Calculation of energy and carbon dioxide on asphalt pavements

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ABSTRACT

This contribution describes an LCA tool (EKA, Energy and Carbon Dioxide in asphalt production), which was developed by the Swedish Transport Administration for calculating the energy and CO_2 emissions during manufacture and laying of asphalt. In addition to describing the various steps in the production of asphalt from "farm to table" EKA can also be used in the development of environmentally friendly asphalt pavements.

EKA is an aid in selecting pavement, binders, aggregates and additives. It can also be used for review and improvement of processes in asphalt production and laying. The goal of the EKA is to increase the use of energy-efficient pavements while maintaining performance and quality.

Calculations with EKA shows that the production of binders and manufacture of asphalt are the processes that require the most energy and generates the most CO2. When reclaimed asphalt is mixed into asphalt mixes, if temperature is reduced or if surface dressing is used it reduces energy as well as CO_2 emissions are reduced, sometimes they can be halved.

By comparing different pavement types we have formulated a strategy for the maintenance program. The summary over the last year's production shows that the average of energy and carbon dioxide per square meter has been reduced.

Keywords: Emissions, Energy saving, Life cycle assessment

1. INTRODUCTION

EKA is the result of a development project run by the Swedish Transport Administration during the period 2012-06-01 - 2014-12-31. When the project was initiated, the Transport Administration had set a goal of saving energy. By making active choices and measures, the energy consumption in the transport sector would be reduced. All different transport modes road, rail, sea and air were supposed to make an effort.

In the road sector, which the authors represent, it was assessed that further work was needed in order to enable savings. Therefore the research project, called "Energy Efficient Asphalt Pavements" was initiated. The project came to include multiple parts, all with the aim to contribute in various ways to reduce energy consumption in the performance of asphalt pavements.

The project included:

1. Finding a suitable LCA tool for asphalt paving.
2. A comparative study of the most common types of asphalt pavements.
3. The energy declaration of asphalt products.
4. What potential there is for improvements?
5. Alternative Products.
6. More efficient asphalt recycling.

To be able to compare different pavement types to each other, it was natural to start by looking for a suitable LCA calculation tool. Studies of some of the existing tools were made, but by using them only CO_2 and greenhouse gases were reported. The choice fell on an LCA calculation model that Roger Lundberg (NCC), presented to the Swedish Transport Administration. It contained what was sought regarding the possibility to calculate not only the CO_2, but also the energy used in asphalt production. The ability to get the results reported per ton or per square meter of paved asphalt was a big plus and not least – it was in Swedish.

This paper describes the LCA tool EKA (Energi och Koldioxid i Asfaltproduktion), Swedish for Energy and Carbon Dioxide in Asphalt Production, which is developed for calculating the energy and CO_2 emissions during production and laying of asphalt. It describes the various steps in the production of asphalt from "farm to table".

The EKA Tool is intended as an aid for selecting types of pavements, including bitumen, aggregates and additives. It can also be used for the development and trimming work in the asphalt industry. The goal of EKA is to increase the use of energy-saving pavements while maintaining performance and quality. In order to compare pavement types and methods the following factors have been taken into account:

1. Lifetime (calculated or based on the actual follow-up).
2. Material consumption including fuels.
3. Energy consumption.
4. Emissions to air.

From the Swedish Transport Administration, Kristina Martinsson and Torbjörn Jacobson have been managing the research project "Energy Efficient Asphalt Pavements" and participated in the work of the development of EKA.

2. BASIC INFORMATION ABOUT THE TOOL

Input data is based on information from the Swedish Environmental Protection Agency, which is also the reporting authority to the UNFCCC and the EU.

Data of bitumen, soft bitumen, emulsions and bitumen transports come from Eurobitume.

Input data for machinery have been taken from machine suppliers' own records of each machine. Input data of other materials are downloaded from the suppliers, who have reported energy consumption and environmental impact of their products. In terms of consumption of various fuels and materials for milling, quarries, crushers and asphalt plants all input are based on real action and real energy consumption and emission.

Some transportation and various machines have been followed for a number of years and the actual consumption is the basis for calculation of fuel consumption. Other information which are included in the calculations are:

Transport and transport speeds.
Terminal times, that is, time for loading and unloading.
Various types of fuel.
Machinery and performances.
Emission values.

Note: Most of the emissions are given as CO_{2ekv}. However in some cases data have only been found presenting CO_2. In the text CO_2 or greenhouse gas is being used.

Below a schematic view of EKA is presented, showing its extent and delimitations (fig. 1).

