Life cycle assessment of modified and recommendations for policy guidelines- A case study of a Small Island Developing State (SIDS)

Avinaash Veeramah[1] and Reshma Rughooputh[2*]

Civil Engineering Department, Faculty of Engineering

***: Corresponding author**

University of Mauritius

ABSTRACT

The incorporation of additives to modify HMA properties has proven to be an environmentally a cleaner and more sustainable pavement solution. In this paper, a comparative LCA showed that, overall, the modified mixes were less of an environmental burden than the normal HMA, particularly in the mix with the incorporation of RAP. The mix with RAP replacement had the lowest emitted negative environmental impacts. Views of local contractors were sought and recommendations for policy decisions have also been brought forward for the small island developing state (SIDS), Mauritius.

Keywords: HMA, sustainable, pavement, RAP, policy, SIDS, LCA

1. Introduction

Mauritius (Figure 1) is located in the Southern part of the Indian Ocean, within latitudes 20.17° and 20.33° South and longitudes 57.33° and 57.55° East. It lies at around 800 km off the Eastern coast of the Republic of Madagascar (Proag, 2006).

Figure 1:- Location of Mauritius.

(Source: Proag, 2006)

According to the World Bank Report (2010), the last measured length of our island's road network, in 2009, amounted to about 2100 km. According to Statistics Mauritius (2015), there has been a steady increase in the number of new vehicles' sales locally and this has, undoubtedly, been reflected in an increased traffic load on our pavements. Currently, a significant portion of the Mauritian road network is in a dismal condition and re-current surfacing is not an effective solution. Additionally, solid waste management is of major concern for a small island like ours. With more than 400 tonnes of scrap rubber being illegally and inadequately disposed of annually, there is a high risk of environmental degradation. Furthermore, the milling of wearing courses result in landfills being loaded with RAP, which is not biologically degradable, further enhancing the problem of solid waste disposal. Not being a resourceful country and having small landfilling areas, Mauritius should be able to recycle and reuse these waste materials in the most efficient way.

The incorporation of warm-mix additives, crumb rubber and RAP into HMA is a good initiative to tackle the above-mentioned problems as well as representing an opportunity for the country to move towards a sustainable road construction industry without hindering the performance and riding quality of its flexible pavements

Sustainability or sustainable development is defined as "*development that meets the needs of the present without compromising the ability of the future generation"* (Brundtland Commission, 1987). In simpler terms, it refers to the proper balance between the economic, social and environmental aspects of our lives such that we are able to maximize on the present resources as well as safeguarding the same for the future. Out of the 3 pillars: economic, social and environmental; the environmental aspect can be considered to be the most important one. This is simply because the other 2 factors cannot be empowered, no matter how much efforts are made, due to their dependency on the greater system they thrive in, i.e. the environment (Thwink, 2014).

Nowadays, this concept is being extended to most sectors in the world, for that we face an uncertain future if appropriate mitigating measures are not enforced as from now itself. The road sector is among the major emitters of GHG emissions, principally through the extraction of the raw materials (World Highways, 2015). If the same is quantitatively described, then, according to AASHTO (2011), pavement construction, on a global scale, accounts for about 22 % of energy consumption, 25 % of fossil fuel use and 30 % of air pollution.

To mitigate the impacts of road construction, sustainable transport means, such as mass transit systems, have been implemented. However, McClendon (2012) advocated that, although such systems are likely to contribute towards a 'cleaner' environment, an immediate shift is, not only logistically impossible, but also culturally impractical. The implication is that people will always rely on motor vehicles, further enhancing the need for new road construction.

1.1 Sustainability in asphalt pavement construction

According to the EAPA (2015), 263.7 million tonnes of hot-mix asphalt, aimed for road construction, was produced in Europe alone in 2014. With an energy requirement of 275 Mega Joules (World Highways, 2015) and an emission of 0.065 kg of greenhouse gases per tonne of asphalt (US EPA, 2000), this represents an energy consumption of more than 70 million Mega Joules and an emission of about 17,000 million kilograms of greenhouse gases. These figures confirm the fact that hot-mix asphalt production is, in fact, one of the most polluting and energy-consuming industry. As a consequence, asphalt pavement constructions are at the receiving end of attention and criticism from policy makers.

According to a study conducted by Feng Ma *et al* (2016), it was shown that the production of mineral aggregates and the asphalt mixing process are the highest-contributing factors to greenhouse gas emissions, accounting for about 43 % and 54 % respectively (Figure 2).

