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Environmental Assessment of the Mineral Extraction and Non-Renewable Energy Due to Dense Graded Hot Mix and Warm Mix Asphalts Processes

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This paper describes the assessment of the use of resources such as mineral extraction and non-renewable energy of a dense graded hot mix asphalt production in a facility located in Colombia, considering four different scenarios for comparison purposes; the reference scenario is the conventional hot mix asphalt process, and the other three scenarios assess the impact of adding three different additives that help lowering the mixing temperatures. These additives allow for lower temperatures during the mixing and laying processes, and this technology is known as warm mix asphalt process. The inventory analysis of the life cycle was done by gathering and calculating information related to the inputs and outputs of the process, in order to identify the hypothesis and limits of the study. Data files of the company were consulted, from January 2011 to June 2012. Based on the inputs and outputs, mass and energy balances were verified, in order to establish the goals and scope for the assessment. The units used for the mass balances were kg/month, and the units for energy balance were MJ/month. Based on this information, the process was quantitatively described. Each units of the process was associated to relevant data, while some stages of the process were excluded of this analysis. Specialized software for Life Cycle Analysis (LCA) and several databases were used to analyze the process stages that involve most of the time and effort of the dense graded hot mix asphalt. Some limitations related to the data gathering were defined; the data excluded from this study were associated to the exploitation and transport of aggregates from the source to the plant, the crude oil refining for producing asphalt binder, and its transportation from the refinery to the mixing plant.

1. Introduction

The hot mix asphalt process generates environmental impacts in the use of natural resources category due to the mining performed to produce stone material and asphalt; it also consumes large amounts of energy during the product manufacture. These components are significant in the process life cycle because they define one hand the amount of energy used and lost in a system, and on the other the use of non-renewable natural resources. The activities developed around the production of asphalt mixtures generate affectations directly to the areas that are adjacent due to the geological soil destabilization.

The work presented below describes the Environmental Impact Assessment (EIA) potential, using the methodology of LCA, ISO 14040/44: 2006, on the production of asphalt hot dense type II (MDC-2) in the batch plant (Celis and Serrano, 2008). The mass and energy balances of process were developed and defined after the quantification of all inputs and outputs of the process steps using existing records in a real plant since 2011 and the first six months of 2012. The objectives and scope of the system under study for stroke were then identified. Finally, inventory analysis (Steen, 1999), which allowed the identification, selection and characterization of environmental burdens associated with the production process mixing method using the IMPACT 2002+ impact assessment (Jolliet, et al., 2002), is performed according to affectations (Hauschild and wenzel, 1998); in the case of the category of harm to resources (Guinée, el at., 2002) only the impact

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categories mining and non-renewable energies (Goedkoop and Spriensma, 2000) were assessed. With the results of the characterization was possible to determine the stage of the process that generates more impact to the environment, this step is essential in order to develop the comparison of the three alternative scenarios according to change of the input additive mass: Sasobit, asphalt Min, Morlife, and that have to goal the decreasing of heating temperature. Therefore, in the asphalt heating, the addition of three different additives into the asphalt was simulated. The LCA inventory analysis of conventional asphalt mixture is compared to those obtained with the three scenarios proposed so as to be able to determine which scenario allows for better environmental mitigation.

2. Methodology

In this research, the methodology used involves the EIA integrated with process analysis from the perspective of LCA. To develop the potential environmental impact assessment, the LCA methodology was applied to the production of hot dense mix asphalt (MDC-2) in a discontinuous plant. The activities described below were performed.

2.1 Goal definition and scoping (Step I)

Mass and energy, inputs and output streams, were identified thanks to a block diagram of the process that was elaborated considering the unit operations involved from storage to hot dense asphalt type II (MDC 2). Six stages of transformation were identified in the block diagram. In order to describe each of the stages, was necessary data collection as: production of hot dense asphalt in type II, raw material inputs (aggregate and asphalt entries), fuels (natural gas and diesel), energy expenditure, gaseous emissions and particulate material emitted from the plant. The data collected regards to 2011 and the first six months of 2012. The information generated during the development of this research was the basis for defining the purpose and scope of this study, the inventory analysis, evaluation of the potential environmental impact and its interpretation, according to the stipulations of the LCA methodology proposed by the ISO 14044 standard.