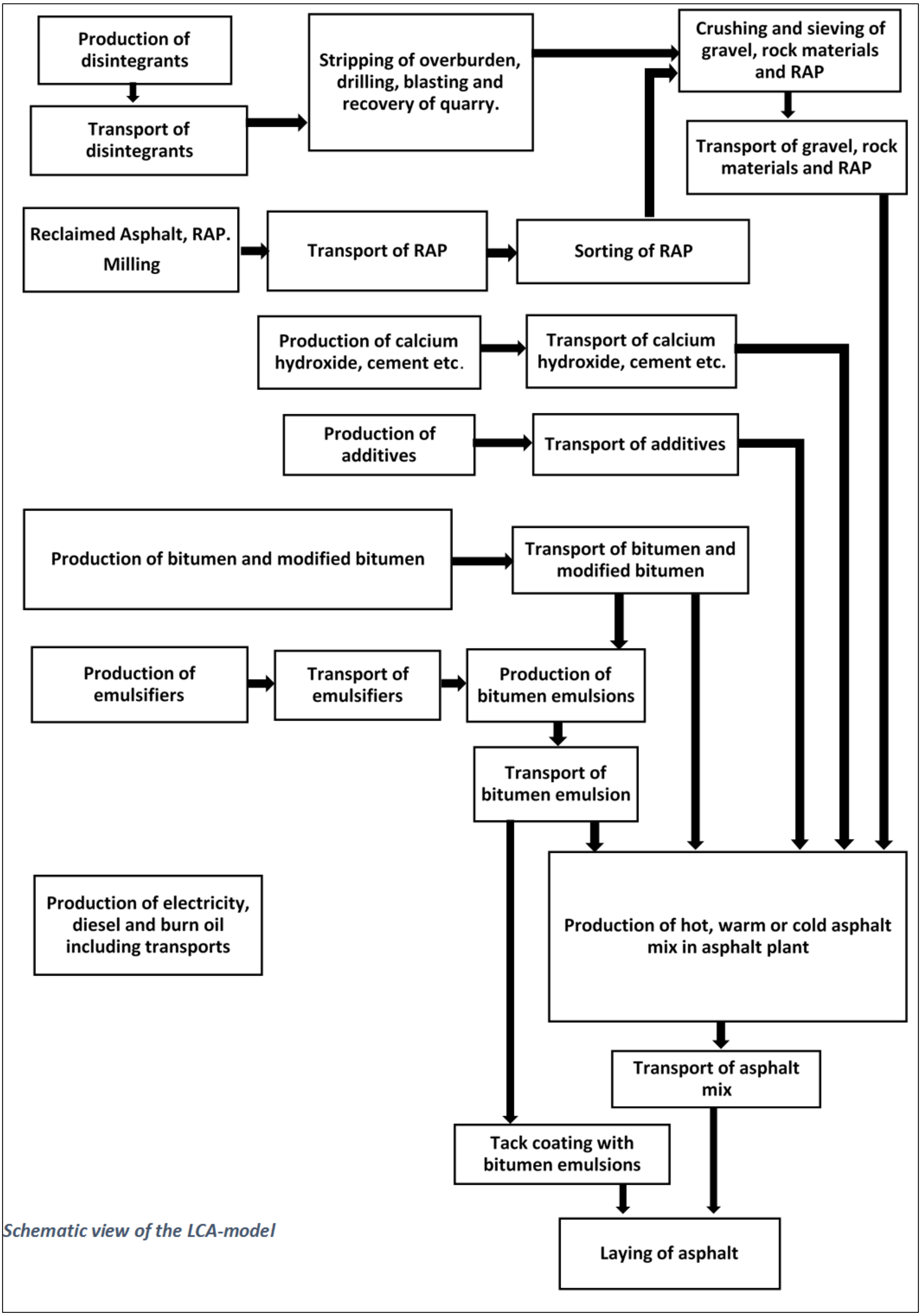


Figure 1: Schematic view of EKA

The Start Page of EKA is divided into four sections (fig.2). Each section represents different data and steps for the calculations and will all be presented further on.

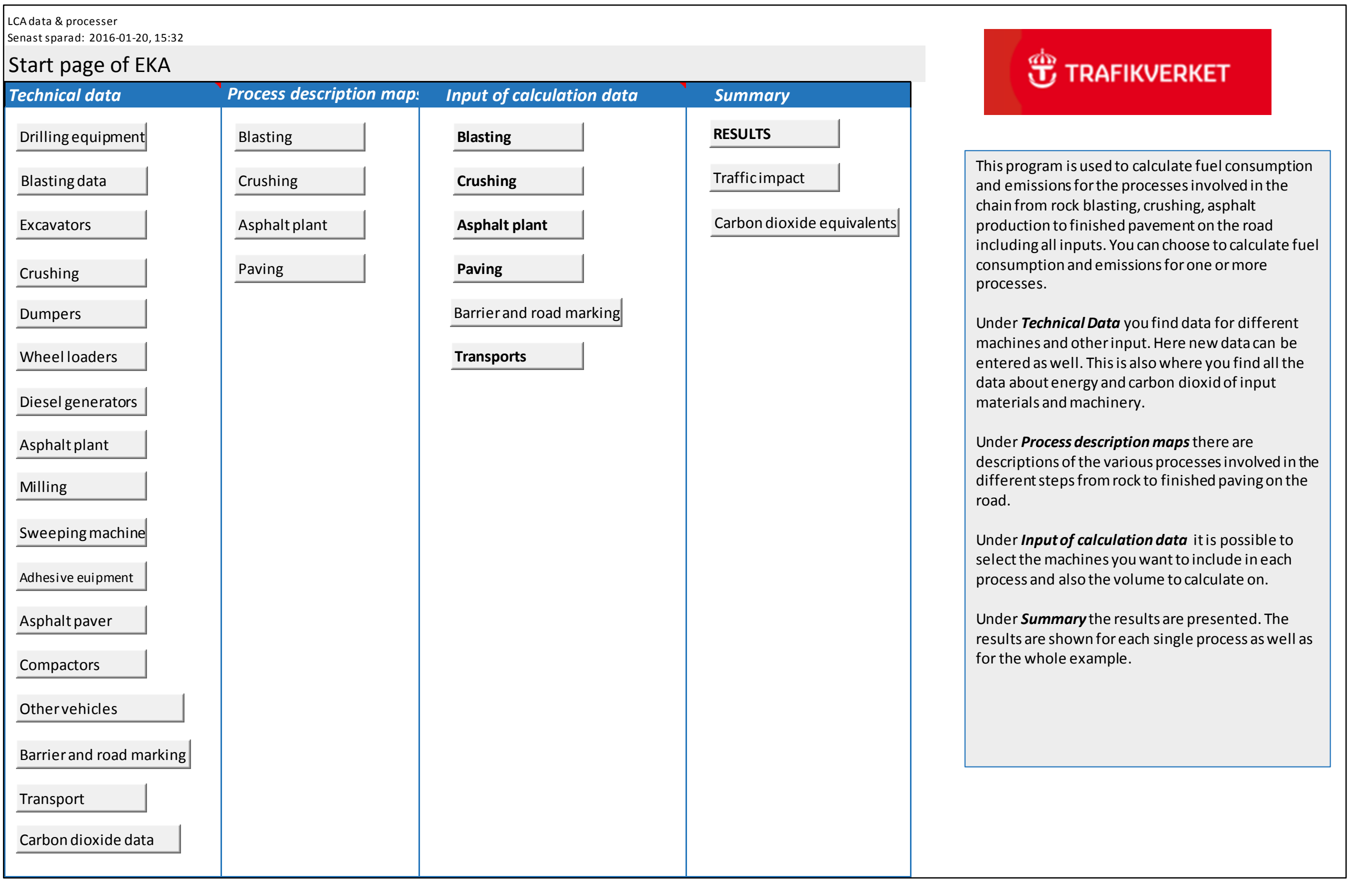


Figure 2: Front page of the EKA tool.

2.1 Technical data.

Under each tab in the left column information about machines and material is presented. The data is locked, but there are additional blank fields if data of a specific machine is missing. Those are the yellow fields shown in fig. 4.

