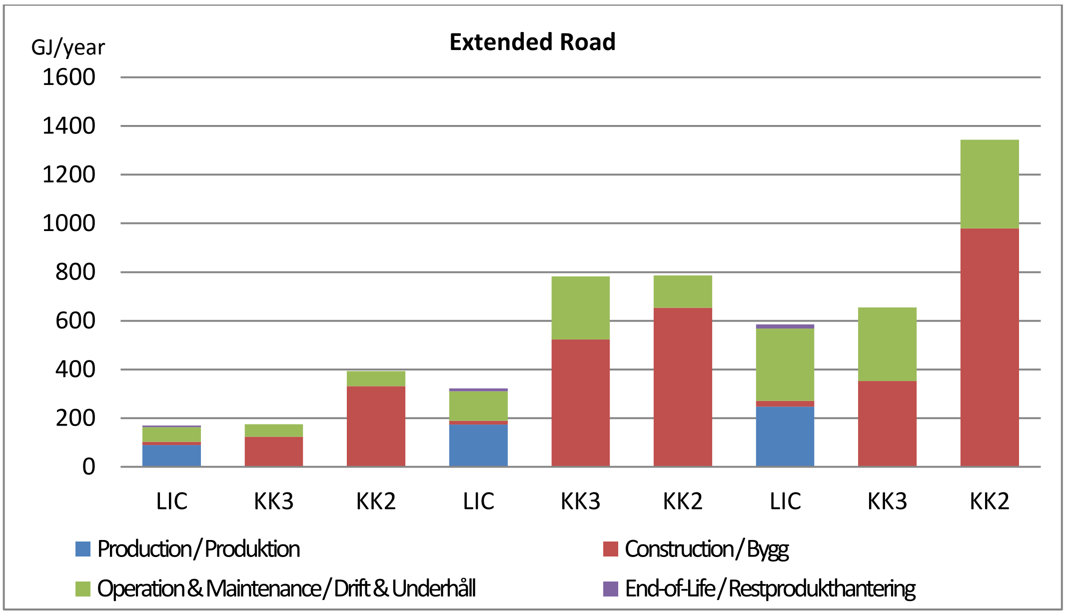
A.1.1.2 Extended road (1km)

ton CO_2-e/year	Extended road								
	1-lane (LIC)	**1-lane (KK3)**	**1-lane (KK2)**	**2-lanes (LIC)**	**2-lanes (KK3)**	**2-lanes (KK2)**	**3-lanes (LIC)**	**3-lanes (KK3)**	**3-lanes (KK2)**
Production	1.48	0.00	0.00	2.53	0.00	0.00	3.61	0.00	0.00
Construction	0.95	3.00	6.00	1.05	5.00	11.00	1.50	7.00	17.00
Operation / Maintenance	0.81	1.00	1.30	1.63	2.00	2.80	4.01	7.00	10.50
End-of-Life	0.39	0.00	0.00	0.79	0.00	0.00	1.13	0.00	0.00

GJ/year	Extended road								
	1-lane (LIC)	**1-lane (KK3)**	**1-lane (KK2)**	**2-lanes (LIC)**	**2-lanes (KK3)**	**2-lanes (KK2)**	**3-lanes (LIC)**	**3-lanes (KK3)**	**3-lanes (KK2)**
Production	89.20	0.00	0.00	174.00	0.00	0.00	248.00	0.00	0.00
Construction	14.10	124.00	331.00	15.80	523.00	654.00	22.50	353.00	980.00
Operation / Maintenance	60.40	51.00	62.10	121.00	260.00	132.40	298.00	302.00	363.40
End-of-Life	5.81	0.00	0.00	11.60	0.00	0.00	16.60	0.00	0.00

Ratio KK3/LIC	**1-lane**	**2-lanes**	**3-lanes**
GWP	1.10	1.17	1.37
Prim. Energ.	1.03	2.43	1.12



