CALCULATION OF ASPHALT PRODUCTION ENERGY FLOW TO COMPARE WARM AND HOT MIX ASPHALT

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ABSTRACT

Warm Mix Asphalt (WMA) technologies allow significant lowering of the production and pavement temperature of conventional Hot Mix Asphalt (HMA) thus reducing the energy demand and greenhouse gas emission in the atmosphere. In order to provide the necessary information on environmental and economical potential of WMA in each specific case these benefits have to be acknowledged in quantitative analysis with a Life Cycle Assessment (LCA) tool. The calculation model, presented in the paper, was developed as inventory of energy flow for asphalt production, which is the first phase in developing LCA tool. The calculation involves all the main areas that can be influenced by choosing WMA instead of HMA, including production, paving and compaction of asphalt, mining and/or manufacturing of all component materials and transportation. The amount of used energy and the energy sources were defined for each of the processes allowing to express the results in terms of total energy demand distribution by the energy source or by unit process, which is significant in further calculation of carbon footprint.

The case study results present the comparison of asphalt energy consumption for seven different modules. Transportation distances and the construction design were defined as typical for a paving site in Latvia. The results showed 7% to 18% energy gain for the WMA in comparison with the reference HMA and indicated that the asphalt production and paving process depend almost entirely on non-renewable energy sources and changes between different modules in this case mostly affect the use of natural gas.

Keywords: Warm Asphalt Mixture, Life Cycle Inventory, Emissions, Energy saving

1. INTRODUCTION

The increased environmental awareness and the demands of Kyoto protocol are setting the way of road building industry to develop more sustainable technologies. Warm Mix Asphalt (WMA) is one of the ways to reach this goal. Using the WMA technologies, asphalt can be produced and placed at lower temperatures thus reducing the energy demand which is very closely related to the reduction of CO_2 and other greenhouse gasses. Putting into practise WMA promises some indirect environmental benefits as well, for example the potential to incorporate higher amount of reclaimed asphalt pavement (RAP) in the mixture, thus resolving the problem of RAP utilisation, saving landfill space, reducing the demand for virgin aggregates and energy used for mining and crushing them. The information about these environmental effects from using WMA has to be acknowledged and presented to politicians and public in order to make sustainable decisions.

The direct decrease of emissions in production process is easy to measure and it has been done is several researches providing with information about the reduction amounts that can be achieved. However use of WMA can influence not only the reduction of heating energy, but can have an effect on other processes related to asphalt production and influence the mechanical characteristics and the durability of pavement. For full assessment of the environmental effects for each production technology it is necessary to provide the information about the entire asphalt pavement life cycle. The calculation has to include mining of raw materials, production of all component materials, production and laying of asphalt, maintenance of the road, reconstruction of pavement, introduction of recycled asphalt (RAP) and eventual disposal of unusable materials.

An effective and easy to use Life Cycle Assessment (LCA) tool is necessary to perform calculation. European standards ISO 14040 [1] and ISO 14044 [2] describe the principles (Figure 1) and methodology of developing such a tool. However the development of LCA requires information on the properties and long-term performance of asphalt and while there is enough information about the traditional Hot Mix Asphalt (HMA), the technologies of WMA are still being developed. Since the oldest WMA test sites are only about ten years old, there may not be enough information on the longevity of pavements constructed with this technology. This then requires also a trustful pavement life cycle prediction method.

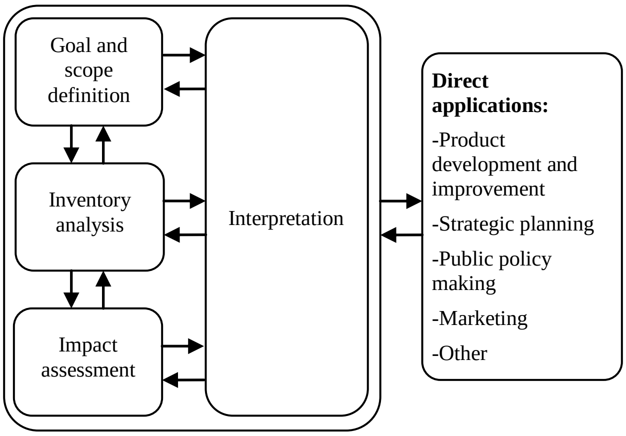

Figure 1 : Framework of the LCA by ISO 14040

The main work in developing complete LCA tool is the Life Cycle Inventory (LCI) phase in which all the environmental impacts are defined in whole life time of asphalt [3].