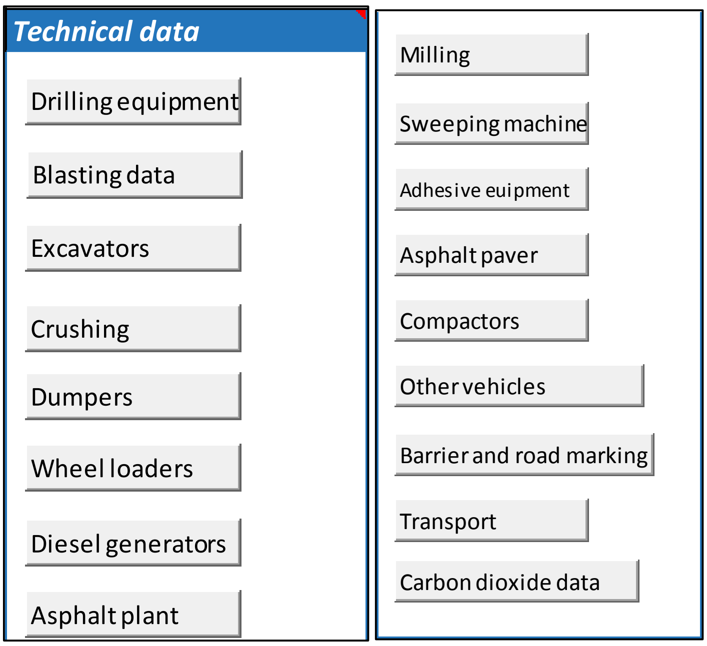


Figure 3: Technical data information tabs

Asphalt paver									
Screed width	Machine model	Screed width	Paving capacity (ton/h)	Effect kW	Consumption, technical data (l/h)	Consumption, follow-up, (l/h)	Consumption propane gas (kg/h)	Other	Latest information (name+date)
<1,2m	Vögele Super 800	1,1	250	45		7	0,8		Mikael Gimvall, NCC 2012-06
1,2-1,7m	Dynapac F6	1,7	250	52	7,5	7,5	1		Dynapac, teknisk data + Mikael Gimvall, NCC 2012-06
5-7m	Bitelli BB680	2,5		92	23,5		2		Bitelli, teknisk data 2012-06
	Dynapac F12	2,5	600	98		15	2		Mikael Gimvall, NCC 2012-06
	Dynapac F-161	2,55	650	116		21	2		Mikael Gimvall, NCC 2012-06
	PÅGRUSSPRIDARE					18			Mikael Gimvall, NCC 2012-06
Remixer	Remixer					35	250		Roger Lundberg, NCC 2012-08
Shuttle buggy	Shuttle buggy SB2500					25			
Heater						10	250		Roger Lundberg, NCC 2012-08
Fogvärmare	Infrakolb						3,2		Mikael Gimvall, NCC 2012-06

Figure 4: Example of technical data. This shows asphalt pavers.

2.2 Input of calculation data

Entered quantity and information from input data is passed on to the next step in the process. Material quantity, bitumen content and the amount of fuel is calculated and the same calculation is also done for each sub-process. Transport and transport length is entered for each process. Greenhouse gas emission and energy consumption can be seen for each sub-process.

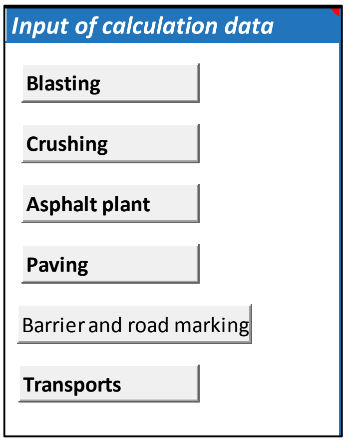


Figure 5: Tabs to input data for the calculations of the various steps in the asphalt production.

Under "Input of calculation data",

Machines.
Blasting.
Crush type.
Amount of aggregate.
Manufacturing method.
Quantity of binder.
Type of mixture.
Additives.
Amount of adhesive.
Amount of RAP.
Milling.

In this way, you work through the program, from quarry and production of aggregate to finished pavement on the road including all materials, machinery, and transportation.

3. PROCESS DESCRIPTION MAPS

The description maps are meant to illustrate the working steps and shows rather pedagogical what is included in the calculations.

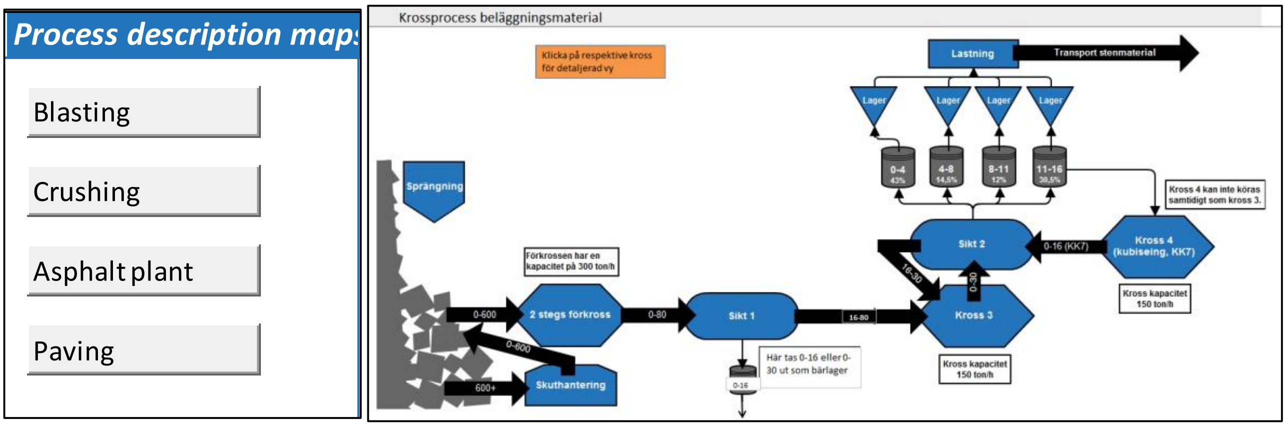


Figure 6: Description of processes – here showing the process of crushing

4. DESCRIPTION OF THE CALCULATION STEPS.

Calculations with the model are systematically organized and follow the building process in the same way that you build up a cost estimate. The program is intuitive and easy to use.

The following pages will show an example of a calculation performed with EKA. The Swedish Transport Administration wanted to be able to compare different pavement types to each other and therefor a fictive object was created, for all products and processes to be compared equally.

The fictive object is 100 000 m² and will be paved with 100 kg/m^2.
The asphalt plant is situated where there is rock material (in this case meaning no transport of gravel).
Bitumen depot is located 30 km from the factory.
Emulsion factory is located 30 km from the plant or work site.
Hauling distance for asphalt mix is 30 km on average.
Milling transports (when milling occurs) is 20 km on average.
Granular is sorted on location.
Fuel transports are 30 km on average.

The calculations shown below, are based on the data for an ABT 16 70/100 (Dense Graded Asphalt). In the yellow marked cells input can be made.

4.1 Input blasting.

The input data for blasting includes:
Amount of blasted materials, which in this example is 10 000 tons.
Scraping.
Drilling depth.
Hole spacing.
Machines.
Disintegrants.
Fuel consumption.

Note: EKA includes very specific information about for example drilling depth and type of explosives and so on. It is not meant for everyone to be experts in that area, so normally one uses a default value for all other calculations.

