TRAFIKVERKET

REPORT

Klimatkalkyl – Calculating energy use and greenhouse gas emissions of transport infrastructure from a life cycle perspective

Version 5.0 and 6.0

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Created by: Susanna Toller
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Contact: Susanna Toller

Contents

Summary

The transport system uses energy and affects the climate through emissions from traffic as well as emissions from construction, operation and maintenance of infrastructure. Klimatkalkyl is a model developed by the Swedish Transport Administration for efficient and consistent calculation, from a life cycle perspective, of the energy use and potential climate impact of transport infrastructure. The model can be used to make climate and energy calculations for whole or parts of investment projects, and for road maintenance contracts, as well as a tool for systematic and effective improvements in climate and energy efficiency of infrastructure. Swedish Transport Administration guideline TDOK 2015:0007[1] lays down when and for what measures climate calculations are to be carried out using the Klimatkalkyl model. Klimatkalkyl also supports climate qualification criteria in procurements for investment projects, as stated in guideline TDOK 2015:0480[2].

The model is based on life cycle assessment (LCA) methodology and uses impact correlations together with an investment's project-specific resource use, or resource-use templates for standard measures, to calculate energy use and emissions of greenhouse gases (CO2 equivalents). The impact correlations used in Klimatkalkyl have been defined by the Swedish Transport Administration as impact correlations (sv. effektsamband)

Klimatkalkyl version 1.0 was developed in connection with the Swedish Transport Administration's preparations in 2013 for its proposed National Transport Plan, and has since been updated annually. In 2016 the format changed from Excel to a web application: Klimatkalkyl version 4.0. Since then the functionality has been improved, and versions 5.0 and 6.0 were launched in April of 2017 and 2018. This report describes Klimatkalkyl version 5.0 and 6.0 and their supporting data, and highlights the changes in these versions compared to version 4.0.

[1]Swedish Transport Administration, 2015: Riktlinje Klimatkalkyl- infrastrukturhållninge ns energianvändning och klimatpåverkan i ett livscykelperspektiv. TDOK 2015:0007
[2] Swedish Transport Administration, 2015: Klimatkrav i planläggning, byggskede, underhåll och på teknisk godkänt järnvägsmateriel. TDOK 2015:0480

1. Introduction

1.1 Background

Under the transport policy objectives, an important task for the Swedish Transport Administration is to limit the energy use and climate impact of the transport system. This task includes limiting the climate impact of traffic as well as minimising the climate impact of infrastructure.

The transport system affects the climate through emissions from traffic and emissions from construction, operation and maintenance of infrastructure. The latter represent a significant proportion of the climate impact of the transport sector. The Government's infrastructure bills from 2008[3] and 2012[4] therefore emphasise that decision guidance documents should include the climate impact of infrastructure from a life cycle perspective. Sweden has a goal to reach net zero emissions of greenhouse gases by 2045, in accordance with the Swedish political climate framework introduced in 2017.

Choices made at early planning stages influence energy use and climate impact during construction and maintenance. From an energy and climate perspective, there are considerable differences between construction inside a tunnel, in a cutting, on a high embankment or on level ground. The volume of earth movement and materials used are affected by choices of location and design. Even in the later planning stages choices are made that affect energy use and climate impact. In particular, this entails design details, the materials chosen and the specific suppliers. A method for calculating the potential climate impact and energy use of infrastructure from a life cycle perspective also needs to be able to consider the emissions that occur in the production of the materials being used.

Klimatkalkyl is the model developed to enable the calculation of potential climate impact, in terms of greenhouse gas emissions and energy use of transport infrastructure from a life cycle perspective. The model is to be used to make calculations for individual investment measures and for elements of investment measures, as laid down in the Swedish Transport Administration's guideline TDOK 2015:0007[5]. The results of these calculations can then be aggregated to indicate the greenhouse gas emissions and energy use of several projects, e.g. in a national transport plan. From version 5.0 forward, the model can be used to calculate climate impact from maintenance measures in a road maintenance contract. The model was developed by WSP at the request of, and in consultation with, the Swedish Transport Administration. The first version of the model, Klimatkalkyl version 1.0, was developed in connection with the Swedish Transport Administration's preparations for its proposed National Transport Plan for the years 2014-2025. It was used to estimate the greenhouse

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[3] Government bill 2008/09:35
[4] Government bill 2012/13:25
[5] Swedish Transport Administration, 2015: Riktlinje Klimatkalkyl- infrastrukturhållningens energianvändning och klimatpåverkan i ett livscykelperspektiv. TDOK 2015:0007

gas emissions resulting from the construction of the investment projects specified in the plan[6].

The model has since been updated annually. In 2016 the format changed from Excel to a web applicationduring the introduction of Klimatkalkyl version 4.0. Since then the functionality has been improved, and version 6.0 was launched in April of 2018. Impact correlations and standard measures used in the model have been updated, and in some cases supplemented or adjusted, in the course of its development. Klimatkalkyl version 5.0 was used in the environmental impact assessment of the national transport plan for 2018-2029.[7]

1.2 Aim

Klimatkalkyl was developed to enable consistent assessments of greenhouse gas emissions and energy use of construction, operation and maintenance of transport infrastructure. Klimatkalkyl can calculate climate impact based on the included standard measures, components, project-specific quantity data for material and energy resources, or road maintenance contracts, which are based on maintenance measures. Swedish Transport Administration guideline TDOK 2015:0007[8] lays down when and for what measures climate and energy calculations are to be carried out using the Klimatkalkyl model. This report describes Klimatkalkyl versions 5.0 and 6.0 and its supporting data, and highlights the changes introduced in these versions.

The aim of the Swedish Transport Administration's Klimatkalkyl model is to enable consistent and efficient:

- Inclusion of energy use and greenhouse gas emissions of infrastructure in the Swedish Transport Administration's decision guidance documents
- Work towards continuous improvements in terms of energy use and greenhouse gas emissions of infrastructure in planning the transport system and implementation of individual measures
- Follow-up and reporting of results
- Use of climate requirements in procurement of investment projects, as stated in guideline TDOK 2015:0480[9]

This means that the model, for example, can be used to:

- follow-up the climate and energy performance of an object or measure through the establishment of a climate declaration
- see how different measures affect the total calculation, as part of the project's work with climate and energy efficiency improvements

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[6] Swedish Transport Administration 2013: Beräkning av infrastrukturens klimatpåverkan i ett livscykelperspektiv för förslag till nationell plan för transportsystemet 2014 - 2025 – Metodbeskrivning och resultat. Case no. TRV 2013/34970

[7] Miljökonsekvensbeskrivning av förslag till Nationell plan för transportsystemet 2018-2029. Publikationsnummer 2017:167. https://trafikverket.ineko.se/se/milj%C3%B6konsekvensbeskrivning-av-f%C3%B6rslag-till-nationell-plan-f%C3%B6r-transportsystemet-2018-2029