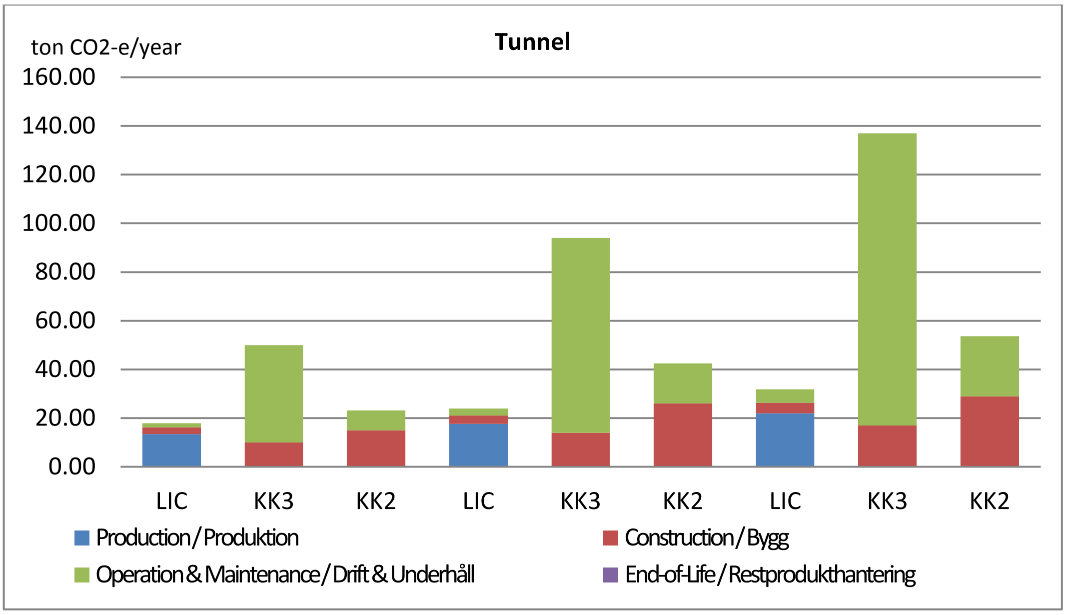


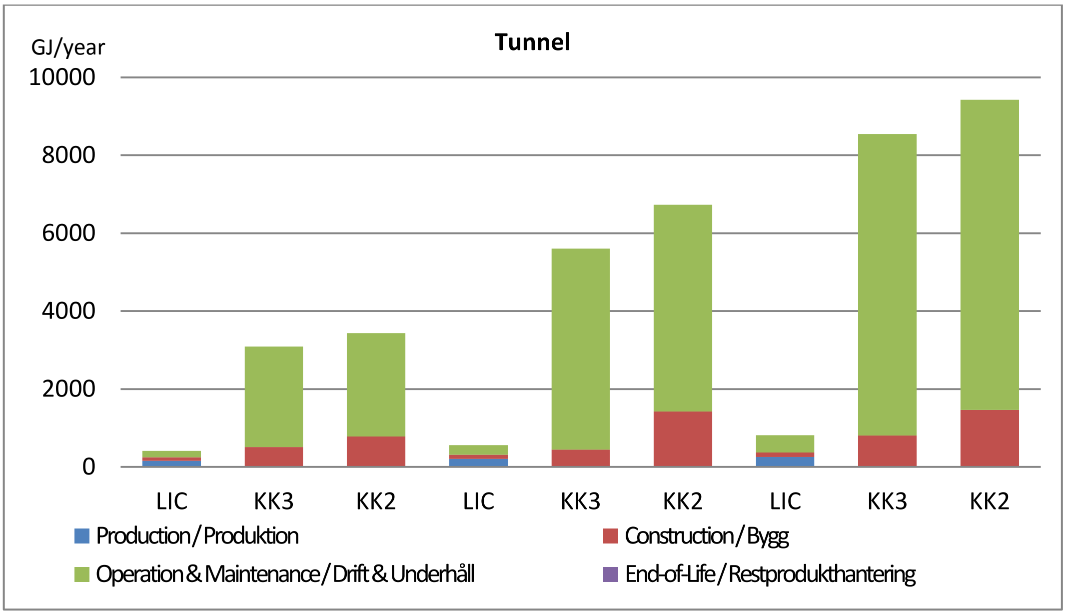
A.1.1.3 Tunnel (1 km)