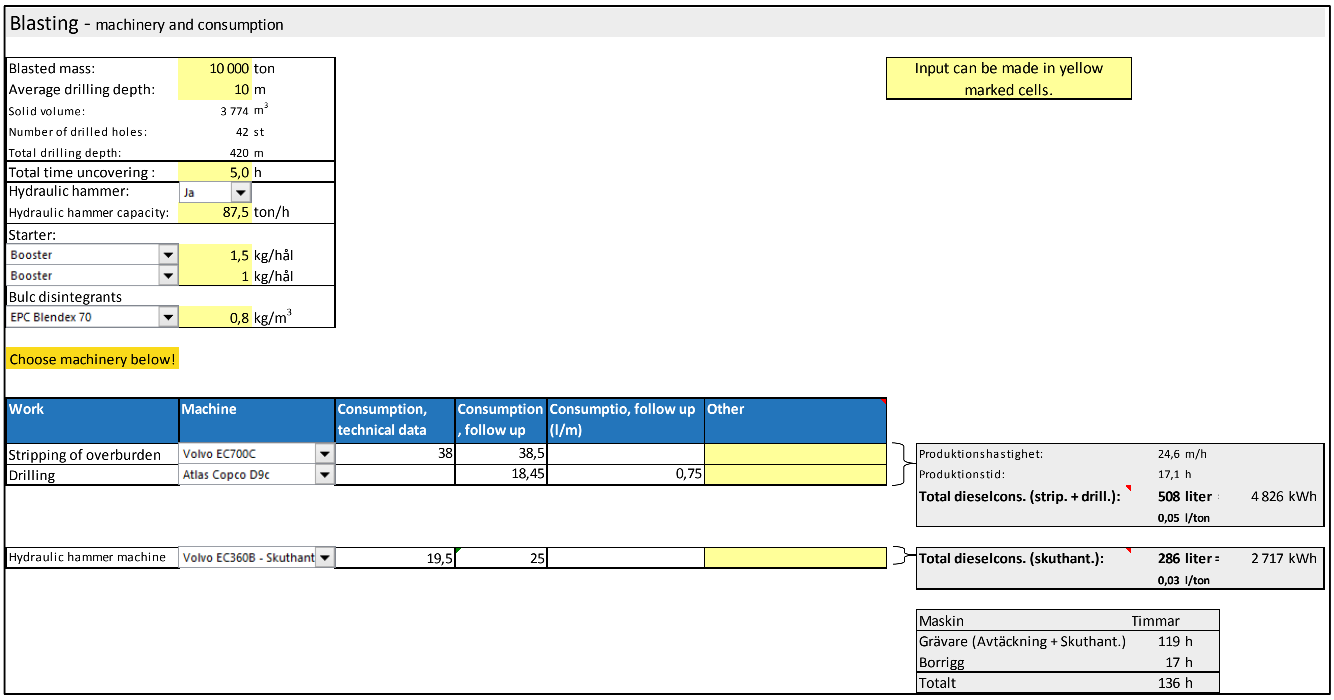


Figure 7: Description of calculation input – here showing the blasting part. In the yellow fields it is possible to add information about the specific object.

4.2 Input crushing

Under the tab “Crush” is entered:
Calculated quantity of crushed materials. As before in this example the calculation is on 10 000 tons.
Type of crusher.
Capacities.
Machines.
Fuels.

Note: One normally makes a general set of suitable machines used for the specific process.

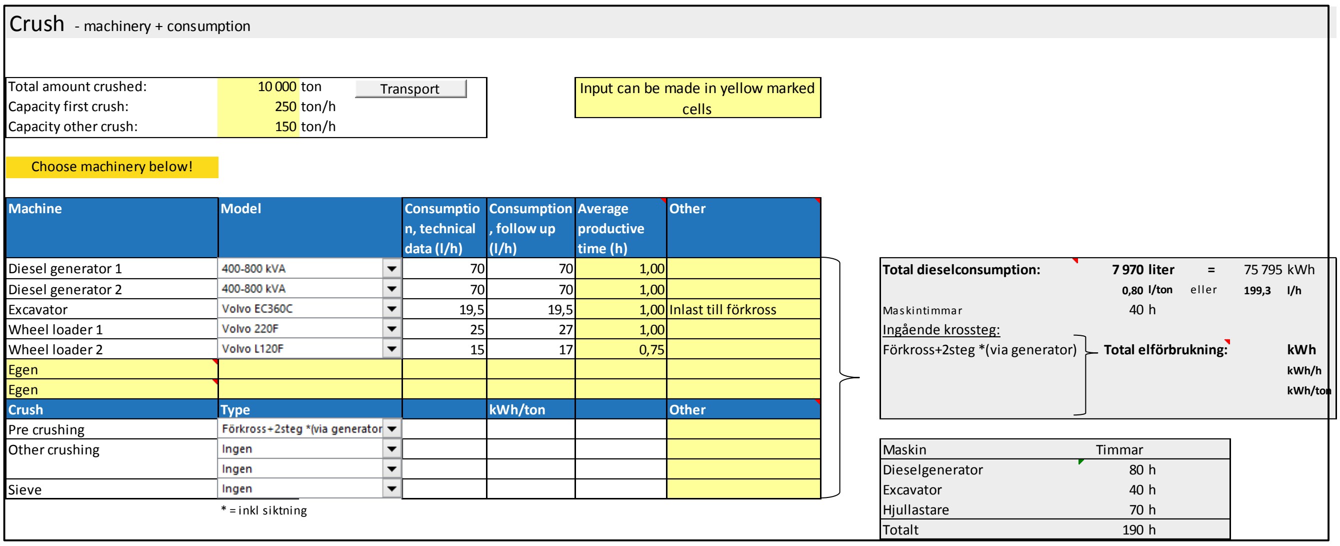


Figure 8: Description of calculation input – here showing the crush part.

4.3 Input field for producing asphalt mix in an asphalt plant.

Here showing the manufacturing procedure (hot, warm or half cold).
The amount of produced asphalt mix for this example is 10 000 tons.
Capacity, meaning the production speed, shows the production capacity on average. This varies from plant to plant and is therefore easy to change in EKA.
Distance to working site: our example says 30 km (one way).
Operation/electric, diesel, WRD, wood pellet and others can be chosen.
Binders and additives: Bitumen content for this example is the calculation value for “ABT 16 70/100”, which is 6,2%
For Warm Mix one simply selects “yes” or “no”. This automatically changes the fuel consumption for the burner.
If RAP or other recycled material is used simply add amount in percent.

Note: Machines as dumpers and wheel loaders are normally set as default.