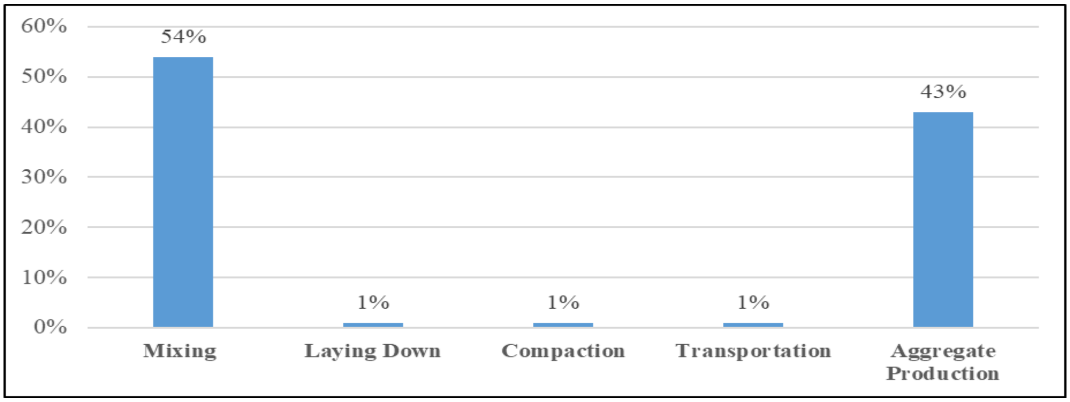

Figure Error! No text of specified style in document. **- Illustration of the greenhouse gas emission from different construction phases of an asphalt pavement.**

(**Source: Adapted data from Feng Ma *et al*, 2016)**

The author further stressed on the fact that if sustainable development was to be achieved in the transportation sector, mitigating measures should have been primarily focussed on the production asphalt itself.

1.2 Current sustainable practices worldwide

In South Africa, there has been an increased use of bituminous emulsions and warm mix asphalt instead of hot mix materials in order to reduce greenhouse gas emissions after the country's President made a personal appeal to companies to give a helping hand in promoting a greener culture (SA ICE, 2010).

Furthermore, the ASCE and T & DI (2010) have both confirmed, through various studies, that recycled materials would indeed further enhance sustainable pavement construction. Recycled content in a pavement mix has various advantages, two of which, are listed below:

- They are cheaper than virgin materials in terms of purchase and transportation costs.
- The load on landfill sites can be reduced.

The ever-appealing interest in sustainable development should, however, not come at the cost of technical performance. In this regards, various studies have been conducted worldwide to evaluate the impact of recycled content on the structural performance of pavements. Results have been promising, till now. According to the ASCE (2010), studies conducted at the Iowa State University showed that the rutting resistance and thermal cracking resistance of asphalt pavements were significantly improved when postconsumer shingles were added. These results were further confirmed by separate studies conducted at the University of Illinois (Behzad, 2012).

Furthermore, cost-benefit analyses of the use of asphalt rubble materials in mixes, carried out at the University of Saskatchewan (Berthelot, 2010), indicated that savings of about 55 % can be made when recycled aggregates are used instead of virgin ones.

An idea of the most popular recycled and renewable materials being used currently is summarised in Table 1.

Table 1: Recycled / renewable road construction materials currently being used worldwide.

(Source: World Highways, 2015)

Recycled / Renewable Materials	Brief description
Recycled Materials Components (RMCs)	Generated from industrial by-products.
Reclaimed Asphalt Pavement (RAP)	Obtained from milling process.
Reclaimed Asphalt Shingles (RAS)	
Coal Combustion Products (CCPs)	By-products of coal burning in plants.
Micro-algae	Can be used to produce asphalt, hence representing an alternative to bitumen and the petroleum industry as a whole.
Pozzolans	Volcanic rocks which are more environmentally-friendly than Portland Cement
Resin	Can be used as an alternative to asphalt.

As an alternative to hot-mix materials, the following are the current practices to decrease greenhouse gas emissions.

- Cold Mix Asphalt
- Half-Warm Mix Asphalt
- Warm-Mix Asphalt

It can be observed that as research is continually pushing the boundaries of material use, recycling and reuse, sustainable practices are going to grow in statue such that the global community integrates them. However, the global picture should not be forgotten. As correctly stated by Wathne (2010), policy makers should not focus solely on construction methods and materials in the aim of sustainable highways since their life cycle uses greatly influence its sustainability footprint.