ton CO_2-e/year	Tunnel								
	1-lane (LIC)	**1-lane (KK3)**	**1-lane (KK2)**	**2-lanes (LIC)**	**2-lanes (KK3)**	**2-lanes (KK2)**	**3-lanes (LIC)**	**3-lanes (KK3)**	**3-lanes (KK2)**
Production	13.40	0.00	0.00	17.60	0.00	0.00	22.00	0.00	0.00
Construction	2.73	20.00	15.00	3.51	14.00	26.00	4.34	17.00	29.00
Operation / Maintenance	1.74	40.00	8.20	2.86	0.00	16.50	5.48	120.00	24.70
End-of-Life	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

GJ/year	Tunnel								
	1-lane (LIC)	1-lane (KK3)	1-lane (KK2)	2-lanes (LIC)	2-lanes (KK3)	2-lanes (KK2)	3-lanes (LIC)	3-lanes (KK3)	3-lanes (KK2)
Production	154.00	0.00	0.00	203.00	0.00	0.00	253.00	0.00	0.00
Construction	95.30	510.00	783.00	107.00	442.00	1424.00	120.00	807.00	1463.00
Operation / Maintenance	166.00	2579.00	2653.00	249.00	5159.00	5306.80	444.00	7738.00	7960.30
End-of-Life	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Ratio KK3/LIC	1-lane	2-lanes	3-lanes
GWP	3.36	0.58	4.31
Prim. Energ.	7.44	10.02	10.46