[8] Swedish Transport Administration, 2015: Riktlinje Klimatkalkyl-infrastrukturhållningens
energianvändning och klimatpåverkan i ett livscykelperspektiv. TDOK 2015:0007

[9] Swedish Transport Administration, 2015: Klimatkrav i planläggning, byggskede, underhåll och på teknisk godkänt järnvägsmateriel. TDOK 2015:0480

- compare energy use and climate impact from construction and maintenance of alternative solutions (such as alternative routings)
- follow-up energy use and potential climate impact as a part of results reporting linked to the Swedish Transport Administration's objectives
- estimate the future energy use and greenhouse gas emissions of several objects, e.g. in a national transport plan
- calculate baselines for climate qualification criteria, and for verification of achived reductions of greenhouse gas emissions.
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2. LCA methodology

The model is based on life cycle assessment (LCA) methodology. LCA is a method for systematically describing and quantifying the potential environmental impact of a system in such a way that an overview and comparisons are possible. In an LCA, the environmental load of a product, a material or a service is determined and evaluated across its entire life cycle. The process of an LCA comprises four steps: defining the goal and scope, inventory analysis, environmental impact assessment, and interpreting the results. The regulatory framework of LCA allows for some choices to be made through the process, and these choices affect the results. This makes transparency important. A standardised approach for LCA is described in the ISO 14040 standard[10]. An LCA can be used to compare different alternatives for producing the same function, or to estimate the total potential environmental impact of a specific function and determine what parts of the system are the biggest contributors.

Determining system boundaries is very significant for how the results of an LCA can be interpreted and used. In an LCA the environmental load of the product or function throughout its life cycle is included – "from the cradle to the grave". However, the assessment often needs to be delimited in different ways, both in order to be relevant to the issue and to be feasible. Sometimes, for instance, the assessment is carried out only for the production part of the life cycle, leaving out subsequent phases of use and final disposal. In these cases the analysis is more of a "cradle to gate" type of assessment and not a full LCA, but it can still be based on LCA methodology for the included parts. In LCAs carried out for roads and railways it is common to exclude the final disposal of the construction, since transport infrastructure is rarely demolished. Instead, a time perspective is sometimes applied as the expected "service life". Klimatkalkyl includes construction and maintenance, as well as the raw materials and products required for construction, and the transportation needed during extraction and processing of raw materials.

The inventory analysis should quantify all relevant inflows and outflows of the system, such as raw materials, products, energy and different types of emissions. Raw material extraction, processing and transportation needed for the products used in the system (e.g. fuel or construction materials) are included in order to account for their life cycles. General information on the life cycle load from different types of products are referred to as impact correlations and these can

[10] ISO 14040, 2006. Environmental management: Life cycle assessment: Principles and framework, International Organization for Standardization, Geneva

be obtained from international databases when there is no need for case-specific data.

In the third step, the environmental impact assessment, the potential environmental impact from the inflows and outflows is assessed. By means of classification and characterisation, the inventoried flows are assigned to different environmental impact categories and converted into a common unit for each category. For example, different greenhouse gases are assigned to the category “climate impact” and are converted into CO2 equivalents. The number of environmental impact categories included in an LCA varies. Klimatkalkyl only includes energy use (converted to primary energy[11]) and climate load in the form of emissions potentially affecting the climate (converted to CO2 equivalents). In the fourth and final step, interpretation of results, conclusions are to be drawn and recommendations given on the basis of the previous steps. Uncertainty and sensitivity analyses are also taken into account, and results and limitations explained.

3. Klimatkalkyl calculation method

3.1 Calculation methodology

Klimatkalkyl applies the basic principles of LCA, which involve defining the system boundaries based on the purpose of the study, quantifying the included resources and multiplying them by impact correlations that describe the emissions implicit in the production process of each resource. The model is based on the underlying assumption that the use of resources causes emissions – in construction, production (extraction, processing) and transportation. A causal relation is thus assumed to exist between the system’s use of resources and energy and the emission of CO2 equivalents. The impact correlations used in Klimatkalkyl have been defined by the Swedish Transport Administration as impact correlations. Impact correlations include energy use in, and emissions from, raw material extraction, processing and transportation of energy resources and materials, as well as from use (combustion) of the energy resources.

The model calculates energy use (primary energy) and greenhouse gas emissions (emissions of CO2 equivalents) for an object or a measure by multiplying the use of resources by impact correlations. In order to estimate the amount of resources that are part of the object or project, the model contains a number of resource templates of different types (Figure 1). In the model, energy use and CO2 equivalents from an object or measure are calculated based on either what kind of standard measures are being used (input A) or based on more detailed information about the components or materials and energy resources that the project uses (input B). You can also choose a flexible input (input C) that allows datasets with a different level of detail. From Klimatkalkyl version 5.0 and on, a

[11] A primary energy carrier is a source of energy in its original form, for example sunlight, wind and water, as opposed to a secondary energy carrier, which is something that has been converted, such as electricity. Source: Swedish Energy Agency

new input – input D – enables climate calculations of road maintenance contracts, based on maintenance measures.

Standard measures consist of components put together, for example square metres of bridge, kilometres of tunnel, kilometres of double track or similar. Components are the sub-components to standard measures, and are in turn built up by material and/or operations (energy resources). The model contains resource templates which describe both the components included in a standard measure, and the material and energy resources included in the respective component, e.g. cubic metres of concrete per square metre of bridge. Resource templates also exist for the operation and maintenance of the most significant standard measures. Templates for operation and maintenance of components are not available, and thus only resource templates for standard measures can be used, even though more detailed information is available for specific components. Maintenance measures in input D should not be confused with resource templates for operation and maintenance mentioned above. Maintenance measures in input D account for activities in whole maintenance contracts, and not single investment projects.

The starting point when carrying out a climate calculation involves using the same data that is being used in the economic calculations[12]. In input A, the data equals data for economic calculations of calculus level 1 and 2, and input B equals data for economic calculations of calculus level 3.