Development of energy demand (energy flow) calculation method for assessing used amount and types of energy for the production is the first, but at the same time the most reliable step in estimating the entire environmental effect. It can be considered as the “input” of the LCA, whereas, for example, air emissions can be classified as “output” [4]. Therefore the model presented in this paper is the base for further development of complete LCA.

2. DEVELOPMENT OF ENERGY INVENTORY CALCULATION MODEL

The goal of the study is to compare LCA results of HMA and WMA. The calculation of energy flow is necessary in order to assess the amount of changes in energy consumption of WMA compared to HMA, and to determine the energy sources used for the process.

Many different types of asphalt layers, production technologies and laying techniques are used today so the calculation model has to be flexible. The used technological units and production sites can have various energy efficiency so the energy input for each process has to be variable. And surely transportation distances can vary in each specific case as well. These reasons define that the calculation model has to be versatile so that the parameters can be input in each specific case.

2.1. System boundaries

There are three main technologies of Warm Mix Asphalt (WMA) production which can be classified as chemical, organic and foaming. The first two are produced by adding some type of additives in the technological process of asphalt production whereas the utilisation of foaming technologies would also require production and installation of additional equipment in the plant site.
A thorough literature study was performed to acknowledge the measured changes in energy consumption for different processes of various WMA technologies compared to traditional asphalt. The main variations in energy consumption are of course those from reduction in aggregate drying temperature in asphalt plant, but it was found that there may be other changes that directly influence energy consumption compared to the traditional HMA. The calculation model was developed so that all of these changes are taken into account:

- –Energy savings in the production process of WMA (20% to 70%), because less heating energy is necessary [5; 6];
- –The energy savings in pavement compaction of WMA (up to 30%), because of lower bitumen viscosity [7];
- –The amount of additives used in production of WMA (0,2% to 4% of bitumen mass) [8];
- –The relatively higher amount of Recycled Asphalt Pavement (RAP) use possibilities in WMA (up to 90% RAP), because of less bitumen ageing and lower bitumen viscosity [8].

Based on the literature study results, only the processes that can be influenced by switching from WMA to HMA are included in the calculation. The system boundaries of the calculation are presented in Figure 2. Bullets represent transportation and are also a part of calculation.