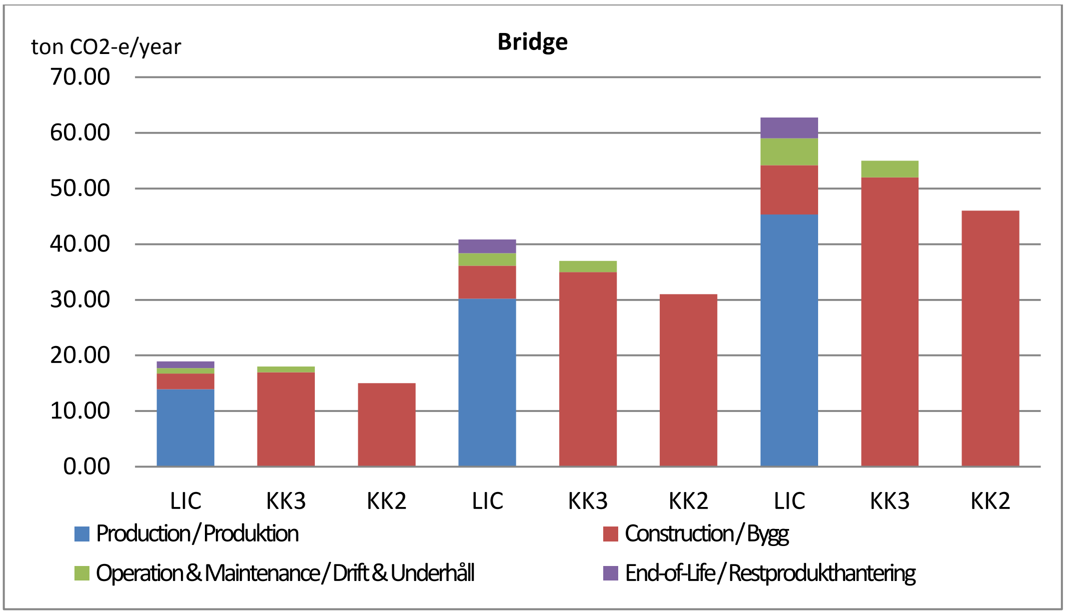


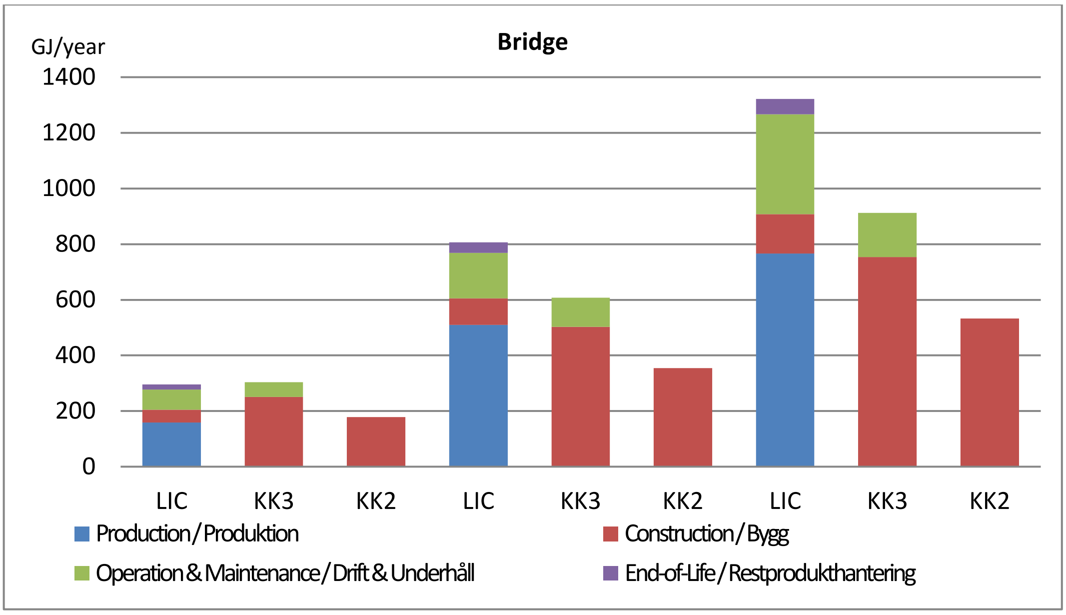
A.1.1.4 Bridge (1 km)

ton CO_2-e/year	Bridge								
	1-lane (LIC)	1-lane (KK3)	1-lane (KK2)	2-lanes (LIC)	2-lanes (KK3)	2-lanes (KK2)	3-lanes (LIC)	3-lanes (KK3)	3-lanes (KK2)
Production	13.90	0.00	0.00	30.20	0.00	0.00	45.30	0.00	0.00
Construction	2.85	17.00	15.00	5.94	35.00	31.00	8.90	52.00	46.00
Operation / Maintenance	0.98	1.00	0.00	2.21	2.00	0.00	4.81	3.00	0.00
End-of-Life	1.22	0.00	0.00	2.51	0.00	0.00	3.76	0.00	0.00

GJ/year	Bridge								
	1-lane (LIC)	1-lane (KK3)	1-lane (KK2)	2-lanes (LIC)	2-lanes (KK3)	2-lanes (KK2)	3-lanes (LIC)	3-lanes (KK3)	3-lanes (KK2)
Production	159.00	0.00	0.00	510.00	0.00	0.00	766.00	0.00	0.00
Construction	45.60	251.00	178.00	95.00	503.00	355.00	142.00	754.00	533.00
Operation / Maintenance	72.90	53.00	0.00	164.00	105.00	0.00	358.00	158.00	0.00
End-of-Life	17.90	0.00	0.00	37.00	0.00	0.00	55.50	0.00	0.00

