Calculation of energy and carbon dioxide on asphalt pavements

Kristina Martinsson¹, a, Torbjorn Jacobson², b, Roger Lundberg³, c

¹ Swedish Transport Administration, Orebro, Sweden
² Swedish Transport Administration, Solna, Sweden
³ NCC Roads AB, Umea, Sweden

a kristina.martinsson@trafikverket.se
b torbjorn.jacobson@trafikverket.se
c roger.lundberg@ncc.se

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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 CO₂ 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 CO₂ 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.

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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ekv. However in some cases data have only been found presenting CO₂. In the text CO₂ or greenhouse gas is being used.
Below a schematic view of EKA is presented, showing its extent and delimitations (fig. 1).

![Schematic view of the LCA-model](image)

**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
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.
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 therefore 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/m².

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

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

![Asphalt plant - machinery + consumption](image)

**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 10 000 m². Thickness of paved layer (kg/m²) is in this example 100 kg/m².

Production speed, as in amount of added mix per hour.

Tack coating with bitumen emulsion (kg/m²).

Milling, when needed, is in (m²) 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.
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.
### 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 m$^2$ (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.

**Figure 11:** Every transport used is listed here.
The diagrams show in different ways how much each part of the production and laying of asphalt cost in form of CO₂ emissions and energy consumption (fig 12b).

Traffic load (trafikbelastning) illustrates the effect of traffic on CO₂ 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 CO₂
4,1 kg CO₂/m² & år
1911 918 kWh
19,1 kWh/m² & år

**Estimated lifetime:** 1 år

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**Figure 12a:** Total emission of CO₂ and energy consumption, per ton and per square meter (enlarged from fig. 12.b).

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**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 CO₂ 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 CO₂. Temperature and transport affect as well CO₂ as energy. The fairest way to report and compare the different pavement types or methods is per m².
### Summary by process

#### Blasting

<table>
<thead>
<tr>
<th>Process</th>
<th>Quantity</th>
<th>Diesel</th>
<th>Kerosene</th>
<th>Bunker</th>
<th>Oil</th>
<th>Total CO2</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprängning</td>
<td>10,000 ton</td>
<td>793 l</td>
<td>63 kg</td>
<td>42 kg</td>
<td>1631 l</td>
<td>2,017 kg CO2</td>
<td>7,780 kWh</td>
</tr>
<tr>
<td>Skuthantering</td>
<td>Ja</td>
<td>63 kg</td>
<td>42 kg</td>
<td>1631 l</td>
<td>2,017 kg CO2</td>
<td>7,780 kWh</td>
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</table>

#### Crush

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<th>Oil</th>
<th>Total CO2</th>
<th>Total kWh</th>
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<td>1631 l</td>
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<td>Total dieselförbrukning (skuthantering)</td>
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<tr>
<td>Booster</td>
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<td>48 l</td>
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<td></td>
<td>2,017 kg CO2</td>
<td>7,780 kWh</td>
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<tr>
<td>Booster</td>
<td>42 kg</td>
<td>48 l</td>
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<td>2,017 kg CO2</td>
<td>7,780 kWh</td>
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#### Asphalt plant

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<th>Oil</th>
<th>Total CO2</th>
<th>Total kWh</th>
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<tbody>
<tr>
<td>Producerad mängd</td>
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<td>519 l</td>
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<td>4,058 kg CO2</td>
<td>15,655 kWh</td>
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<tr>
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<td>790 l</td>
<td>519 l</td>
<td>3019 kg</td>
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<td>4,058 kg CO2</td>
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<td>kWh</td>
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<td>kWh</td>
<td>kWh</td>
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#### Paving

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<th>Oil</th>
<th>Total CO2</th>
<th>Total kWh</th>
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<tbody>
<tr>
<td>Utilgäld massa</td>
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<td>578 l</td>
<td>40 ton</td>
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<td>13,673 kg CO2</td>
<td>52,742 kWh</td>
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<td>578 l</td>
<td>40 ton</td>
<td>2 ton</td>
<td></td>
<td>13,673 kg CO2</td>
<td>52,742 kWh</td>
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#### Transports

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<th>Oil</th>
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<th>Total kWh</th>
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<td>Total dieselförbrukning (frästtransport)</td>
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<tr>
<td>Total dieselförbrukning (bitumenstransport)</td>
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<tr>
<td>Total dieselförbrukning (asphalttransport)</td>
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<tr>
<td>Total dieselförbrukning (klistratransport)</td>
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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 CO₂ value per ton of asphalt, but give a low CO₂ 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 CO₂/ton including all material, transports and paving. This means that about 375,000 tons of CO₂ 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 CO₂ 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 CO₂ emissions and energy. Variables that gives the greatest effect on reducing emissions are the use of biofuels and larger amount of recycling. CO₂ 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 CO₂ from the road sector. Summaries from the last five years of paving show that the average of CO₂ 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