[12] Swedish Transport Administration, 2015. Kalkylblock samt struktur för underlagskalkyl, väg och bana. TDOK 2011:183

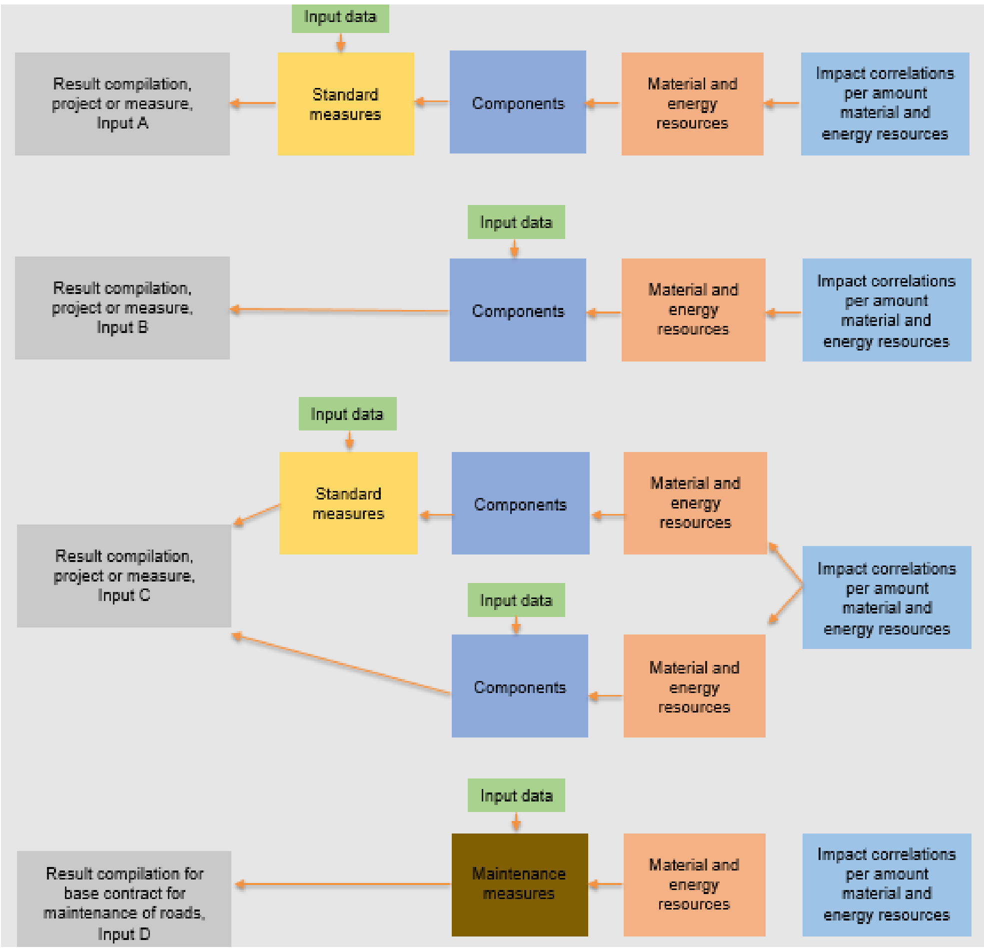

Figure 1. *Klimatkalkyl, its supporting data and need of input data using input A, B, C or D. Impact correlations and resource templates are used in the model to calculate energy use and climate impact per standard measure, component or maintenance measure. Combined with the amount of standard measures or components included in the object or measure – or the standard measure included in the maintenance contract – the total energy use and climate impact is calculated. Resource templates relate to the type and quantity of components in the standard measures, and to the type and quantity of the material and energy resources included in the components and maintenance measures.*

When carrying out a climate calculation using input A, the user specifies input data for the object or measure in the form of standard measures. The model then multiplies the material and energy resources included in the templates for these standard measures by impact correlations. The only input data required from the user is how much of each standard measure will be used. The user can, if needed, adjust the resource templates by changing the amount of components in the standard measure to fit with the current object or measure. Templates for operation and maintenance automatically follow the resource templates of every standard measure.

When carrying out a climate calculation using input B, the user specifies input data about the object or measure in the form of components. The model then multiplies the material and energy resources included in the templates for these components by impact correlations. The user can, if needed, adjust the resource templates by changing the amount of material and energy resources in the component to fit with the current component or project. The effect of selecting materials with lower environmental impact can be studied by altering the emission factor for the existing materials. When carrying out a climate calculation using input B, the user should be aware that thestandard measures representing operation and maintenance have to be added separately, based on what standard measure the components represent, since templates for operation and maintenance are not available at component level.

When carrying out a climate calculation using input C, the user specifies input data about the object or measure in the form of components and/or standard measures. The model then multiplies the material and energy resources included in the templates for these components and/or standard measures by impact correlations. Here, the user can adjust the resource templates for both components included in the standard measures, and the material and energy resources included in the components. Using input C, the user should be aware of the risk of double-entry book-keeping, since components can be added separately as well as included in standard measures. The effect of selecting materials with lower environmental impact can be studied by altering the emission factor for the existing material. This option is not available for standard measures, where only the amount of material can be altered. Templates for operation and maintenance automatically follow the templates of the added standardmeasures. Templates representing operation and maintenance have to be added separately, based on what standardmeasure the components represent, since templates for operation and maintenance are not available at component level.

Input D is only available in version 5.0 and later. It allows the user to carry out a climate calculation for a road maintenance contract. The user enters input data (amount) for a number of predefined maintenance measures. The option to alter the resource templates and impact correlations for single resources in the maintenance measures is currently limited.

3.2 Structure of included standard measures, components and maintenance measures

The structure of standard measures and components in Klimatkalkyl (inputs A-C) is based on the structure for cost calculation level 3 in guidelines governing basic data calculations [13], and has been harmonised with the Swedish Transport Administration's guideline TMALL 0167, which is a template for how basic data calculations should be structured (table 1). The main categories and sub-categories in Klimatkalkyl can thus be found in the basic data calculations for objects and components. Klimatkalkyl also includes the sub-category, "*energy use (in addition to components)*", in order to meet the requirement from those users who need to be able to add energy use separately.

[13] Swedish Transport Administration, 2015. Kalkylblock samt struktur för underlagskalkyl, väg och bana. TDOK 2011:183

Table 1. *Structure of climate calculations based on Official TMALL 0167, with a number of major categories and sub-categories.*

Main heading	**Sub-heading**
5 Environmental measures	Noise measures
6.1 Ground work – Railway	Dewatering, pipelines, wells, drums & drainage
	Felling, clearing etc.
	Energy use (in addition to what is included in components)
	Fillers, terracing
	Geotechnical reinforcement measures
	Landscaping & planting
	Channelisation
	Demolition & removal
	Railings, fences
	Excavation
	Road pavement
6.2 Building	Dewatering, pipelines, wells, drums & drainage
	Felling, clearing etc.
	Energy use (in addition to what is included in components)
	Fillers, terracing
	Geotechnical reinforcement measures
	Channelisation
	Construction
	Demolition & removal
	Railings, fences
	Excavation
	Road pavement
6.3 Tunnel	Dewatering, pipelines, wells, drums & drainage
	Felling, clearing etc.
	Structures/Buildings
	Energy use (in addition to what is included in components)
	Fillers, terracing
	Geotechnical reinforcement measures
	Channelisation
	Demolition & removal
	Railings, fences
	Excavation
	Road pavement
6.4 Road	Dewatering, pipelines, wells, drums & drain *
	Felling, clearing etc.
	Energy use (in addition to what is included in components)
	Fillers, terracing *
	Geotechnical reinforcement measures *
	Landscape gardening & planting
	Channelisation
	Demolition & removal
	Railings, fences *
	Excavation *
	Road signs, traffic signals, lighting and cable etc.
	Pavements *

7.1 Ban	Energy use (in addition to what is included in components)
	Tracks
7.2 El	High voltage power (Ktl, Auxiliary Power)
	Energy use (in addition to what is included in components)
7.3 Signal	Energy use (in addition to what is included in components)
	ERTMS
7.4 Tele	Energy use (in addition to what is included in components)
	Tele facility

The structure for included maintenance measures in Klimatkalkyl (input D) is based on maintenance measures in the listing of amounts, the MIP report and the sand-salt follow-up, all of which are linked to the use of material and/or energy resources.