2.2 Life-cycle inventory (Step II)

The life-cycle inventory was developed considering the goal and scope defined. The step II was carried out using qualitative and quantitative data provided by the discontinuous plant. To develop the inventory analysis and environmental impact assessment of the life cycle, the specialized Sima Pro software version 7.1, was used. This software allows to characterize the most important environmental burdens associated with the main product and their contributions to the process during its life cycle. The perspective "door to door" was used. Using the results obtained it was also possible to compare the environmental loads of the different stages involved in the life cycle. Figure 1 shows the production process of mixing (MCD-2) (Lopera, 2011).

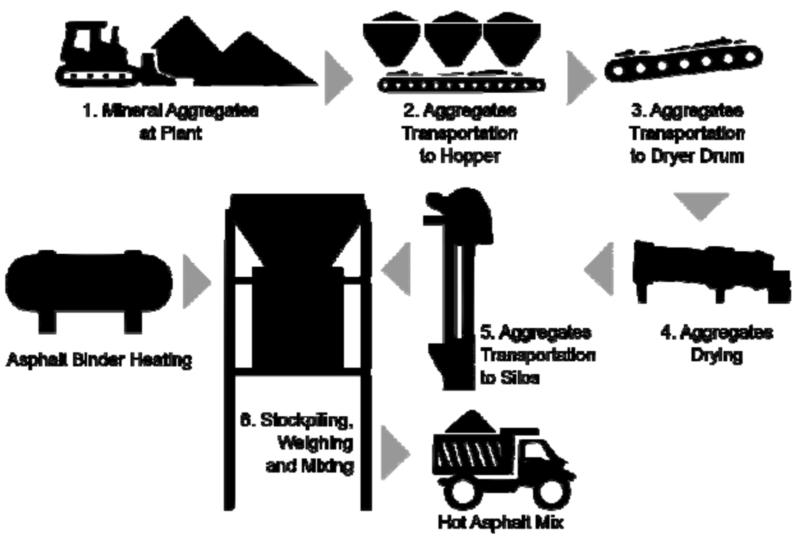

Figure 1: Process diagram for hot asphalt mix production

The first stage is the pre-heating of asphalt or asphalt cement at an optimum temperature of 155 °C for 5 h time. This heating is performed by coils that contain thermal oil which is heated by a boiler at 220 °C for an additional time of 4 h for the preparation of hot mix asphalt, In the second stage transport aggregates occurs from storage to hoppers gathering, the third and fourth stage refers to the transport of aggregates to the dryer drum and drying aggregate, these materials go through stage five where it is transported thick and thin to the hopper collection and aggregates eventually end up in a sixth step collection, weighing and mixing (Ruiz et al, 2013).

2.3 Environmental impact analysis (Step III)

A relationship or link between the stage of the process and its environmental impacts was established in the environmental impact analysis step, through the environmental profile of the process. For the Environmental Impact Analysis (EIA) the steps performed were:

Identification, impact categories selection and environmental burdens characterization. The environmental impact categories selected were: use of non-renewable energy and mineral extraction, which are associated with the categories of environmental impact of the production process in the manufacture of asphalt dense hot type II (MDC-2). In the characterization of environmental burdens were determined qualitatively and quantitatively, the associated effects of environmental burdens identified in the inventory phase.

2.4 Comparison of alternative scenarios

At this point, three scenarios were proposed as improvements in the production of mixtures: Scenario 1, Scenario 2 and scenario 3. The application of these mixtures was based on warm mixtures technology, since it differs from hot mixtures (conventional method) by the addition of additives in the binder (asphalt cement) (Celis and Serrano, 2008). The addition of these additives can reduce the temperature of the mixture production and the temperature to place them on the road. Such additives can be: Sasobit (Sasobit, 2004), Aspha-Min (Eurovia) (Suares and Santos, 2004) and Morlife (Hurley, 2005).

3. Results and analysis

For the EIA, the impact categories considered are related to the pollutants emitted by the mixture production process. The pollutants were identified according to the inventory analysis obtained in this study. The next step in the methodology was the characterization and the elaboration of the environmental profile by stages for the impact categories associated with the process.

3.1 Goal definition and scoping (Step I)

The goal of this study was evaluate the adding of three different additives in a conventional hot mix asphalt production process, with the intent of lowering the temperatures during the processes of mixing and laying, for energy saving. The batch plant used for this research is located in the industrial zone of Girón, province of Santander (Colombia). The scope was defined by considering the product, the geographical and temporal boundaries and the functional unit. The functional unit defined for this study was $3{,}960 \cdot 10^3$ t/month. This unit is basic to accounting the mass and energy consumptions during the process. The geographical boundary is defined by the location of the plant; the temporal boundaries for this assessment were defined by the production data, gathered from January 2011 to June 2012.