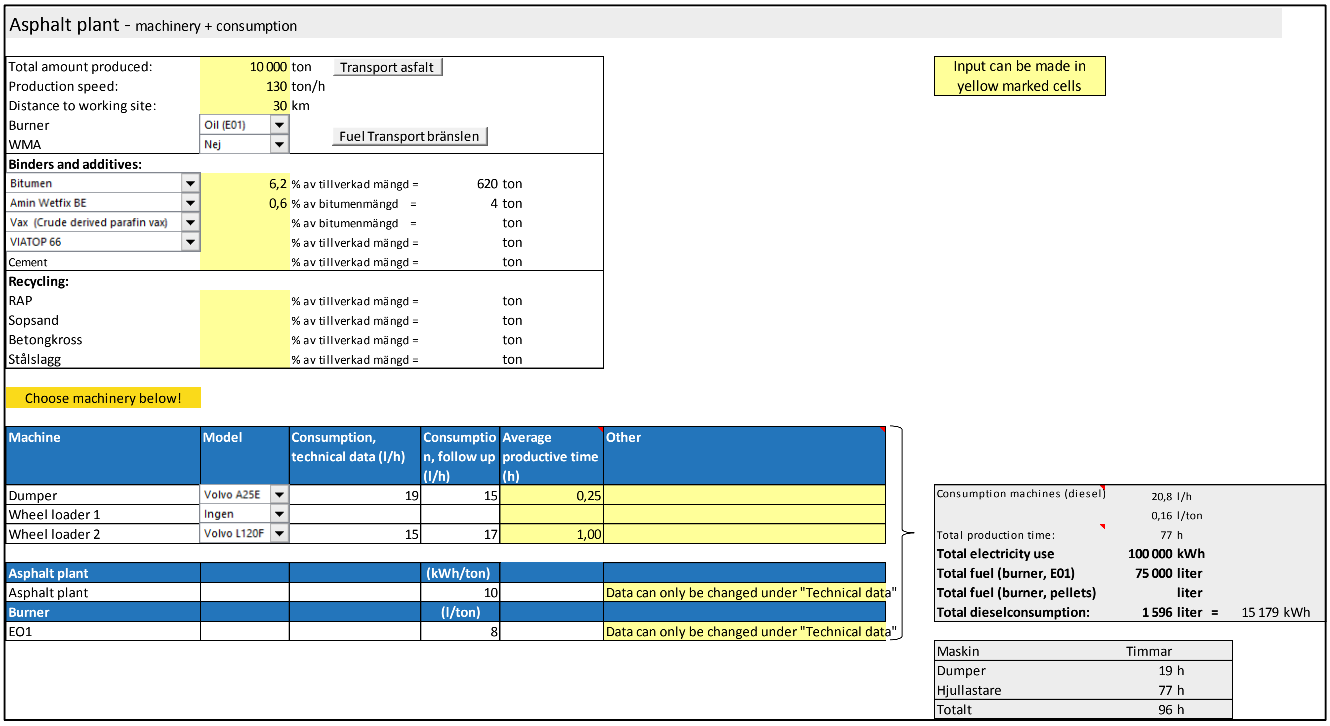


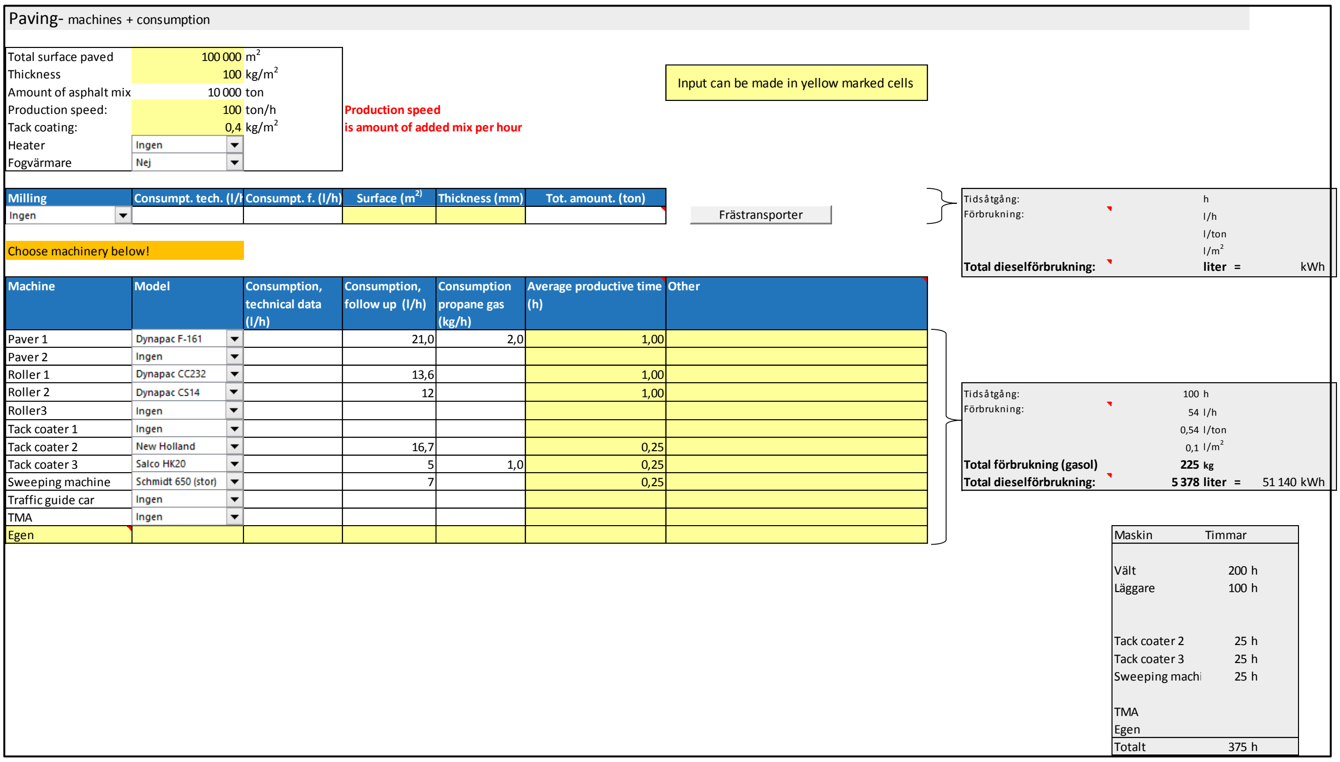
Figure 9: The asphalt manufacturing. It is easy to add information about the amount of asphalt mix produced, bitumen type and bitumen content.

4.4 Input paving.

Start by entering the total surface paved. In our example it is 100 000 m^2.
Thickness of paved layer (kg/m^2) is in this example 100 kg/m^2.
Production speed, as in amount of added mix per hour.
Tack coating with bitumen emulsion (kg/m^2).

Milling, when needed, is in (m^2) and thickness (mm). There are a number of different milling machines in the list to choose from. Under the grey button ad transport information for your case.

Note: Paving machines, compactors and other machines can be added for each work site, but can also be given as default.


Paving- machines + consumption

Total surface paved	100 000	m²
Thickness	100	kg/m²
Amount of asphalt mix	10 000	ton
Production speed:	100	ton/h
Tack coating:	0,4	kg/m²
Heater	Ingen	
Fogvärmare	Nej	

Production speed
is amount of added mix per hour

Input can be made in yellow marked cells

Milling	Consumpt. tech. (l/h)	Consumpt. f. (l/h)	Surface (m²)	Thickness (mm)	Tot. amount. (ton)
Ingen					

Frästransporter

Tidsåtgång:		h
Förbrukning:		l/h
		l/ton
		l/m²
Total dieselförbrukning:	liter =	kWh

Choose machinery below!