1.3 Environmental sustainability in Mauritius

Mauritius is a small developing country which is highly dependent on fuel imports for its energy requirements. According to the UNEP (2010), more than 83 % of our energy requirements are derived from fuel imports. The burning of these fuels has an inevitable consequence of emitting greenhouse gases, mainly carbon dioxide, and the latter has been following an upward trend due to an increase in energy and transportation demands. Figure 3 depicts the trend in carbon dioxide emission from 1999 to 2009.

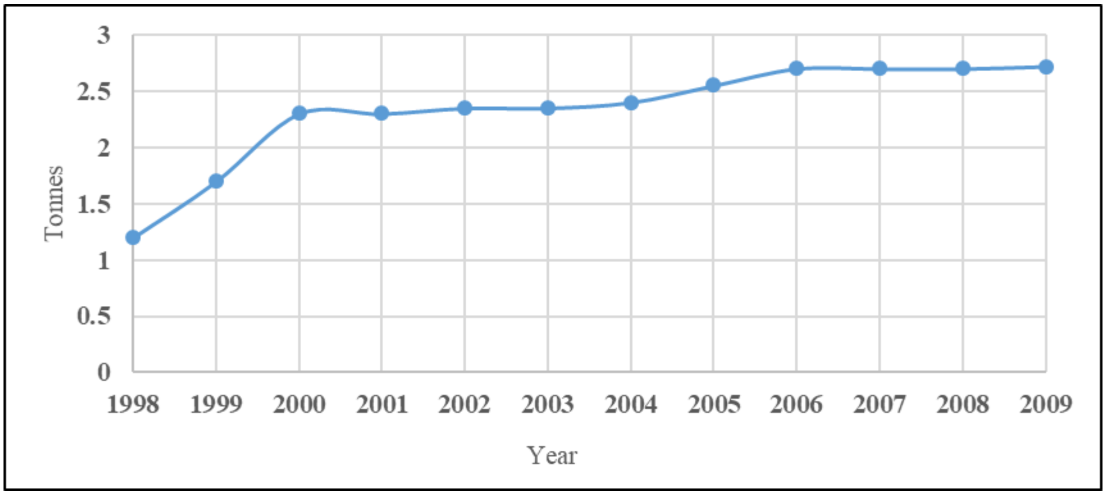

Figure 3: Carbon dioxide emissions per capita.

(Source: Mauritius Environment Outlook Report, 2011)

According to the CSO (2009), the road sector alone is responsible for 25 % of the greenhouse gas emissions in the country, as shown in Figure 4.

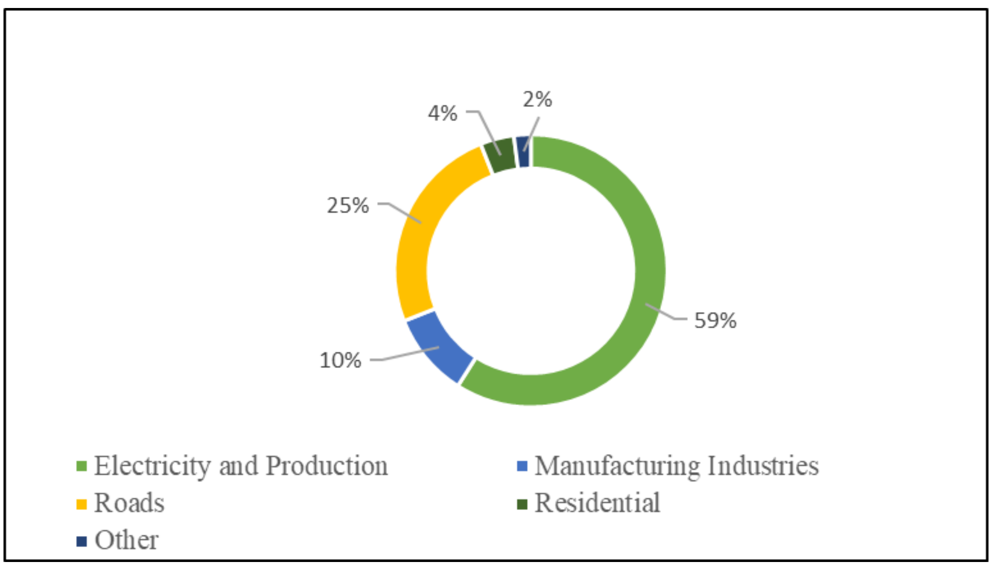

Figure 4: Sectorial emission of greenhouse gases in Mauritius.