Ratio KK/LIC	1-lane	2-lanes	3-lanes
GWP	0.95	0.91	0.88
Prim. Energ.	1.03	0.75	0.69




Bridge
GJ/year
1400
1200
1000
800
600
400
200
0
LIC
KK3
KK2
LIC
KK3
KK2
LIC
KK3
KK2
Production / Produktion
Construction / Bygg
Operation & Maintenance / Drift & Underhåll
End-of-Life / Restprodukthantering

A.2 Swedish case study

A.2.1 Results zero alternative

Life Cycle Stage (ton CO_2-e/year)	LICCER	KlimatKalkyl v3.0	KlimatKalkyl v2.0
Production	0	0	0
Construction	0	0	0
Operation / Maintenance	25	27	41
End-of-Life	8	0	0

Life Cycle Stage (GJ/year)	LICCER	KlimatKalkyl v3.0	KlimatKalkyl v2.0
Production	0	0	0
Construction	0	0	0
Operation / Maintenance	1990	1200	1990
End-of-Life	116	0	0

A.2.2 Results alternative 1

Life Cycle Stage (ton CO_2-e/year)	LICCER	KlimatKalkyl v3.0	KlimatKalkyl v2.0
Production	18	0	0
Construction	8	71	137
Operation / Maintenance	38	61	41
End-of-Life	15	0	0

Life Cycle Stage (GJ/year)	LICCER	KlimatKalkyl v3.0	KlimatKalkyl v2.0
Production	911	0	0
Construction	120	2588	5 958
Operation / Maintenance	2930	2652	1 990
End-of-Life	216	0	0

A.2.3 Results alternative 2

Life Cycle Stage (ton CO_2-e/year)	New road (LIC)	New road (KK3)	New road (KK2)	Ext. road (LIC)	Ext. road (KK3)	Ext. road (KK2)	Bridge (LIC)	Bridge (KK3)	Bridge (KK2)	Total LIC	Total KK3	Total KK2
Production	16	0	0	18	0	0	1	0	0	36	0	0
Construction	10	36	90	13	28	77	0	2	4	23	66	171
Operation / Maintenance	16	30	29	17	40	24	0	0	0	33	70	53
End-of-Life	11	0	0	7	0	0	0	0	0	17	0	0

Life Cycle Stage (GJ/year)	New road (LIC)	New road (KK3)	New road (KK2)	Ext. road (LIC)	Ext. road (KK3)	Ext. road (KK2)	Bridge (LIC)	Bridge (KK3)	Bridge (KK2)	Total LIC	Total KK3	Total KK2
Production	480	0	0	511	0	0	13	0	0	1004	0	0
Construction	151	1407	3751	202	1170	3103	4	24	47	357	2601	6901
Operation / Maintenance	1180	1031	1021	1360	1632	1165	8	3	0	2548	2666	2186
End-of-Life	155	0	0	101	0	0	1	0	0	257	0	0

A.2.4 Results alternative 3

Life Cycle Stage (ton CO_2-e/year)	New road (LIC)	New road (KK3)	New road (KK2)	Ext. road (LIC)	Ext. road (KK3)	Ext. road (KK2)	Bridge (LIC)	Bridge (KK3)	Bridge (KK2)	**Total LIC**	**Total KK3**	**Total KK2**
Production	15	0	0	8	0	0	1	0	0	23	0	0
Construction	15	37	104	2	24	62	3	2	4	19	63	170
Operation / Maintenance	17	34	33	14	34	21	0	0	0	32	68	54
End-of-Life	8	0	0	6	0	0	0	0	0	14	0	0

Life Cycle Stage (GJ/year)	New road (LIC)	New road (KK3)	New road (KK2)	Ext. road (LIC)	Ext. road (KK3)	Ext. road (KK2)	Bridge (LIC)	Bridge (KK3)	Bridge (KK2)	**Total LIC**	**Total KK3**	**Total KK2**
Production	557	0	0	384	0	0	13	0	0	954	0	0
Construction	224	1563	4335	35	1001	2615	37	24	47	296	2588	6997
Operation / Maintenance	1280	1191	1180	1200	1397	997	8	3	0	2488	2591	2177
End-of-Life	114	0	0	86	0	0	1	0	0	201	0	0