3.3 Basic data for calculations

Basic data for calculations in Klimatkalkyl consists of impact correlations that specify emissions and energy consumption per amount of used materials or energy resources (impact correlations), or the use of resources in standard measures, components or maintenance measures (resource templates).

In the web applications tab "Model" (sv. Modell), basic data with references is presented. Impact correlations describe the use of energy and the CO2 emissions that occur when a particular resource is used by the system. These are described in the "Impact correlations" (sv. Emissionsfaktorer) sub-tab. In construction and maintenance of infrastructure, energy is used and emissions of CO2 equivalents generated by the use of machinery, vehicles and materials, which generate emissions upstream in the system, when they are produced (raw material extraction, processing and transportation). Steel and concrete are examples of materials that require large amounts of energy and generate considerable emissions in production[14]. Impact correlations thus include emissions from raw material extraction, processing and transportation of both energy and material resources. For energy resources, emissions from the use of the resources are also included, e.g. the emissions caused when fuel is used in a machine. No emissions are assumed to be generated during the use of materials. Some of the impact correlations are taken from the database Ecoinvent, and it should be noted that these may only be used by organisations that have a user license. For a more detailed description of the impact correlations used, refer to the Swedish Transport Administration’s defined impact correlations .[15]. In the sub-tab "Material and Activities" (sv. Material och arbetsmoment) it is clarified which impact correlations in the model is applied to which material or energy resource.

The resource templates for construction of standard measures and components are presented under the sub-tabs “Standard Measures” (Typåtgärder” and “Components” (sv. Byggdelar). These are based on data from previous civil

[14]Swedish Transport Administration, 2012. Förstudie livscykelanalys i planering och proj ekterin Swedish Transport Administration publication 2012:182.
[15]Swedish Transport Administration, 2018. The effect catalogue ”Bygg om eller bygg nytt ”, chapter 7. Available at: www.trafikverket.se/effektsamband

engineering cost estimates and environmental product declarations, or specific product information sheets. The resource templates are based on a number of projects assumed to be representative of the Swedish Transport Administration's overall product portfolio. The resource templates for standard measures in road construction are based on data from civil engineering cost estimates for Förbifart Stockholm and Umeåprojektet 2, Phase 1, Norra länken ("Cirkulationsplats Hissjö"). For median barriers and guardrails, data from specific product information sheets have been used for the resource templates. For a more detailed description of how resource templates for roads have been developed, please refer to the WSP data report[16].

Resource templates for standard measures in railway construction are based on certified environmental product declarations, EPDs, for the Bothnia Line[17]. These EPDs are based on a life cycle assessment of the entire Bothnia Line infrastructure and were reviewed and approved by a third party, in keeping with the regulations of the international EPD system. The LCA models for the Bothnia Line were reviewed and the underlying information on resource use identified and compiled in resource templates[18].

The resource templates used to calculate future operation and maintenance are mainly based on current situation data regarding the various standard measures. Which resource templates are used, and how they are built up by single components, is explained in the in tab "Model", in the sub tab "Operation and maintenance" (sv. Drift och underhåll). Their development is described in the data report from WSP [19]. Resource templates for railway operation (point machines, rail grinding, switch heating, heat and power to station buildings, power to EST and tunnel operation) are based on the Bothnia Line's EDPs.

Items included in the case of continuous operation and maintenance of the roads are winter road maintenance and pavement maintenance. The same maintenance tasks are also included for road bridges. A new feature in Klimatkalkyl v 4.0 was that the users weregiven the opportunity to complement the operation and maintenance template with road lighting. This is done by adding the Operation and Maintenance template "Light Point" (sv. Belysningspunkter väg) in the calculation. "Light Point" is specified as the number of lamp posts for a given stretch of road.

Templates for winter maintenance, pavement maintenance and road lighting are based on data from VTI (Swedish National Road and Transport Research Institute). In the model, paving maintenance is calculated as part of ongoing operation and maintenance, although this is debatable since in practice such maintenance involves replacing/improving a component at the end of its service

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[16]Uppenberg & Öman, 2013. Beräkning av transportinfrastrukturens klimatbelastning i ett livscykelperspektiv - Metodbeskrivning och resultat för bedömning av nationell trans portplan 2014 – 2025 (TRV 2011/51696)
[17] Botniabanan, 2010. Certified environmental product declarations, EPDs, for the infrastructure of the Bothnia Line. Available (in Swedish) at www.environdec.com
[18]Uppenberg & Öman, 2013. Revidering av modell Klimatkalkyl för infrastrukturprojekt,

modellversion 2.0. (TRV 2011/51696)
[19] Uppenberg & Öman, 2013. Revidering av modell Klimatkalkyl för infrastrukturprojekt, modellversion 2.0. (TRV 2011/51696)

life. However, paving maintenance is a resource-intensive activity which is determined entirely by road use and wear, and can therefore not be calculated with reference to technology lifetimes as can other reinvestments.

The model currently lacks maintenance measures for tunnels and bridges. However, tunnel maintenance includes power for lighting, ventilation and pumping of water. Templates for tunnel lighting and tunnel operation are based on VGU (design

requirements for roads and streets)[20], together with the experience from previous case studies. For winter road maintenance, resource templates are based on information about the amount of salt and sand put down and the number of vehicle runs, combined with weather data for different regions and Svevia's tool for calculating costs for winter road maintenance[21,22,23]. This has then been calibrated against the Swedish Transport Administration's annual budgets for road maintenance. The calculations are described in greater detail in the data report from WSP. For paving maintenance, resource templates are based on data from the LCC Väg tool cost estimates of road maintenance [24], developed by VTI for the Swedish Transport Administration.

Using the tool, resource quantities for paving maintenance have been identified on the basis that the quality and functionality of the road type in question be maintained over time. The resource templates are dependent on traffic load, specified as ADT (annual daily traffic). As a default, an average ADT value is used for each standard measure, but the user of Klimatkalkyl can also choose to specify project-specific ADT values for calculations of paving maintenance.