3.2 Life-cycle inventory (Step II)

As mentioned in the methodology, six stages were considered for the qualitative analysis of the process. The first stage is the heating of asphalt binder, at 155 °C during 5 h, by heat exchange from thermal oil, which is heated by a boiler that operates at 220 °C during 4 h. The oil is then transported through heating coils to the drum mixer. The second stage of the process is the transport of aggregates from the stockpiles to the hoppers. A front loader weighing 10 to 15 T goes over 5,2 km each batch and transports $2{,}676 \cdot 10^1$ m^3/h of aggregates. In the third stage, two belt conveyors transport aggregates from the hoppers to a drum dryer. The fourth stage consist of aggregates drying in the drum, where the heating is supplied by burning natural gas in presence of air, which is draught by a turbofan. Coarse aggregates are taken to a primary collector, while medium size aggregates are retained in a multi-cyclone unit, and fine aggregates are retained by a filter sleeve. This filter has an air inlet from a compressor, and the outlet is driven by an exhaust fan connected to a chimney. The fifth stage comprises transportation of aggregates (coarse, medium and fines) by a screw conveyor to the bucket line. At the sixth stage, the bucket line transports the aggregates to the silos; then aggregates are weighed together with the asphalt to be finally mixed.

The units T, kg or m^3 were used to identify materials streams and MJ for energy inputs and outputs. Measures of mass flows and energy rates of the different streams for each stage were taken on the base of 1 T/month of asphalt mix. Table 1 shows the main streams of the process.

Table 1: Production process of dense graded hot mix asphalt

Stream	Composition	Unit/month	Quantity	Stream	Composition	Unit/month	Quantity
In	Asphalt binder	T	$4{,}90 \cdot 10^{2}$	Out	Carbon Dioxide	kg	$1{,}01 \cdot 10^{1}$
	Mineral aggregates	T	$9{,}50 \cdot 10^{-1}$		Particulate matter	kg	$6{,}00 \cdot 10^{-3}$
	Energy	MJ	$1{,}37 \cdot 10^{1}$		Sulphur Dioxide	kg	$2{,}20 \cdot 10^{-3}$
	Diesel	T	$1{,}10 \cdot 10^{-3}$		Nitrogen Oxide	kg	$8{,}80 \cdot 10^{0}$
	Air	T	$6{,}30 \cdot 10^{-1}$		Oxygen	kg	$5{,}54 \cdot 10^{1}$
	Natural Gas	m^3	$7{,}60 \cdot 10^{0}$		Steam	kg	$3{,}80 \cdot 10^{1}$
					Carbon monoxide	kg	$6{,}90 \cdot 10^{-2}$
					Dinitrogen	kg	$1{,}74 \cdot 10^{2}$
					Asphalt mix	T	$1.0 \cdot 10^{0}$

3.3 Environmental impact analysis

Based on the emissions identified in the life cycle inventory, several environmental impact categories were chosen. Impacts were determined by the characterisation provided with the Life cycle analysis software.

Identification and selection of environmental impact categories. The identification and selection of impact categories of non-renewable energy and mineral extraction is showed in Table 2, considering the involvement of these in the use of resources associated with the process steps in this study. Figure 2 shows the environmental profile of the process according to the impacts determined for each process steps and Table 3 presents the characterization of environmental impact categories associated with the production stages of process.

Table 2: Identification and selection of the categories of environmental impact associated with the production

Impact category	Equivalent factor	Reference unit	Environmental intervention	Allocation
Non-Renewable Energy	1,0	MJ primary	Crude	Resource use
mineral extraction	16,32	MJ surplus	Aggregates	