(Source: Adapted data from Digest of Environmental Statistics, 2009).

Considering the fact that 80 % of these emissions is due to fuel consumption in motor vehicles (UNEP, 2010), then, the local road construction industry is responsible for 5 % of greenhouse gas emissions. Judging by the size of this industry, it is surprising to what extent it can prove to be harmful to local environment. Hence, there is an urgent need for the road construction industry to adopt sustainable practices in a bid to reduce these emissions.

1.4 Importance of implementing sustainable practices locally

As we move forward in the quest for modernisation, sustainable development is being encouraged to address another important issue: the phenomenon of global warming resulting in climate change.

The US NOAA (2016) defines global warming as the increase in the Earth's surface temperature globally: a phenomenon which has been enhanced by human activities. As a consequence, climate change has been induced which, in turn, has negative and unpredictable effects on different aspects of our lives – natural ecosystems, food security, health and socio-economic factors amongst others. Boodhoo (2009) stressed on the fact that the impacts of climate change would be even more significant for small island developing states with limited resources such as Mauritius. Coastal inundation, sea level rise and longer drought periods have already been witnessed during the last few decades.

1.5 Locally-feasible sustainability practices in the road construction industry

Different materials being used locally for a typical road construction project as displayed in Table 2.

Table 2 - Materials used in different pavement layers.

Layer	Materials used
Sub-base	Engineering fill or crusher run
Base	Crusher run
Wearing course	Hot Mix Asphalt

It can be deduced that by modifying the materials (Table 3) making up HMA in the wearing course, the issues of greenhouse gas emission and sustainable development can be tackled to a certain extent.

Table 3: Locally feasible alternatives to HMA.

Aim	Target	Modifications
Sustainable development	Decrease energy requirements without affecting performance.	Use WMA instead of HMA.
	Reduce use of virgin materials by incorporating recycled materials without affecting performance.	Replace virgin aggregates by RAP or RAS.
	Use locally-available materials as far as possible.	Use milled RAP, RAS or crumb rubber.
	Improve durability and eventual lifespan of pavement.	Make use of crumb rubber in asphalt mix.
Greenhouse gas emission	Use asphalt mix which reduces greenhouse gas emissions during production and laying of wearing course.	Use WMA instead of HMA.

From above, the combination of WMA, crumb rubber and RAP seems to be the most suitable choice of material.

1.6 Life Cycle Assessment and its importance

The UNEP (2016) defines LCA as *"a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle".* Initially, the LCA has been used as a tool to assess solid waste management options (Huang, 2007). However, with sustainable development becoming an important aspect of the road construction industry, much importance is being given to use LCA tools to assess the impacts of bituminous pavements on the environment, in terms of energy requirements and emissions. The phases of a LCA framework is are described in Table 4.

Table 4: Description of the different phases of a LCA framework.

(Source: Adapted data from Huang, 2007)

	Phase	**Description**
1	Goal & Scope definition	Set the boundaries, detailing level and time frame for study.
2	Life Cycle Inventory Analysis	Collect and compiles environmental data for input and output within the system.
3	Life Cycle Impact Assessment	Evaluate the inventory through the conception of a model.
4	Interpretation	Compile, check and evaluate results obtained to form a conclusion and make recommendations.

Such LCA frameworks have been developed for different types of asphalts (Table 5). It has been observed that the use of WMA, asphalt rubber and RAP do provide significant savings on the energy and emission aspects as compared to HMA.

Table 5: LCA analysis results for different types of asphalts.