Regarding results for construction and reinvestments, the same resource templates as for construction are used, and annual resource use for reinvestments is calculated on the service life of the system's components. For input data on service lives of the various components, default values are suggested in the model. The model's default values are based on the technical service lives of the components, or the actual service lives (which is also often used in life cycle cost analyses, LCC). Actual service lives are in some cases longer than components' economic service lives, and these are considered to be the most relevant to use in Klimatkalkyl since they are more differentiated and more in tune with the Swedish Transport Administration's reinvestment needs analyses. Currently, service lives are defined on a template basis according to the various components included, although in reality service lives are also determined by the wear on each component.

[20]Swedish Transport Administration, 2012. Krav för vägars och gators utformning (design requirements for roads and streets). Swedish Transport Administration publication 2012:179

[21]The Swedish Transport Administration's statistics on the amount of salt and sand used in each district, 2008/9-2012/13.

[22]Winter weather index. Swedish Transport Administration http://vintervaderindex.vvi.vv.se/Index2.asp

[23]Calculation tool for assessing maintenance contract costs for operation of roads, suppli ed bySvevia in 2013 on commission from the Swedish Transport Administration and VT.

[24] LCC Väg. Excel-based tool developed by VTI and delivered to the Swedish Transport Administration during 2014, documented in a manual and in scientific articles included i n a PhD project by Jonas Wennström.

Resource templates regarding maintenance measures used for climate calculations for maintenance contracts (input D), are described under the tab “Modell”, in the sub-tab “Underhållsåtgärder” (Maintenance Measures). Resource templates are based on an inventory of the most significant maintenance measures in road maintenance contracts.[25].

3.4 Limitations

Klimatkalkyl considers energy use (primary energy) and potential climate impact (emissions of CO2 equivalents) of road and railway infrastructure, from a life cycle perspective (Figure 2). Klimatkalkyl includes construction, operation and maintenance, but not a possible future phase-out, since transport infrastructure is rarely demolished. However, demolition of a specific component can be taken into account using input A or B. For the continuous exchange of components that occur when they reach the end of their service life, demolition is seen as negligible in comparison to the production of the new material.

The energy use and emissions of traffic are not considered in Klimatkalkyl; these are currently only calculated using other models. However, this is something that should be taken into account with future development, as decisions regarding infrastructure influence future traffic in several ways. There is a coming future need to define the interface between Klimatkalkyl and existing models for the calculation of emissions and energy use generated from traffic.

The model calculates emissions and energy use on the basis of current technology and choice of material, and any marginal effects are not considered. This is in contrast to many road traffic analyses, which do consider future developments in technology. However, Klimatkalkyl allows for such aspects to be added manually for individual project calculations.

All transport generated within the contract and specified as cost items in the original cost estimate are included in the climate and energy calculation. This means that e.g. earth and rock moving within the project are included. Emissions from transport in connection with raw material extraction and processing are included in the impact correlations applied. However, transportation from the production source of parts and materials used in the contract, such as concrete and installations, is generally not included. These types of transport are generally assumed to represent a minor contribution to energy use and greenhouse gas emissions[26]. Asphalt and salt are subject to exception, since transport to site is included. This is shown in details “Detaljer”, under the heading Technical Representation, “Teknisk representativitet” in order to enable comparisons with environmental declarations that have narrower system boundaries. The future possibility to include transport templates (production to site) is part of the Klimatkalkyl development plans.

[25] Swedish Transport Administration Research project: Climate calculation for road maintenance contracts. WSP. Contact person: Håkan Johansson.
[26]Botniabanan, 2010. Certified environmental product declarations, EPDs, for the infras tructure of the Bothnia Line. Available (in Swedish) on www.environdec.com

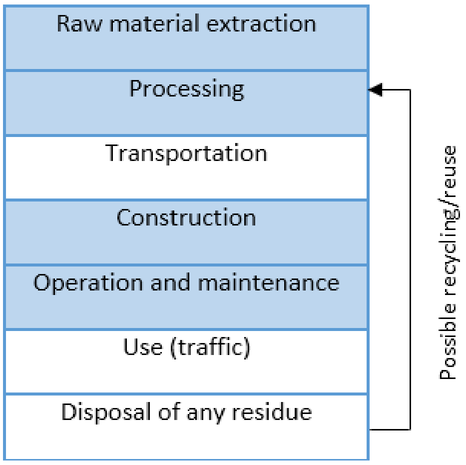

Figure 2. *Klimatkalkyl considers raw material extraction, processing and transportation (within the processing chain) of energy resources and materials, construction, operation and maintenance, as well as combustion of energy resources within these (boxes shaded in blue). Maintenance refers to exchange of components that reach the end of their service life, as well as the continuous operation and maintenance of the system (e.g. winter maintenance). Transport from production to the site, emissions from future traffic use of the infrastructure, and disposal of any residue are not included (white boxes).*

Items included in the case of continualoperation and maintenance of roads are winter road maintenance, pavement maintenance and tunnel operation (lighting, ventilation and pumping water), as well as the opportunity to add lighting points separately. Winter road maintenance includes the use of salt and sand, as well as the energy used to spread them and to clear snow. Continuing operation and maintenance of railways includes point machines, rail grinding, switch heating, heat and power to station buildings, power to EST (Power, Communication and Train Control) and tunnel operation (lighting, electronics, frost avoidance for fire protection water).

The items mentioned above have been included in the continuing operation and maintenance since they have been identified as significant contributors to energy use and climate impact, based on the certified environmental product declarations (EPDs) from the Bothnia Line [27], the Swedish Transport Administration's LCC work and climate and road map for energy efficiency and climate mitigation in the Swedish Transport Administration's various areas of activity. A number of items are, based on the above sources, assumed to be minor contributors to energy use and climate impact and these are not included in the model. Such items include railway snow clearance, weeding, dust-binding, inspection, sweeping, clearance of obstacles etc.

At present, project-related operation and maintenance are only included in the form of templates for standard measures and not for individual components.

[27]Botniabanan, 2010. Certified environmental product declarations, EPDs, for the infrastructure of the Bothnia Line. Available (in Swedish) at www.environdec.com

3.5 Sources of error and uncertainty

Input data uncertainty for individual objects, measures or maintenance contracts is considered to be the principal uncertainty and error source when using the tool. Regarding specific objects, these uncertainties are unavoidable in the early stages, when there is not yet complete knowledge of how the object will be built. The data for Klimatkalkyl is the same as for the cost calculations. As this data becomes more specific in the course of planning, the accuracy of both cost and climate calculations increases. There are also uncertainties regarding resource templates and how well they represent standard measures. Variations within standard measures depend upon design variations, e.g. as a result of topographic variations affecting the need for foundation reinforcement and excavation. Variations within components also exist. The user can adjust these parameters in the model by adding project-specific information. The possibility to modify resource templates for maintenance measures in maintenance contracts is currently limited. In the long term, the plan is to expand these possibilities.