Machine	Model	Consumption, technical data (l/h)	Consumption, follow up (l/h)	Consumption propane gas (kg/h)	Average productive time (h)	Other
Paver 1	Dynapac F-161		21,0	2,0	1,00	
Paver 2	Ingen					
Roller 1	Dynapac CC232		13,6		1,00	
Roller 2	Dynapac CS14		12		1,00	
Roller3	Ingen					
Tack coater 1	Ingen					
Tack coater 2	New Holland		16,7		0,25	
Tack coater 3	Salco HK20		5	1,0	0,25	
Sweeping machine	Schmidt 650 (stor)		7		0,25	
Traffic guide car	Ingen					
TMA	Ingen					
Egen						

Tidsåtgång:	100	h
Förbrukning:	54	l/h
	0,54	l/ton
	0,1	l/m²
Total förbrukning (gasol)	225	kg
Total dieselförbrukning:	5 378 liter =	51 140 kWh

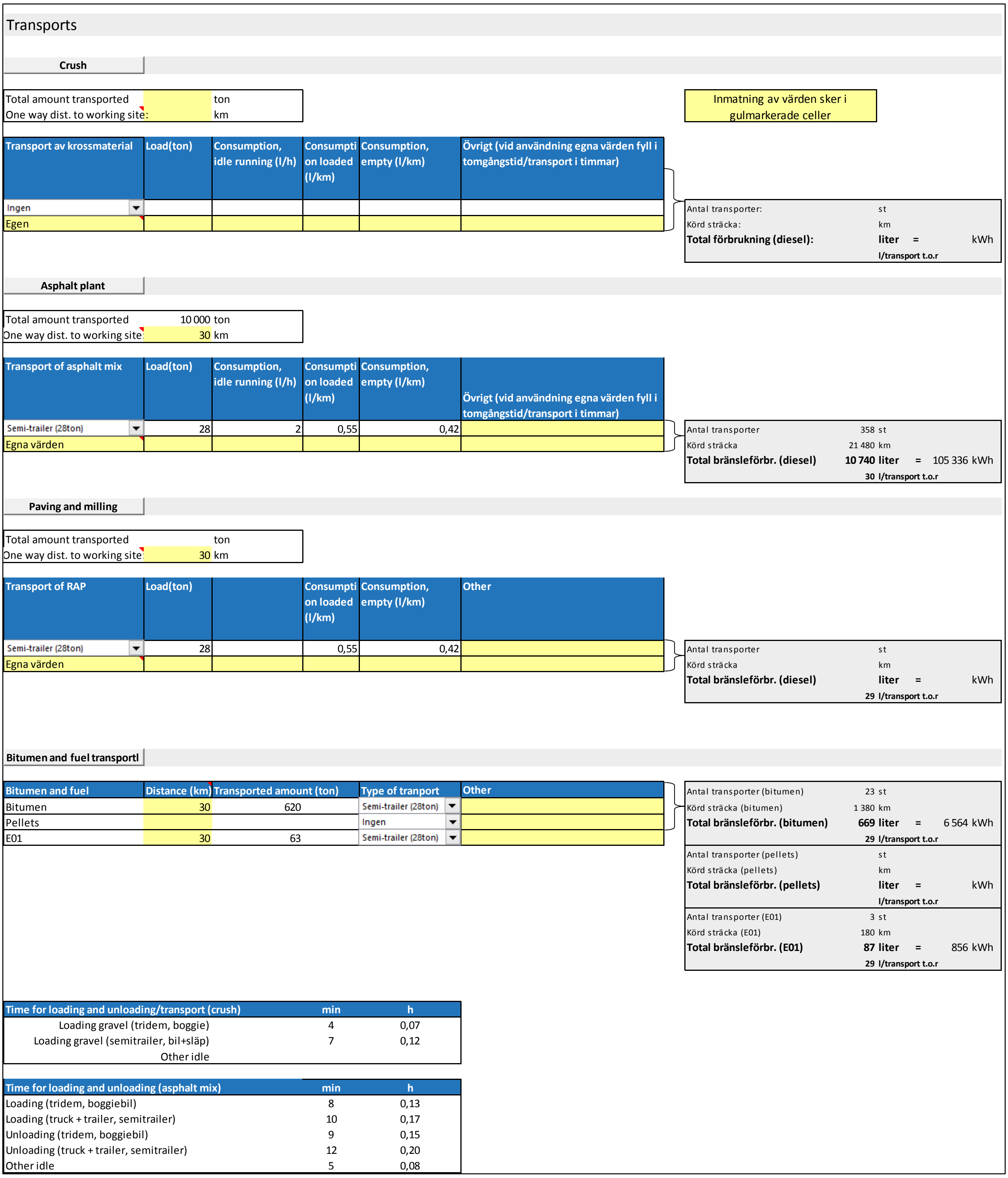
Maskin	Timmar
Vält	200 h
Läggare	100 h
Tack coater 2	25 h
Tack coater 3	25 h
Sweeping machi	25 h
TMA	
Egen	
Totalt	375 h

Figure 10: Paving. Add surface paved and choose different machines for each specific work site. Total consumption for each step is shown in the grey boxes to the right.

5. TRANSPORTS

Under the tab "transport" all transports for each sub-process are added.

The transports consists of:
Stone and material transport.
Milling transport
Bitumen transport.
Asphalt transport.
Various additive transport.
Oil and fuel transport.



Transports

Crush

Total amount transported		ton
One way dist. to working site:		km

Inmatning av värden sker i gulmarkerade celler

Transport av krossmaterial	Load(ton)	Consumption, idle running (l/h)	Consumption loaded (l/km)	Consumption, empty (l/km)	Övrigt (vid användning egna värden fyll i tomgångstid/transport i timmar)
Ingen					
Egen					

Antal transporter:		st	
Körd sträcka:		km	
Total förbrukning (diesel):		liter =	kWh
		l/transport t.o.r	

Asphalt plant

Total amount transported	10 000	ton
One way dist. to working site:	30	km

Transport of asphalt mix	Load(ton)	Consumption, idle running (l/h)	Consumption loaded (l/km)	Consumption, empty (l/km)	Övrigt (vid användning egna värden fyll i tomgångstid/transport i timmar)
Semi-trailer (28ton)	28	2	0,55	0,42	
Egna värden					

Antal transporter	358	st	
Körd sträcka	21 480	km	
Total bränsleförbr. (diesel)	10 740	liter =	105 336 kWh
	30	l/transport t.o.r	

Paving and milling

Total amount transported		ton
One way dist. to working site:	30	km

Transport of RAP	Load(ton)		Consumption loaded (l/km)	Consumption, empty (l/km)	Other
Semi-trailer (28ton)	28		0,55	0,42	
Egna värden					

Antal transporter		st	
Körd sträcka		km	
Total bränsleförbr. (diesel)		liter =	kWh
	29	l/transport t.o.r	