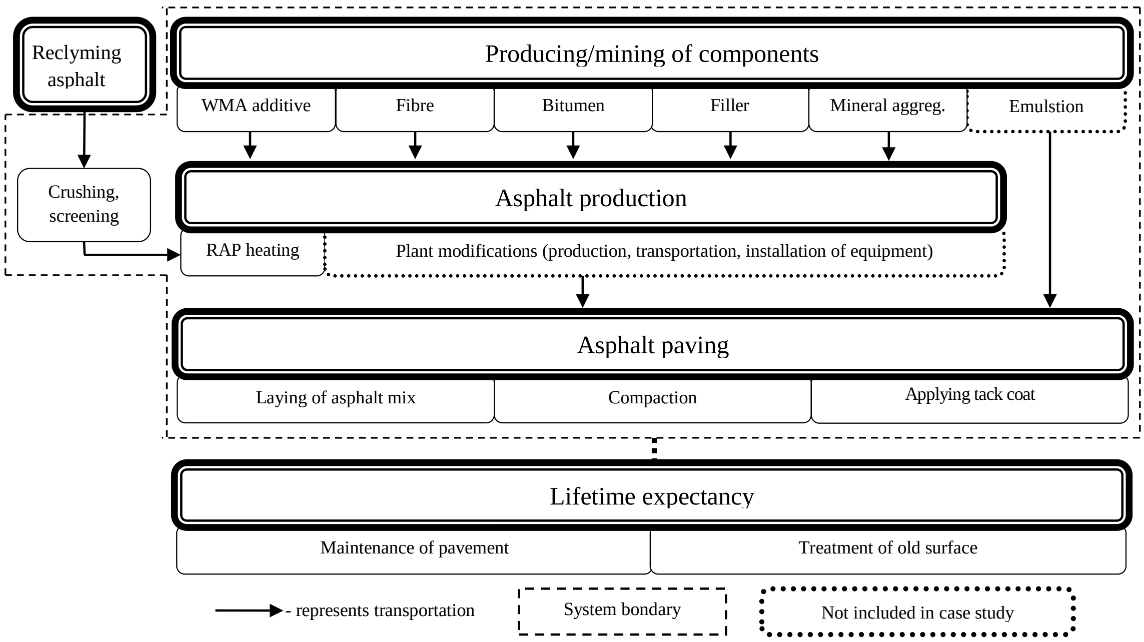

Figure 2 : System boundaries of asphalt LCI calculation

2.2. Calculation principle

Microsoft Excel® software is used for calculation. The calculation structure of the worksheets is illustrated in Figure 3. There are separate files (workbooks) for each of the calculation modules and for the overview of the results. The required information that is defined in Table 1 has to be input in the first sheet of the workbook file. The other three sheets of the workbook are for representing the results and are linked with the first by calculation formulas. The results can be traced for each of the processes separately which is necessary to build further the LCA model. One more sheet is for expressing the energy demand summary for the entire module. The summary of each workbook is linked to a separate file called 'overview' where the results are expressed in one table for easy comparison of different modules and better visualization by drawing charts.