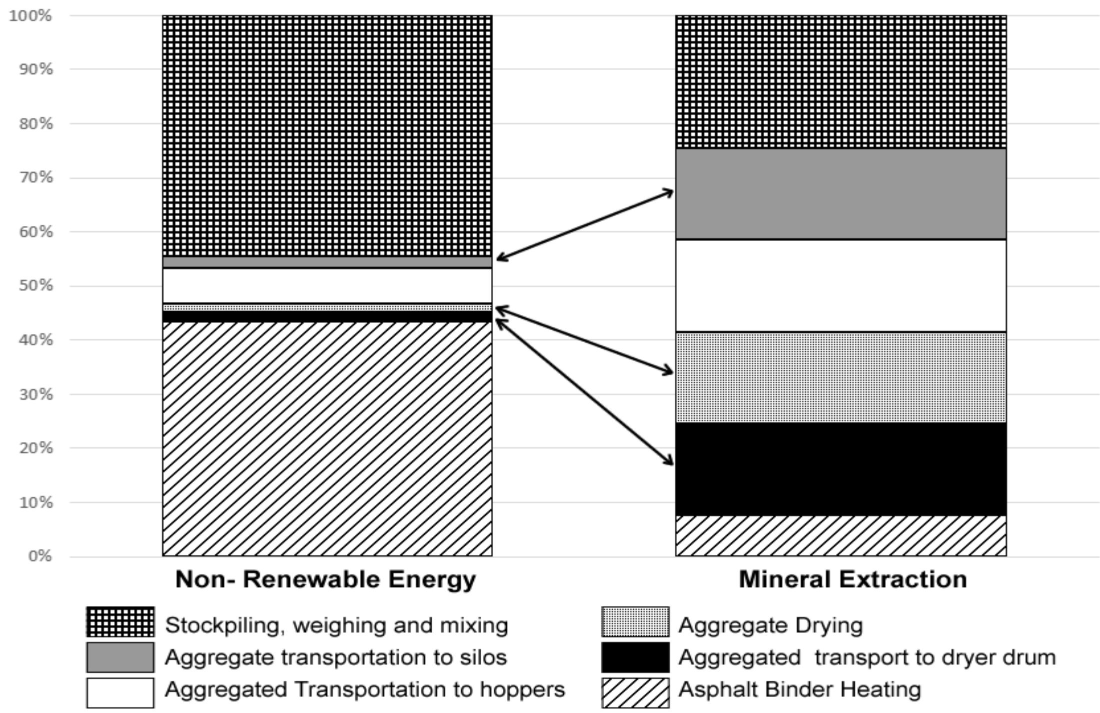

Figure 2: Environmental profile of production process of dense graded hot mix asphalt

Table 3: Characterization of environmental impact category associated with the production stages of dense hot mix asphalt (MDC-2)

Impact category	Process steps production dense hot mix asphalt					
	Asphalt binder heating	Aggregated transportation to hoppers	Aggregated transport to dryer drum	Aggregate drying	Aggregate transportation to silos	Stockpilling, weighing and mixing
Non-Renewable energy *[MJ primary]*	$7{,}86 \cdot 10^4$	$1{,}45 \cdot 10^4$	$1{,}40 \cdot 10^4$	$6{,}23E \cdot 10^4$	$1{,}41 \cdot 10^4$	$9{,}08 \cdot 10^4$
Mineral extraction *[MJ surplus]*	$1{,}00 \cdot 10^7$	$3{,}93 \cdot 10^5$	$3{,}84 \cdot 10^5$	$1{,}53 \cdot 10^6$	$3{,}86 \cdot 10^5$	$1{,}04 \cdot 10^7$

According to Table 3 and Figure 4, the largest contribution in the impact category Non-Renewable Energy and Mineral extraction of the process steps are: stockpiling, weighing and mixing, aggregate drying and asphalt binder heating; this means that they are the stages that require more resource use to crude and aggregate.

3.4 Comparison of alternative scenarios

Three scenarios were analysed: **Scenario Reference:** this scenario considers the process for production of "conventional" dense graded hot mix asphalt; **Scenario 1:** this scenario considers the process to produce dense graded hot mix asphalt in which a 3wt% of a polyvinyl resin is added to the asphalt binder before to be mixed with the aggregates. The polyvinyl resin consists of long aliphatic chains; **Scenario 2:** In this scenario, a powder synthetic zeolite is added (0.3wt%) to the asphalt binder before mixing it with the aggregates (Barthel, et al., 2005); **Scenario 3:** In this scenario, a liquid amine-based compound is added (1wt%) to the asphalt binder before mixing it with the aggregates (Hurley and Prowell, 2005).

Figure 3 shows the comparison between the contributions of each impact categories (Non-Renewable Energy & Mineral Extraction) for different scenarios. Table 4 shows the characterization of this comparison on the production of dense graded hot mix asphalt by three different scenarios analysed.