Bitumen and fuel transportl

Bitumen and fuel	Distance (km)	Transported amount (ton)	Type of tranport	Other
Bitumen	30	620	Semi-trailer (28ton)	
Pellets			Ingen	
E01	30	63	Semi-trailer (28ton)	

Antal transporter (bitumen)	23	st	
Körd sträcka (bitumen)	1 380	km	
Total bränsleförbr. (bitumen)	669	liter =	6 564 kWh
	29	l/transport t.o.r	
Antal transporter (pellets)		st	
Körd sträcka (pellets)		km	
Total bränsleförbr. (pellets)		liter =	kWh
		l/transport t.o.r	
Antal transporter (E01)	3	st	
Körd sträcka (E01)	180	km	
Total bränsleförbr. (E01)	87	liter =	856 kWh
	29	l/transport t.o.r	

Time for loading and unloading/transport (crush)	min	h
Loading gravel (tridem, boggie)	4	0,07
Loading gravel (semitrailer, bil+släp)	7	0,12
Other idle		

Time for loading and unloading (asphalt mix)	min	h
Loading (tridem, boggiebil)	8	0,13
Loading (truck + trailer, semitrailer)	10	0,17
Unloading (tridem, boggiebil)	9	0,15
Unloading (truck + trailer, semitrailer)	12	0,20
Other idle	5	0,08

Figure 11: Every transport used is listed here.

6. SUMMARY OF RESULTS AND OUTPUT.

6.1 Presentation of summaries.

The summary of the results are available in tabular form or in graphical format and you can choose the type of output you want. Emission (CO_2) and energy consumption (kWh) are presented in total and per operation and per ton as well as per m² (fig 12a). It is also possible to ad estimated lifetime, to make a full LCA-analysis. This is not added automatically, since lifetime still is one of the questions we deal with.

The diagrams show in different ways how much each part of the production and laying of asphalt cost in form of CO_2 emissions and energy consumption (fig 12b).
Traffic load (trafikbelastning) illustrates the effect of traffic on CO_2 and fuel consumption. This is not included in the EKA calculations, but is important if you aim to do a complete LCA study of a road.

Total emissions end energy consumption		
414 892 kg CO_2	1 911 918 kWh	
41,5 kg CO_2/ton & år	191,2 kWh/ton & år	
4,1 kg CO_2/m^2 & år	19,1 kWh/m^2 & år	
Estimated lifetime:	1	år

Figure 12a: Total emission of CO_2 and energy consumption, per ton and per square meter (enlarged from fig. 12.b).

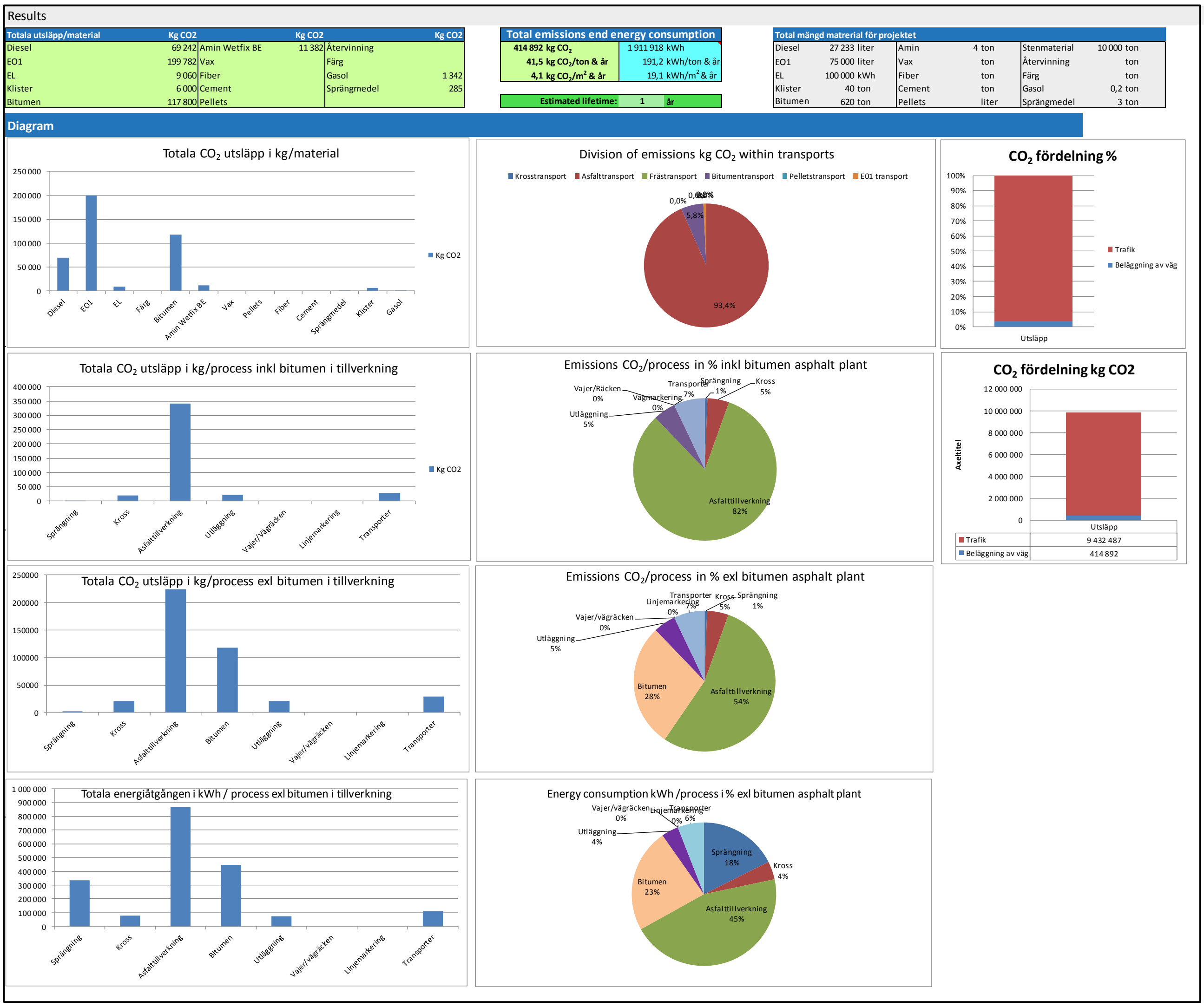


Figure 12b: The first part of the summary page, showing emissions and energy consumption in graphical format.

The summary fields shows how much each process represent in CO_2 emissions and energy consumption (fig. 12b).

Type of energy, type of raw materials and products as well as thickness of the coating is completely ruling when it comes to CO_2. Temperature and transport affect as well CO_2 as energy. The fairest way to report and compare the different pavement types or methods is per m².