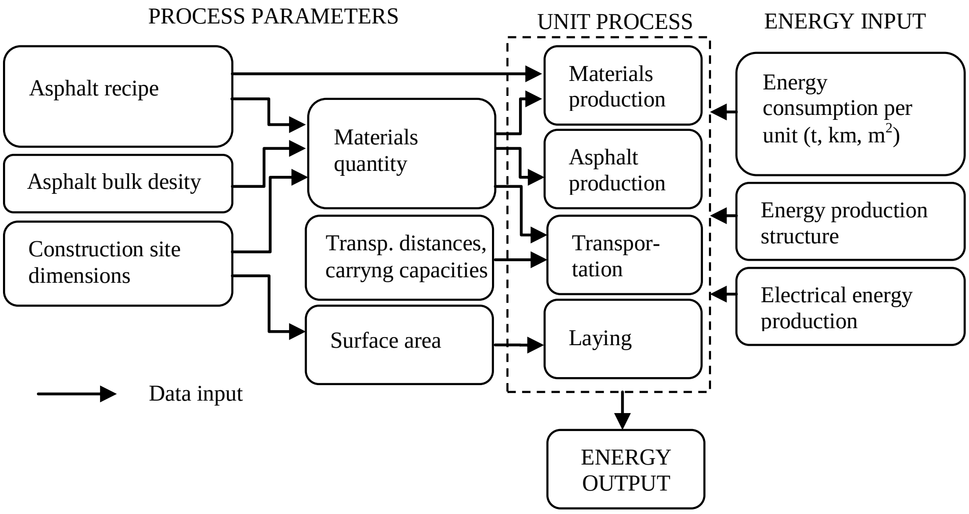

Figure 3 : Energy flow calculation principle

Table 1 : The required information for the calculation of energy flow

Unit process	Required information
Construction site	–The dimensions of site –The construction of asphalt layer
Asphalt mixture	–The mixture composition –The materials used –The maximum density of mixture
Production of electrical energy	–The use of different energy sources for the production of electricity in the specified region –The necessary amount of specific power intensity of electricity from used power sources
Production of asphalt	–The energy source used for production –The energy amount used for asphalt production per tonne –The energy amount for production, transportation and installation of any necessary additional plant equipment
Production of asphalt components	–The types of energy used for mining and/or production of component materials –The amount of energy used for producing each component per tonne
Asphalt paving	–The energy demand for paving and compaction of HMA per m^2 –The efficiency of paving and compaction –The density of asphalt layer
Transportation	–The types of transport used –The sources of energy used –The carrying capacity for each transport type –The energy use per km for each transport type –Transportation distances of component materials and asphalt

It is assumed that all production processes also involve loading the material in the truck. The energy demand for transportation with trucks is assumed at maximum carrying capacity and empty truck return, while for water transport and trains it is considered that the carrying capacity is unlimited and the energy demand is for one way. In the calculation the laying, speed has been assumed to be constant 4 m/min and the energy consumption is independent of the asphalt layer thickness. For compaction the same principle is used. Since electricity is used for the production of component materials and the mixture itself, the contribution of different energy sources and the effectiveness of producing 1 MJ of electricity has to be taken into account when performing the calculation.

3. CASE STUDY

A case study was performed to get a general overview of the energy flow of HMA and WMA. No specific product for this purpose was chosen.

For the case study it was assumed that the equipment necessary for the addition of WMA additives is available in the plant, so in the energy flow calculation for production of WMA, the only additional energy application is for the production and transportation of WMA additive. This calculation principle would be applicable for most of the organic and chemical WMA technologies, but not for foaming technologies, because special equipment needs to be installed in the asphalt production site in this case. If plant modifications are necessary (e.g. installation of additive dosage systems or

special equipment for foaming technologies), there is a possibility to include them in the calculation model as illustrated in Figure 2.
The potential changes in energy consumption are qualified as variables from the reference mixture and are included in different calculation modules as indicated below.

3.1. Construction site

It was assumed that mechanical characteristics of the traditional hot mix and warm mix asphalt are similar, so the pavement construction can be the same for both types of asphalt. The construction site was defined as the surface of pavement with a layer thickness of 4 cm and the area of road of 4000 m^2 which is considered to be an average amount of work for a week day.

3.2. Asphalt mixture

The reference module calculation was carried out for SMA 11 type asphalt with mix composition as defined in Table 2. The density of mix after compaction is assumed as 97.5% and maximum density of 2469 kg/m^3.

Table 2 : Composition of SMA 11 mixture

Component material	Content in mixture, %
Bitumen 40/60	6.55%
Lime powder	4.66%
Granite 0/2	23.31%
Granite 2/5	9.33%
Granite 5/8	13.99%
Granite 8/11	41.96%
Fibre	0.20%
WMA additive (when used)	3% of bitumen mass

3.3. Energy consumption

The amount of energy demand for different processes that were covered in the reference calculation is presented in Table 3. The main data of energy demand for energy consumption of different processes are taken from the European Asphalt Pavement Association (EAPA) and Eurobitume report "Life Cycle Inventory of Asphalt Pavements" [9]. Since no data were found on the energy demand for production of WMA additives, the producers of three WMA technologies were contacted. None of them were able to provide, within the time frame of this project, the necessary information on the amount and types of energy used in the production of these products. Therefore, the energy demand for production of WMA additive after consultation with chemical engineers is assumed theoretically to be similar to that of bitumen production. The energy demand for compaction of HMA covers complete rolling of one layer of asphalt assuming that the final compaction is reached after 6 roller passes.