A.3 Trafikverket LCA case study

A.3.1 Input details in LICCER KlimatKalkyl v3.0 and v2.0

Alternative A tot=5.5 km			
	LICCER	**KlimatKalkyl v3.0**	**KlimatKalkyl v2.0**
new road (km)	**5.0**	**5.0**	**5.0**
number of lanes	3	3	3
total road width (m)	14.0	14.0	11.5
soil excavation (m3/km)	24400	24400	24400
rock excavation (m3/km)	4100	4100	4100
soil filling	Not included	0	0
rock filling	Not included	0	0
kc pilling	Not included	0	0
asphalt base bounded (m)	0.180	0.180	0.180
unbounded base	0.000	0.000	not specified
Center guardrail %	100%	5km	5km
side guardrail %	10%	0.5km	0.5km
lighting %	20%	not specified	not specified
bridge (km)	**0.476**	**0.476**	**0.476**
number of lanes	3	3	3
total road width (m)	20.0	20	20.0
asphalt base bounded (m)	0.180	0.180	0.180
reinforcement	Not included	0	0
steel beam elements	Not included	0	0
concrete works	Not defined	1 m3/m2	1 m3/m2
secondary roads (km)	**2.883**	**2.883**	**2.883**
number of lanes	2	2	2
total road width (m)	7.0	6.5	8.0
soil excavation (m3/km)	162670	162670	162670
rock excavation (m3/km)	63150	63150	63150
soil filling	Not included	0	0
rock filling	Not included	0	0
kc pilling	Not included	0	0
asphalt base bounded (m)	0.180	0.180	0.180
unbounded base	0.000	0.000	not specified
side guardrail %	100%	2.833 km	2.833 km
lighting %	100%	not specified	not specified
pedestrian / cyclist (km)	**3.408**	**3.408**	**3.408**
number of lanes	2	2	2
total road width (m)	3.0	3.0	3.0
soil excavation (m3/km)	10980	10980	10980
rock excavation (m3/km)	0	0	0
Aver. An. Daily Traf. (AADT)	**7400**	**7400**	**7400**
operation years	**40**	**40**	**40**

Alternative B tot=4.3 km		
	LICCER	**Klimatkalkyl v3.0**
new road (km)	**3.280**	**3.280**
number of lanes	3	3
total road width (m)	14.0	14.0
soil excavation (m3)	344520.0	344520.0
soil excavation (m3/km)	105037	105037
rock excvation (m3)	26200	26200
rock excavation (m3/km)	7988	7988
soil filling (m3)	Not included	90020
soil filling (m3/km)	Not included	27445
rock filling (m3)	Not included	0