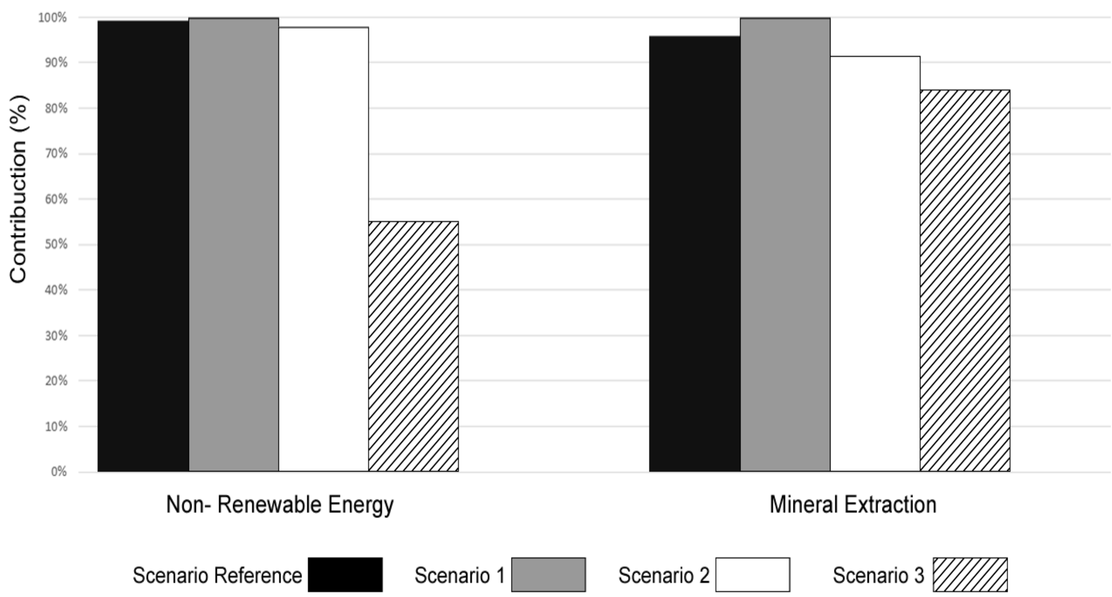

Figure 3. Comparison of contribution to the impact categories (Non-Renewable Energy & Mineral Extraction) of the different scenarios

The scenario 3 has higher mitigating effect than the alternative 2; this is due to a lower requirement of materials for producing the amine-based liquid additive comparing to zeolite. Other advantages related to use of additives are the lower requirement of asphalt binder and lower temperature for heating the asphalt binder, which helps reducing the emissions of the whole process.

Table 4: Comparison of the characterization results obtained from the different scenarios for the dense graded hot mix asphalt.

Impact category	Reference scenario	Scenario 1	Scenario 2	Scenario 3
Non-renewable energy [MJ primary]	$2{,}23\cdot10^7$	$2{,}25\cdot10^7$	$2{,}21\cdot10^7$	$1{,}23\cdot10^7$
Mineral extraction [MJ surplus]	$6{,}32\cdot10^2$	$5{,}86\cdot10^2$	$5{,}83\cdot10^2$	$5{,}80\cdot10^2$

According to Figure 3 and Table 4, it can also be observed that Scenario 3 reduces impact approximately 35% in the non-renewable energy and minerals extraction compared with the scenario reference, scenario 1 and scenario 2. According to these results, it is possible to affirm that the most beneficial effect is obtained with the addition of an amine-based enhancer.

4. Conclusions

The results presented above shows that the steps of Stockpilling, weighing and mixing, aggregate Drying and asphalt binder heating, have greater contribution to the impact categories in the stages of production of dense hot mix asphalt, the other steps involved in the process.

The application of the technique of warm mixtures is given because they are produced at lower temperatures than the hot mix, between 100 and 135 °C, making it possible to produce and place the asphalt cement at temperatures considerably lower than those conventional techniques, this means there is an energy saving since it is not necessary to dry and heat the aggregate prior to mixing plant; foamed bitumen is dosed directly to the cold and wet aggregates. Furthermore, the introduction of additives reduction of resource use the Non-renewable and mineral extraction as show in this study that reducing power consumption of about 35 % can be achieved by reducing production temperatures in the asphalt plant.

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