Table 3 : Energy demand and used energy sources of different unit processes

Unit process	Diesel	Natural gas	Electrical power
Components of asphalt, MJ/kg			
Bitumen, MJ/kg	-	3.25	1.09
Granite, crushed sand, MJ/t	17,00	-	21.20
Lime filler, MJ/kg	0,02	-	0,22
RAP processing	-	-	21.20
Fibre, MJ/kg	0,04	1,2	0,06
WMA additive, MJ/kg	-	3.25	1.09
Production of asphalt, MJ/kg			
Heating of recycled asphalt MJ/t	-	8,78	-
Asphalt production	-	340,00	32,00
Paving of asphalt, MJ/kg			
Laying of asphalt (Dynapac F121)	0.702	-	-
Compaction with Dynapac CC222	0.620	-	-
Transportation, MJ/km			
Truck (24 tonnes)	13,3	-	-
Ship	0,143	-	-

3.4. Transportation distances and transport type

Transportation distances of the different components and the final asphalt mix to the site were assumed as typical haul ranges for the asphalt industry in Latvia and are listed in Table 4. The carrying capacity of truck assumed 24t.

Table 4 : Distances for transportation of component materials and product

Transport	Truck	Ship
	km	km
Granite to mixing plant	250	800
Sand & gravel to mixing plant	100	-
Bitumen to mixing plant	200	-
Lime filler to mixing plant	100	-
Fibre to mixing plant	250	-
WMA additive to mixing plant	2000	-
Recycled asphalt to processing, to plant	100	-
Asphalt mix to site	70	-

3.5. Production of electricity

The energy demand for production of 1 MJ of electrical power and the contribution from different energy sources in Latvia for the year 2009 [10] are presented in Table 5.

Table 5 : Energy demand of producing electric power and contribution from different sources in Latvia

Electrical power production source	Contribution, MJ per 1 MJ el-power	Production of 1 MJ el-power, MJ
Hydro power	63,3%	0,289
Natural gas	25,4%	0.674
Other fossil fuel	9,7%	0.412
Other sustainable energy	1,6%	0.242

3.6. Variables

Based on these findings seven different asphalt energy demand LCI calculation modules were created where each of them represents several modifications that are typical for WMA. The ranges compared to reference HMA that were used for this case study are listed in Table 6. Changes in transportation distances are also included according to Table 4. In the modules with RAP use in the mix, the amount of granite and bitumen was reduced by the respective amount of the introduced RAP (containing 5% soluble binder content). It is assumed that 70% mixing occurs between virgin and RAP bitumen [11]. An approximate value of 15% energy demand increase was applied, because usually it is necessary to provide more heating energy [12; 13] and additional compaction force in order to compensate stiffer bitumen in the RAP. The energy use and compaction force of WMA were left in the same level as for reference HMA, because WMA technologies increase the workability of the mix thus allowing to work at lower temperatures.

Table 6 : Process variables for LCI calculation

No.	Production process	Process variations		
		WMA additive	Energy usage of asphalt plant	Compaction effort
1.	HMA, Reference	0	100%	100%
2.	WMA, Production process -20%	3%	80%	100%
3.	WMA, Production process -50%	3%	50%	100%
4.	WMA, Compaction -20%	3%	100%	80%
5.	WMA, Compaction -20%, Production -20%	3%	80%	80%
6.	HMA with 20% RAP	0%	115%	115%
7.	WMA with 40% RAP	3%	100%	100%

3.7. Results and discussion

The results of each unit process can be expressed separately; however, in the context of this research the total energy consumption of the process is more essential for demonstrating the differences between WMA and HMA. Therefore only the total amount of energy used in each process will be expressed in order to see the potential savings. All results represent the total energy demand for the paving site – 4000 m^2 or 395 tonnes of asphalt.

The asphalt energy consumption sorted by the process unit for all seven calculated modules is shown in Figure 4. The energy demand, sorted by the energy source, is presented in Figure 5. The charts also represent the relative difference in percentage for each process with the hot mix asphalt, which has energy demand of 375147 MJ, being used as the base-line.

From the chart in Figure 4 it is clear that the changes in the energy consumption for asphalt production are by far the most important part regarding comparison of LCI for HMA and WMA. While for LCI of the reference HMA the production of asphalt adds up 39% of total energy demand, for WMA with 20% energy reduction in production process it is only 33% of the total energy demand of the respective module. The results show possible savings of 7% of the total energy consumption of asphalt LCI process when the production energy is reduced by 20% and 18% when it is reduced by 50%.