rock filling (m3/km)	Not included	0
kc pilling	Not included	0
asphalt base bounded (m)	0.190	0.190
unbounded base	0.140	0.140
unbound base (m3)	7785	7785
unbound base (m3/km)	2373	2373
Center guardrail %	100%	3.280 km
side guardrail %	10%	0.328 km
lighting %	30%	not specified
bridge (km)	**0.420**	**0.420**
number of lanes	3	3
total road width (m)	15.0	20
asphalt base bounded (m)	0.180	0.180
reinforcement	Not included	0
steel beam elements	Not included	0
concrete works	Not defined	1 m3/m2
cut and cover tunnel (km)	**0.590**	**0.590**
number of lanes	2	2
total road width (m)	8.0	8.0
soil excavation (m3)	252000	252000
soil excavation (m3/km)	427119	427119
fuel use for excavation (l/km)	0	Not included
concrete works (m3)	28818	28818
concrete works (m3/km)	48844	48844
lighting (km)	100.0	not specified
asphalt base bounded (m)	0.180	0.180
unbounded base	0.000	0.000
secondary roads (km)	**2.490**	**2.490**
number of lanes	2	2
total road width (m)	7.0	6.5
soil excavation (m3)	85946	85946
soil excavation (m3/km)	34516	34516
rock excavation (m3)	3300	3300
rock excavation (m3/km)	1325	1325
soil filling (m3)	Not included	220434
soil filling (m3/km)	Not included	88528
rock filling	Not included	0
kc pilling	Not included	0
asphalt base bounded (m)	0.180	0.180
unbounded base (m)	0.140	0.140
unbounded base (m3/km)	1519	1519
side guardrail %	100%	2.490 km
lighting %	100%	not specified
pedestrian / cyclist (km)	**2.600**	**2.600**
number of lanes	2	2
total road width (m)	3.0	3.0
soil excavation (m3/km)	0	0
rock excavation (m3/km)	0	0
Aver. An. Daily Traf. (AADT)	**8800**	**8800**
operation years	**40**	**40**

Alternative C tot=4.3 km		
	LICCER	**Klimatkalkyl v3.0**
new road (km)	**3.870**	**3.870**
number of lanes	3	3
total road width (m)	14.0	14.0
soil excavation (m3)	386500.0	386500.0
soil excavation (m3/km)	99871	99871

rock excvation (m3)	22850	22850
rock excavation (m3/km)	5904	5904
soil filling (m3)	Not included	90020
soil filling (m3/km)	Not included	23261
rock filling (m3)	Not included	0
rock filling (m3/km)	Not included	0
kc pilling	Not included	0
asphalt base bounded (m)	0.190	0.190
unbounded base	0.140	0.140
unbound base (m3)	8540	8540
unbound base (m3/km)	2207	2207
Center guardrail %	100%	3.870 km
side guardrail %	10%	0.387 km
lighting %	30%	not specified
bridge (km)	**0.420**	**0.420**
number of lanes	3	3
total road width (m)	15.0	20
asphalt base bounded (m)	0.180	0.180
reinforcement	Not included	0
steel beam elements	Not included	0
concrete works	Not defined	1 m3/m2
secondary roads (km)	**2.490**	**2.490**
number of lanes	2	2
total road width (m)	7.0	6.5
soil excavation (m3)	85946	85946
soil excavation (m3/km)	34516	34516
rock excavation (m3)	3300	3300
rock excavation (m3/km)	1325	1325
soil filling (m3)	Not included	220434
soil filling (m3/km)	Not included	88528
rock filling	Not included	0
kc pilling	Not included	0
asphalt base bounded (m)	0.180	0.180
unbounded base (m3)	3782	3782
unbounded base (m3/km)	1519	1519
side guardrail %	100%	2.490 km
lighting %	100%	not specified
pedestrian / cyclist (km)	**2.600**	**2.600**
number of lanes	2	2
total road width (m)	3.0	3.0
soil excavation (m3/km)	0	0
rock excavation (m3/km)	0	0
Aver. An. Daily Traf. (AADT)	**8800**	**8800**
operation years	**40**	**40**

A.3.2 Results in Life cycle energy GJ/year

Total Energy GJ/year	**Alt A LIC**	**Alt A SP**	**Alt A KK3**	**Alt B LIC**	**Alt B SP**	**Alt B KK3**	**Alt B KK3d**
Production / Produktion	967.61	0.00	0.00	3 827.00	0.00	0.00	0.00
Construction / Bygg	419.06	10 323.00	4 268.00	1 205.20	15 136.08	8 831.98	7 829.45
Operation & Maintenance / Drift & Underhåll	5 217.23	5 317.20	2 834.00	4 254.00	1 090.02	2 079.00	2 079.00
End-of-Life / Restprodukthantering	220.06	0.00	0.00	276.60	4 447.44	0.00	0.00