Impact correlations are chosen to be representative of resources for Swedish conditions, even though the variation can be substantial. The goal is to have impact correlations that constitute a conservative and representative average of emissions, verified through third party reviewed environmental product declarations (EPD:s).

The sensitivity on the results from the choice of impact correlations is high. A change in the emission factor has a considerable effect on the result. Some of the impact correlations are somewhat less accurate than others, e.g. for bitumen, where the supporting data has been weak. These impact correlations will need to be updated once better data is available. Impact correlations are continuously overseen.

A validation of previously defined impact correlations was carried out in the summer of 2014. This included a critical review and quality assurance of the impact correlations that had been used. Sources were reviewed, and impact correlations compared with those used in other, similar studies and models. Impact correlations were adjusted based on the results. In the summers of 2015 and 2016 further reviews were undertaken in order to update the impact correlations[28]. However, there remain some uncertainties, especially regarding the system boundaries used in the different supporting data. A new review is planned, partly to ensure compliance with the European Standard[29].

[28] Swedish Transport Administration, 2018. The effect catalogue ”Bygg om eller bygg nytt”, chapter 7. Available at: www.trafikverket.se/effektsamband
[29] EN 15804, Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.

4. Changes from previous versions

4.1 Development of Klimatkalkyl

Klimatkalkyl was developed in order to address the need to be able to calculate the energy use and greenhouse gas emissions of transport infrastructure from a life cycle perspective throughout planning, implementation and follow-up of projects. It therefore needed to be applicable both to a national transport plan and to various stages of planning of individual objects or measures. The first version of Klimatkalkyl (version 1.0) was an excel tool primarily developed to assess greenhouse gas emissions in the proposal for the 2014-2025 national transport plan. At that early planning stage there was no way of determining what quantities of material the various objects in the plan might ultimately require. Instead, existing data on the objects was about what standard measures they encompassed. The preparatory work on Klimatkalkyl version 1.0 therefore focused on producing general resource templates for these standard measures. Klimatkalkyl version 2.0, adopted and published in 2014, could be applied during early stages but gave the user greater flexibility, so that where information was available, some of the significant items in the existing resource templates for standard measures could be modified.

Klimatkalkyl version 3.0 improved user-friendliness, transparency, flexibility and completeness in terms of user needs. With Klimatkalkyl 3.0, the possibility to carry out climate calculations based on project-specific components or quantities of material and energy resources was also added.

In 2015 and 2016 work was being done in order to replace the previous Excel format with a web application. This was in line with the Swedish Transport Administration's IT policy, and necessary in order to meet demands regarding information handling (traceability, availability and decreased vulnerability), user-friendliness, support and functionality in climate efficiency work. The development work led to the launch of the web application Klimatkalkyl version 4.0 in April 2016. During the development, the resource templates were subject to some structural changes, additions and smaller refinements. The web application was a necessity for future development.

The development of Klimatkalkyl version 5.0 and 6.0 was centered around the Swedish Transport Administration's will to set climate requirements in public procurement[30]. The revision of the tool was also based on submitted user experiences from projects in which the tool had been used, as well as from a user group consisting of representatives from all business areas and planners on both a regional and national level.

4.2 Klimatkalkyl version 5.0

The following revisions were introduced during the introduction of Klimatkalkyl version 5.0 in april 2017:

[30] TDOK 2015:0480 Klimatkrav i planläggning, byggskede, underhåll och på teknisk godkänt järnvägsmateriel, gäller från 2016-02-15

- Interface and texts: Version 5.0 was adapted to the Swedish Transport Administration graphical profile. Instructions were modified for clarity. A beta was developed where the folder system is more like the Windows Explorer folder system. When implemented for all users, this will increase user-friendliness, and also enable the development of requested functions. The changes do not affect the calculations, and were implemented for all versions.

- Improved administration: A new tab was developed where advanced users can access all climate calculations in the system, which makes support and large compilations easier. An automatic test function was implemented for the IT environment, which makes future development easier. The ability to manage different model versions has also been developed. The changes do not affect the calculations, and were implemented for all versions.

- Updated impact correlations impact correlations: The impact correlations were updated in accordance with the adjustments and completion of the impact correlations determined on October 1st 2016.

- Expanded function to include operation and maintenance in investment in late planning stages (inputs B and C): The user was given the opportunity to add operations and maintenance templates for standard measures, when making a climate calculation based on components, materials and fuels for which future operation and maintenance cannot be defined. This is done in a separate step in the guide, and is also presented separately in the presentation of the results.

- Climate calculation for road maintenance contracts: New maintenance measures connected to road maintenance contracts were added to the model. A new type of folder and input guide (input D) has been created.

The new function to perform climate calculation for road maintenance contracts follows the same methodology as for investment objects. In the new input, input D, the user states the maintenance measures that are part of the maintenance contract. Every maintenance measure has a predefined use of resources in the form of materials and fuels. These amounts are presented together with the source of the assumption under the tab “Modell”, and the sub-tab “Underhållsåtgärder” (Maintenance Measures). In The current model the user is unable to alter these amounts.

The new function of calculation for road maintenance contracts meant that significant maintenance measures, together with resource templates, had to be found. This led to the parallel research project “Klimatkalkyl för baskontrakt Underhåll väg” (climate calculation for road maintenance contracts). The project mapped out what activities in a maintenance contract contributed most to greenhouse gases emissions, as well as relevant data to calculate this. A selection of maintenance contracts were identified in order to obtain a wide representation, which took into account geography, contractors, weather, type of roads etc. Greenhouse gas emissions were then calculated for the significant items found in these contracts. From there a suggestion for structure in the Klimatkalkyl model, together with resource templates, was presented. This was then firmly established with project managers and national coordinators for maintenance contracts.

Table 2. *Assumptions to calculate resource templates for maintenance measures in the Klimatkalkyl model, input D.*

Assumption	Amount	Unit
Percentage of salt in “Mechanical de-icing material, with salt mixture”	5	%
Amount of plough blade per year	10	mton
TMA templates for tube repairer (number of vehicles per measure)	1	pc
TMA templates repairs using aggregate (number of vehicles per measure)	1	pc
Sealing, bitumen	1,6	kg/m2
Sealing, gravel	1,5	cm/m2
TMA templates sealing (number of vehicles per measure)	1	pc
Edge cutting, excavation area	0,15	m2
TMA template edge cutting	0,02	hr/m3
TMA template ditch clearing	0,02	hr/m3
Salt for dust-binding	0,7	ton/km
Repair. of steel line crash barriers	5	pcs/hr
Repair. of steel beam crash barrier	9	m/hr
TMA template for rep. of crash barrier (number of vehicles per measure)	1	pc
TMA template for repair. of crash barrier, left side (number of vehicles per measure)	3	pcs
Percentage of salt in mechanical de-icing material, with salt mixture”	3	%

Transport distance from source for maintenance gravel	10	km
Weight per steel line crash barrier post	7,45	kg

The work that has been carried out means that there is a foundation for continuing work with climate qualification criteria for the maintenance operations. In the long run, established climate calculations are expected to improve resource templates in the model, not just for the road maintenance contracts, but also for operation and maintenance for individual objects.