WMA with a compaction force reduced by 20%, but production temperature left the same, was included in order to verify what effect on energy consumption production of the WMA at HMA temperature would have. This may be necessary in order to perform cold weather paving, when WMA is produced at temperatures of HMA or to achieve necessary compaction levels for stiff asphalt mixes. The results show an increase of 1% which is considered to be significant, however may be justifiable if necessary for the purposes described above.

Further, the processes of mixing and compaction energy reduction of 20% were combined showing that an additional 1% saving to the module with mixing energy reduction may be realised by reducing the compaction effort. However, the transportation of rollers to the paving site is not included in the LCI process, but would add up the same amount for both HMA and WMA, reducing the relative benefit of saving the compaction energy. Therefore, energy savings of the reduced compaction effort in the total asphalt LCI process are considered to be insignificant. The potential problems and additional energy demand that can occur if the pavement is not compacted to the necessary level because of less compaction force applied may by far outweigh the savings of this operation.

As described above, the introduction of 20% RAP to conventional HMA usually requires additional heating energy for the attainment of the necessary binder viscosity. However, the shorter hauling distances and the reduction in bitumen demand overcome the asphalt plant energy increase, therefore the total energy demand decreases by 3%. When WMA technology is applied with RAP content of 40% and reduced energy demand in heating and paving process, it is possible to reduce the energy demand by 13 more presents.

It can be seen from the chart in Figure 5 that the asphalt production and paving process depend almost entirely on non-renewable energy sources and changes between different modules mostly affect the use of natural gas. Because CO_2 and other greenhouse gases are produced in utilisation of natural gas, switching from HMA to WMA technologies has a direct effect in the reduction of carbon footprint generated by asphalt industry.