Total Energy GJ/year	**Alt C LIC**	**Alt C SP**	**Alt C KK3**	**Alt C KK3d**	OLD Alt B (LIC)	OLD Alt B (SP)	OLD Alt B (KK3)
Production / Produktion	1 255.00	0.00	0.00	0.00	3639	0	0
Construction / Bygg	190.40	10 954.20	4 631.68	4 475.00	1260.6	11898	5563
Operation & Maintenance / Drift & Underhåll	4 312.00	474.05	2 377.00	2 377.00	4375	4193.1	2079
End-of-Life / Restproduktthantering	168.10	4 447.44	0.00	0.00	192.76	0	0

A.3.3 Results in GWP

Total GWP ton CO_2-eq/year	**Alt A LIC**	**Alt A SP**	**Alt A KK3**	**Alt B LIC**	**Alt B SP**	**Alt B KK3**	**Alt B KK3d**
Production / Produktion	51.19	0.00	0.00	0.00	981 051.82	2 160.00	2 160.00
Construction / Bygg	27.62	552.50	127.00	Total	5 945 664.39	0.00	0.00
Operation & Maintenance / Drift & Underhåll	62.59	181.60	75.00	3 827.00	0.00	0.00	0.00
End-of-Life / Restproduktthantering	14.90	0.00	0.00	1 205.20	Total	Total	Total
Total GWP ton CO_2-eq/year	**Alt C LIC**	**Alt C SP**	**Alt C KK3**	**Alt C KK3d**	OLD Alt B (LIC)	OLD Alt B (SP)	OLD Alt B (KK3)
Production / Produktion	0.00	426 656.54	2 480.00	2 480.00	277.42	0	0
Construction / Bygg	0.00	5 945 664.44	0.00	0.00	79.34	810	305
Operation & Maintenance / Drift & Underhåll	Total	0.00	0.00	0.00	51.06	145	54
End-of-Life / Restproduktthantering	0.00	Total	Total	Total	13.02	0	0

A.3.4 Results for the different road segments

Total Energy GJ/year	**Alt A LIC**	**Alt A SP**	**Alt A KK3**	**Alt B LIC**	**Alt B SP**	**Alt B KK3**	**Alt B KK3d**	**Alt C LIC**	**Alt C SP**	**Alt C KK3**	**Alt C KK3d**
New Road Ny väg	622.31	3 150.00	2 447.00	705.30	4 609.23	1 956.00	1 856.60	818.50	5 211.38	2 269.63	2 190.55
Bridge/ Bro	400.93	3 150.00	598.00	326.00	2 050.69	1 306.90	1 306.90	326.00	2 050.69	1 306.90	1 306.90
Tunnel/ Tunnel	0.00	0.00	0.00	3 700.00	4 784.03	4 513.95	3 688.43	0.00	0.00	0.00	0.00
Sec. Roads/ Sekundära vägar	583.49	4 023.00	1 223.00	300.90	3 692.13	1 053.88	991.03	300.90	3 692.13	1 055.13	977.53

Total GWP ton CO_2-eq/year	**Alt A LIC**	**Alt A SP**	**Alt A KK3**	**Alt B LIC**	**Alt B SP**	**Alt B KK3**	**Alt B KK3d**	**Alt C LIC**	**Alt C SP**	**Alt C KK3**	**Alt C KK3d**
New Road/ Ny väg	26.54	137.50	50.00	17.42	163.02	53.78	51.28	19.55	182.60	60.60	60.50
Bridge/ Bro	32.36	237.50	41.00	26.60	163.92	97.40	97.40	26.60	163.92	97.40	97.40
Tunnel/ Tunnel	0.00	0.00	0.00	286.90	412.32	444.33	326.55	0.00	0.00	0.00	0.00
Sec. Roads/ Sekundära vägar	34.82	177.50	36.00	8.58	127.85	32.90	27.40	8.58	127.85	32.90	27.40