4.2 Klimatkalkyl version 6.0

The first improvements of Klimatkalkyl 5.0 were performed during the summer of 2017. These were imporovements connected to the user experience, and did not affect the calculations. Development of the he folder system introduced in version 5.0 gave users the possibility of seeing their own and assigned calculations under the tab "Klimatkalkyler", as well as seeing limited information (excluding results) about all other calculations. A search function was introduced, where users could search for calculations in the system using either a string of text, or more advanced options such as object numbers etc. New functions for moving or copying calculations were introduced. In addition to this a function for creating compilations of up to 50 calculations was added.

In June 2017 the possibility of exporting calculations as a saveable file was introduced to improve the experience and ease of use for external users without a user account.

The following revisions were introduced during the introduction of Klimatkalkyl version 6.0 in april 2018:

- Correction of two standard measures: In version 6.0, the operation and maintenance templates were updated for the standard measures "Stationsbyggnad" and "Tvåfältsväg (6,5m)".
- Addition of two components: Two new components "Rörbo" and "Stödmur". The resource use for each component was estimated from experience of similar constructions.
- Smaller adjustments, that do not affect the calculations: The possibility of including several identical standard measures and components, and the possibility to name these, was introduced. The reports that can be generated were adjusted to serve specific purposes, and their appearance was updated. The search function for standard measures was expanded to include meta data. In addition to this, help texts, icons and the commentation function were improved. The changes do not affect the calculations, and were implemented for all versions.
- Changes in user categories: Available levels are "user", "super-user" and "adm". For "super-user", the possibility to make changes in other user's calculations was revoked. This gives a possibility to allow more users to

have a “super-user” access in the system, and therefore increases the level of insight for affected users. The change does not affect the calculations, and were implemented for all versions.

5. Use of Klimatkalkyl

5.1 Availability

Klimatkalkyl is accessable as a web application. In order to use all the functions, a Swedish Transport Administration user account, as well as authorisation for the model, is needed (Klimatkalkyl-User). Klimatkalkyl is also available as an open access version, which is a duplicate of the full version, with the exception that completed calculations cannot be saved in the Swedish Transport Administration system. Completed calculations can be saved as a file on the user’s desktop, and reports can be exported (.pdf, .docx. or .xlsx.). The files can be distributed, and reopened to enable continuous work with a calculation. Export of a file is performed using the function “Exportera kalkyl” at the bottom right side in an open calculation. The calculation will be saved along with the folder it is located in. Import of a file is done using the function “Importera kalkyl” In the tab “Mina kalkyler”. Saved files can also be imported to the Swedish Transport Administration’s system. The open access version is available at http://webapp.trafikverket.se/Klimatkalkyl/.

For users who have a Swedish Transport Administration computer, authorization to klimatkalkyl (user or super-user) is applied for in Arthur. Users outside the Swedish Transport Administration need both a user account and authorisation for the model. This is applied for by the project’s contact person within The Swedish Transport Administration.

5.2 Carry out a climate calculation

All climate calculations that are created and saved in the model are placed in a so-called calculation folder (sv. Kalkylmapp) belonging to a specific investment project or measure (could also be a measure or ÅVS[31], which then becomes an object or measure, or a specific maintenance contract). Climate calculations can be created at various stages of the planning process, but several calculations can also be created at the same stage to compare different options. By saving the climate calculations that are created for the same object or measure in the same calculation folder, searches and comparisons between calculations are easily performed. If necessary, several calculation folders can be created for parts of an object, for example if sections are managed by different contractors. The climate calculations can only be seen by the user who created the folder, and the ones that the user shared the folder with. This applies to the user category User. Super-users can view all calculations and folders in the system. Under the tab "My Climate Calculations" (sv. Mina klimatkalkyler), the user can see all created or shared climate calculations. It is from this tab the user can create new

[31] Studies regarding selection of measures

calculation folders, new climate calculations, see previously created climate calculations and make changes to them.

To carry out a new climate calculation in Klimatkalkyl, the user is guided through five main steps, which are designed to reduce the risk of errors. Initially, the user selects the input level based on the type of project and supporting data, which in turn depends on what phase the project is in. Inputs A-C are used for investment objects or measures, while input D is used for road maintenance contracts. Input A uses the same data as the economic calculations of calculus level 1 and 2. Here, users need to know the amount of standard measures that will be used. Input B uses the same data as the economic calculations of calculus level 3. This consists of more detailed information concerning the amount of components and the materials and energy resources these include. If operation and maintenance are to be added using input B, the user must make an assumption about what standard measures the components constitute. Input C is a flexible input that allows the user to use data with different levels of detail in the same calculus, which means both standard measures and components can be combined. When using input C, the user must be aware that operation and maintenance for components must be added separately, based on what standard measures the components constitute.

In input levels B and C, the user has the opportunity to use their own supplier-specific impact correlations, and thus is able to demonstrate the effect of choosing a material with improved environmental performance. When not using the model's default emission factor, it is important that this is supported by an approved third party certified environmental product declaration according to European Standard[32] or the equivalent. A comment with a reference to the source has to be included.

When a climate calculation is saved, changes can be made as long as the status is set to "Working Version" (sv. Arbetsversion). When setting the status to "Final Version" (sv. Slutlig version), the calculation is locked for future changes. The reason for this is to guarantee traceability, i.e. to see what decision support was taken into account. If there is a need to continue working on the same calculation, a copy can be made. The copy will automatically be given the status "Working Version". When making a copy it is important to update name, description and phase, so that it is clear what the new calculation contains.

When starting a climate calculation in Klimatkalkyl, the user selects which version to use for the calculations. This cannot be changed after the calculation is created.

5.3 Supporting data and calculations

All supporting data for the calculations, the main calculation formulas and all model components is displayed under the tab "Model". The tab is locked for editing, and is only shown so that the user can follow calculations and review the default resource templates and impact correlations. The user can also see what

[32] EN 15804, Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.

components compose what standard measures, what materials and operations are included in the components, and finally the resource templates used for these. Impact correlations, re-calculation factors, templates for operation and maintenance, templates for maintenance measures in maintenance contracts, as well as the structure that shows what category standard measures or components relate to, are all presented. Some of the impact correlations are taken derived from the database Ecoinvent and it should be noted that these may only be used by organisations that have a user license. However, all results showing emission per standard measure, component or maintenance measure can be used with no such restriction.