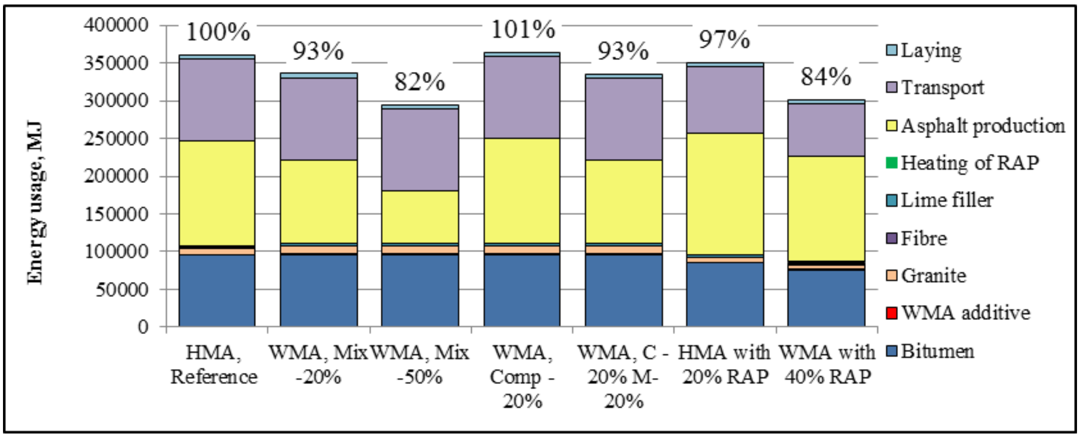

Figure 4 : Energy demand for different modules by LCI process

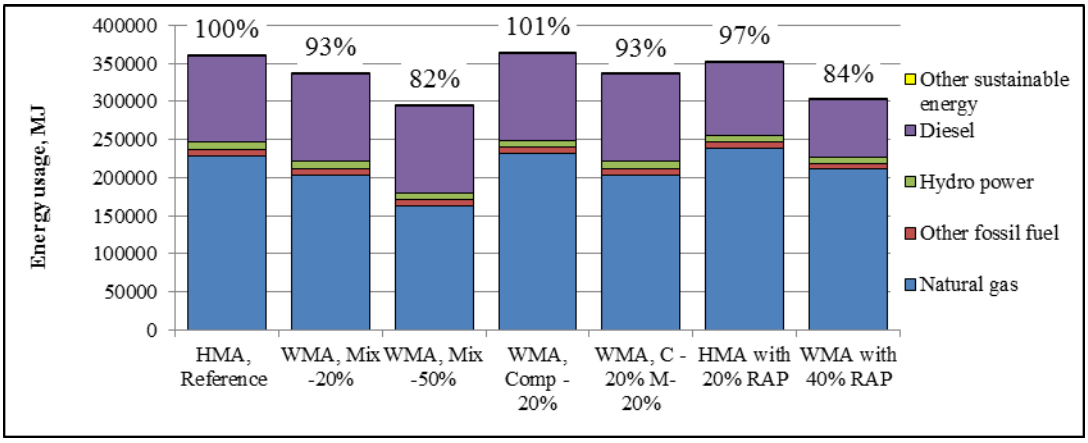

Figure 5 : Energy demand for different modules by energy source

4. CONCLUSIONS

Life cycle assessment is essential for the calculation of such key impacts as the energy consumption and carbon footprint. Therefore it is an important tool in the tendering process to choose the most sustainable construction technology. Acceptance of Warm Mix Asphalt technologies mostly rely on proving environmental their benefits so development of an easy to use LCA is necessary for gaining wide implementation of these technologies. Assessment of asphalt life cycle is also important in order to recognise variations between different WMA technologies and specific products. However, the development of LCA tool is rather complex as it must include durability of materials and the asphalt pavement must be analysed in a long period (e.g. 40 years) so further laboratory testing and a life cycle prediction method, based on the testing results, is necessary in order to predict the asphalt behaviour over time.

If you look at the entire Life Cycle Assessment (LCA), the calculation model presented in this paper focuses on the energy flow of Life Cycle Inventory (LCI) part. According to EN 14040 this can be considered as an “intermediate product” to whole LCA and it does not take into account environmental or economic aspects. Impact assessment of energy flow in production and paving process still can be performed, but care should be given to interpretation of this study in terms of environmental impact as some inaccurate conclusions can be made. For example, although according to calculation use of RAP may require additional energy in the process of HMA production, it saves the amount of necessary virgin aggregates, reduces the greenhouse gases from crushing them, resolves the problem with RAP utilisation and also reduces the asphalt price. Similarly, different WMA additives may be the reason for discussions as they have various energy demand levels for the production and have various effects on the environment. Additional calculations were performed to verify this and it was found that if the additives are produced using 9.5 times the energy that is used in this study, the energy demand of module No.2 (production -20%) equals that of the reference HMA. This may be the case when high energy consuming additives are used, for example Fischer-Tropsch process wax. However, a data acquisition and analysis are necessary to verify this statement.

There may be some modifications to the calculation principle in terms of process boundary or calculation precision, however these changes are unlikely to have a significant effect on the overall findings. It would be much more significant to improve the precision of the energy demand data for different processes. For example, the energy demand data for WMA production were assumed theoretically. Other energy input data that was used in the case study should be calibrated by actual construction objects because this would allow enhancing the precision of the results. To evaluate foaming technologies data collection for production of additional plant equipment should be performed and a calculation, including the modifications in asphalt plant, performed. Furthermore the data should be collected from different sources for the same unit processes to perform data validation.

The results of the case study showed that running Warm Mix Asphalt production technologies has enormous potential in cutting demand of non-renewable energy sources. If the calculated difference of 7% between the energy demand of reference HMA and WMA module with a realistic 20% energy reduction in asphalt production was applied to the yearly asphalt production amount in Latvia (1,3 million tonnes in year 2009) the annual decrease of energy demand would add up $8{,}7 \cdot 10^7$ MJ.

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