Summary by process

Blasting

Sprängd massa	*10 000*	*ton*
Skuthantering:	*Ja*	
Total dieselförbr. (sprängning):	**508**	**liter**
	0,05	l/ton
Total dieselförbr. (skuthantering):	**286**	**liter**
	0,03	l/ton
Sprängmedel, starter:		
Booster	63	kg
Booster	42	kg
Bulksprängmedel:		
EPC Blendex 70	3019	kg

Diesel	793 liter	2 017 Kg CO2	7 780 kWh	
Booster	63 kg	2 Kg CO2	6 615 kWh	
Booster	42 kg	2 Kg CO2	4 410 kWh	
EPC Blendex 70	3 019 kg	281 Kg CO2	316 981 kWh	
	Totalt	**2 302 Kg CO2**	**335 786 kWh**	
		0,23 Kg CO2/ton	**33,6 kWh/ton**	

Crush

Krossad mängd:	*10 000*	*ton*
Ingående krossteg:	*Förkross+2steg *(via generator)*	
Total dieselförbrukning:	**7 970**	**liter**
	0,80	l/ton
Total elförbrukning:		**kWh**
		kWh/ton

Diesel:	7 970 liter	20 264 Kg CO2	78 168 kWh
EL:	kWh	Kg CO2	kWh
	Totalt	**20 264 Kg CO2**	**78 168 kWh**
		2,0 Kg CO2/ton	**7,8 kWh/ton**

Asphalt plant

Producerad mängd:	*10 000*	*ton*
Total dieselförbrukning:	**1 596**	**liter**
	0,16	l/ton
Total bränsleförbrukning (E01):	**75 000**	**liter**
	75 000	l/ton
Total förbrukning (pellets):		**liter**
eller		**kg**
		l/ton
Total elförbrukning:	**100 000**	**kWh**
	10	kWh/ton
Bitumen	**620**	**ton**
Amin Wetfix BE	**4**	**ton**
Vax (Crude derived parafin vax)		**ton**
VIATOP 66		**ton**
Cement		**ton**
Återvinning		**ton**

Diesel:	1 596 liter	4 058 Kg CO2	15 655 kWh
E01:	75 000 liter	199 782 Kg CO2	746 847 kWh
Pellets:	liter	Kg CO2	kWh
El:	100 000 kWh	9 060 Kg CO2	100 000 kWh
Bitumen	620 ton	117 800 Kg CO2	447 640 kWh
Amin Wetfix BE	4 ton	11 382 Kg CO2	2 120 kWh
Vax	ton	KgCO2	kWh
VIATOP 66	ton	Kg CO2	kWh
Cement	ton	Kg CO2	kWh
Återvinning	ton	Kg CO2	kWh
	Totalt:	**342 082 Kg CO2**	**1 312 262 kWh**
		34,2 Kg CO2/ton	**131,2 kWh/ton**

Paving

Utlagd massa:	*10 000*	*ton*
Utlagd yta:	*100 000*	*m^2*
Fräst massa		*ton*
Fräst yta		*m^2*
Total dieselförbrukning (utläggning):	**5 378**	**liter**
	0,05	l/m^2
Total dieselförbrukning (fräsning):		**liter**
		l/m^2
Total förbrukning (klister):	**40 000**	**kg**
Total förbrukning (gasol):	**225**	**kg**

Diesel:	5 378 liter	13 673 Kg CO2	52 742 kWh
Klister:	40 ton	6 000 Kg CO2	20 200 kWh
Gasol:	0,2 ton	1 342 Kg CO2	3 kWh
	Totalt	**21 014 Kg CO2**	**72 945 kWh**
		2,1 Kg CO2/ton	**7,3 kWh/ton**
		0,21 Kg CO2/m2	**0,73 kWh/m2**

Transports

Krosstransport		*ton*
Asfalttransport	*10 000*	*ton*
Frästransport		*ton*
Bitumentransport	*620*	*ton*
Pelletstransport		*ton*
E01 transport	*63*	*ton*
Tot dieselförbr. (krosstransport):		**liter**
		l/ton
Tot dieselförbr. (asfalttransport):	**10 740**	**liter**
	1,1	l/ton
Tot dieselförbr. (frästransport)		**liter**
		l/ton
Tot dielförbr. (bitumentransport)	**669**	**liter**
	1,1	l/ton
Tot dieselförb. (pelletstransport)		**liter**
		l/ton
Tot dieselförbr. (EO1)	**87**	**liter**
	1,4	l/ton

Diesel (krosstrsp.):	liter	Kg CO2	kWh
Diesel (asfalttrsp):	10 740 liter	27 307 Kg CO2	105 336 kWh
Diesel (frästrsp):	liter	Kg CO2	kWh
Diesel (bitumentrsp):	669 liter	1 702 Kg CO2	6 564 kWh
Diesel (pelletstrsp):	liter	Kg CO2	kWh
Diesel(EO1 trsp):	87 liter	222 Kg CO2	856 kWh
	Totalt	**29 231 Kg CO2**	**112 757 kWh**
		2,7 kg/ton	**10,6 kWh/ton**

#REFERENS!

Figure 12c: The summary page showing emissions and energy consumption in tabular form.

By going through all the different pavement types systematically the same way, it is possible to make a comparison between different pavement types and/or paving method. The results show that a product or method can affect the environment through high CO_2 value per ton of asphalt, but give a low CO_2 value per m² of coating. The same applies to the calculation of energy consumption, especially when it comes to various special methods, such as Remixing and Repaving.

The total amount of produced asphalt mix in Sweden is approximately 7,5 million tons a year. On average the emissions from hot mix asphalt is about 50 kg CO_2/ton including all material, transports and paving. This means that about 375 000 tons of CO_2 comes from the paving industry yearly.

6. CONCLUDING REMARKS

It is necessary for everyone to make an effort to lower the environmental burden. The paving industry represents a large load of CO_2 emissions distributed on transportation, combustion, industrial processes and electric power. It demands new ways of thinking whether you represent the road authority, a contractor or consultant.

EKA shows in a pedagogical way, what affects the environment the most. Between normal asphalt mixes there is no significant difference on CO_2 emissions and energy. Variables that gives the greatest effect on reducing emissions are the use of biofuels and larger amount of recycling. CO_2 and energy can both be reduced by temperature-lowering activities.

Transport is a major environmental burden that can be reduced by thinner coatings, shorter journeys through mobile asphalt plants and if possible near-urban quarries.

All savings refers to the condition that the coating achieves expected quality and performance.

Different information is needed to make the selection of the right type of coating.

It is possible for asphalt producers to trim the production and transport planning with help of the detailed information from EKA.

For The Swedish Transport Administration EKA is used as a tool and help for making the planning strategy of maintenance, to be able to reduce CO_2 from the road sector. Summaries from the last five years of paving show that the average of CO_2 emissions and energy consumption have been lowered every year, which was the goal from the beginning of the project of "Energy Effective Asphalt Pavement".

REFERENCES

[1] Energieffektiv asfaltbeläggning, LCA-verktyget EKA, FUD-ID 4930, Trafikverket, Roger Lundberg, 2015-04-17.