5.4 Results presentation and interpretation

The results of a climate calculation (inputs A-C) are presented in the top row of an open calculation, divided into:

- **Construction, total for the project:** energy use and greenhouse gas emissions (emissions of CO2 equivalents) from all resources linked to the construction of the project.
- **Construction & Reinvestment, per project and year:** energy use and greenhouse gas emissions (emissions of CO2 equivalents) are presented for the same activities as under *Construction, total*, but expressed per year on the basis of the defined service lives of all components included in the model. Thus it reflects the annual impact of an installation which maintains its function, on the basis that components are replaced with varying frequency depending on their defined service lives.
- **Operation and Maintenance, per year:** energy use and greenhouse gas emissions (emissions of CO2 equivalents) are presented, per year, for the operation of components (e.g. fans, lighting, switch heating etc.) included in standard measures, as well as for paving maintenance and winter road maintenance.

Results charts for emissions of climate gases appear above the result table. In theleft-hand chart, emissions for the total construction of the project are shown. Using input A, the result is divided into the five most significant standard measures, with the remaining standard measures sorted into "Others". The input levels B and C use the same display, but divided into categories. In the right-hand chart, the result is displayed as annual emissions resulting from Construction & Reinvestment (emission of construction, per year, based on the defined service lives of each component), and Operation & Maintenance (winter maintenance, pavement maintenance and energy consumption for operations).

A climate calculation made using input D only shows emissions and energy use per maintenance contact and year. A chart shows the five biggest items and "Others". Input data and results can alså be presented in a report that can be saved as a file or printed. Thre reports can be generated in a word of PDF format and contains a selection of information from the calculation depending on the purpose of the report. For a single calculation, the report types are "Utgångsläge klimatkrav", "Underlag klimatkrav", "Bilaga SEB" and "All information inclusive figurer". "Jämförelse av två kalkyler" and "Sammanställning" are two reports that describe more than one calculation. They can be created through selecting several calculations in the tab with the folder system and using the function "Hantera".

5.5 Publication of results

Swedish Transport Administration guideline TDOK 2015:0007 describes how Klimatkalkyl should be incorporated in decision guidance documents for bigger investment projects. When a climate calculation is a part of a publically published decision guidance document, the climate calculation should be available to the public as well. This is also true for climate calculations that are used in public procurement. The climate calculation in a public procurement should be regarded as the Swedish transport Administration's experience based estimations of the emissions from a project, and should not be interpreted as a guide on how to perform the studied investment project.

6. Future development

In the short term, there are a few planned measures within the management plan for the tool. They mainly aim to increase the user experience and ease of use, i.e. through report improvements, clearification of references and user support in the form of meta data.

In the longer term, there is a range of possible development measures. The ones identified as the most important include:

- Oversight of resource templates: Adding more information from finished projects, which would give more representative resource templates. Adding more standard measures and components to further increase accuracy.
- Oversight of impact correlations regarding representation representativeness and compliance to international standards.
- Clarified connection to international standards for EPDs, and product category rules (PCR) used in environmental assessments of roads[33] and railways[34].
- Define an interface to other existing models and calculation tools that complement Klimatkalkyl (such as Geokalkyl, EKA as well as models for the calculation of traffic emissions).
- System enlargement (in particular the transportation of materials between production and construction site, as well as impact from exploitation of organogenic land).
- Review of future possibilities to manage and ensure the quality of impact correlations.

Continued development should include some system expansion or collaboration with other systems. For example, the use of the investment measures, i.e. future traffic, is not included, even though the infrastructure affects emissions and energy use of traffic. Traffic is affected by routing and choice of corridor, as well

[33] PCR 2013:20 Highways (except elevated highways), streets and roads (Version 2.0)

[34] PCR 2013:19 Railways (Verision 2.0)

as by rolling resistance and maintenance needs. A review needs to be carried out of how the Swedish Transport Administration's existing calculations of emissions and energy for traffic can be combined with results from the Klimatkalkyl model, and of whether or not this is desirable and if so, how the model can best be made to capture those aspects of traffic that are affected by the construction of infrastructure.

An expansion with respect to traffic has the potential to increase the model's applicability as a basis for studies regarding selection of measures, and for localisation decisions. Transportation of products from processing to the construction site is another part of the system that is currently not included, but if it turns out that there are cases in which these affect the energy and climate performance of the object, there will be reason to try to find a method for including them as well.

One element of the development towards greater accuracy in the climate and energy calculations is to identify which improvement measures the Klimatkalkyl tool needs to be able to capture, and for which measures other tools may be more appropriate. We already believe that better linking with geological conditions when assessing excavation and stabilisation needs during the construction phase could improve the tool's accuracy considerably. The possibility of using existing models, such as Geokalkyl and LICCER, should be reviewed in these development efforts. The EKA tool, which deals with calculating climate impact and energy use in paving work, is another tool Klimatkalkyl should be linked to in order to achieve increased accuracy.

Besides increased accuracy and a possible expansion, the tool will also be further developed in order to meet needs arising from its use in climate qualification criteria for public procurement[35].

[35] Swedish Transport Administration, 2016. Klimatkrav i planläggning, byggskede, underhåll och på teknisk godkänt järnvägsmateriel. TDOK 2015:0480.

7. Glossary

Table 2. *Concepts used in Klimatkalkyl.*

Concepts	Description
Calculation folder	Folder containing climate calculations for an object or measure.
Climate calculation	A calculation that describes energy use and climate impact from construction of an object or measure from a life cycle perspective.
Climate declaration	The final climate calculations carried out for an object or measure.
Component	Components are parts of standard measures and include materials and work processes.
Impact correlations	Impact correlations describe the energy consumption and the emissions that occur due to raw material extraction, transport and refining of energy resources and materials, as well as from the use (combustion) of energy resources.
Klimatkalkyl	Model developed by the Swedish Transport Administration to effectively and consistently carry out climate calculations.
Maintenance measure	Components which constitute a maintenance contract.
Materials	Materials, together with the work processes, constitute the smallest element in Klimatkalkyl. The amount of material is multiplied by the impact correlations to describe the energy consumption and the emissions from the use of the material.
Phase	Refers to the phase in the planning process.
Standard measure	The biggest sections in Klimatkalkyl that an object is made up of.
Status	A climate calculation can either have the status of working version or final version. Final versions are locked for continued editing.

Work process	Work processes, together with materials, constitute the smallest element in a Klimatkalkyl. A work process means the use of energy resources. These energy resources are then multiplied by impact correlations to describe the energy consumption and the emissions generated by the work process.

TRAFIKVERKET
SWEDISH TRANSPORT ADMINISTRATION
The Swedish Transport Administration, 781 89 Borlänge.
Visiting adress: Röda vägen 1
Phone: 0771-921 921

www.trafikverket.se