Type of asphalt	Functional Unit	Time Frame for analysis / years	Author	Carbon Dioxide emission / %	Resources consumption / %	Energy consumption / %	Water use / %
WMA + 20 % RAP – Base Course	1 km length, 15 m width, 0.14 m thickness	30 (including 3 maintenance operations at 8-year intervals)	Giani *et al* (2014)	-5.50	-8.50	-8.40	-9.00
Sasobit® WMA – Wearing Course	*	*	Austrauds Ltd. (2010)	-18.00	*	-20.00	*
Sasobit® WMA – Wearing Course	300 m length, 6 m width, 45 mm thickness	48 (including 3 maintenance operations at 14-year intervals)	Anthonissen *et al* (2015)	-8.00	-15.00	*	- 10.00
Zeolite-based WMA – Wearing course	300 m length, 6 m width, 45 mm thickness	48 (including 3 maintenance operations at 14-year intervals)	Anthonissen *et al* (2015)	-31.00	+4.00	*	+11.00
Crumb-rubber modified HMA – Wearing course	1 km length, 21.9 m width, 40 mm thickness	18 years (including maintenance operations at 5-year intervals)	Farina *et al* (n.d.)	-21.00	*	-20.00	-14.00
Crumb-rubber modified HMA – Wearing course	1 km length, 7 m width, 20 mm thickness	40 years (including maintenance operations at 8-year intervals)	Bartolozzi *et al* (n.d)	-35.00	*	-39.00	-32.00[1]

[1] Fields marked with * indicate that no data related to such a sustainability aspect is available.

Although the different LCA models provide scope for reducing detrimental load on the environment, these models should not be rigidly used since, as Anthonissen *et al* (2015) advocated, the results have been based on the different data sources and service life requirements, therefore making it necessary to conduct LCA of such pavements relative to the country in which it is implemented. According to Huang, Bird and Heidrich (2009), clear definitions of LCA procedures for road paving applications are yet to be standardized. Hence, based on the study of Angela *et al* (n.d), a methodology was developped whereby only the main environmental indicators have been considered. These are the Gross Energy Requirement (GER) and the Global Warming Potential (GWP). GER reflects the energy required over the product's life cycle while GWP quantifies the effects of climate change, which is expressed as the amount of equivalent carbon dioxide emission (in kg). These 2 indicators are, according to Wu and Qian (n.d), predominant and more specifically suited to evaluate the sustainability of asphalt materials.

In light of the literature, the aim of this paper is to look into the life cycle assessment and the environmental properties of warm-mix asphalt rubber, with and without RAP, in an attempt to provide a sustainable alternative to HMA in Mauritius.

2. Methodology

The design mixes as in Figure 5 were developed and analysed.

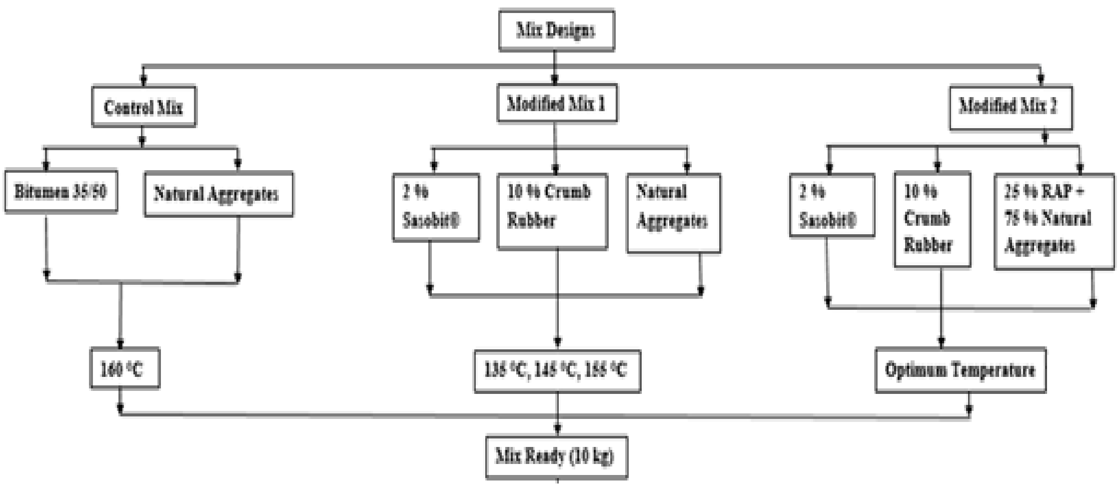

Figure Error! No text of specified style in document.**.1 - Sectorial emission of greenhouse gases in Mauritius.**

2.1 Goal & Scope

The scope of this work was specific to the La Chaumiere Asphalt Plant and the LCA is a process-based one. The main goal was to be able to compare and quantify the environmental savings, with respect to traditional HMA, which can be made when the different modified mixes are produced. The LCA was carried out according to ISO 14040 Series (ISO, 2006). In order to reach our goal, the processes required to construct and maintain a typical local asphalt pavement, as illustrated in Figure 6, were analysed.

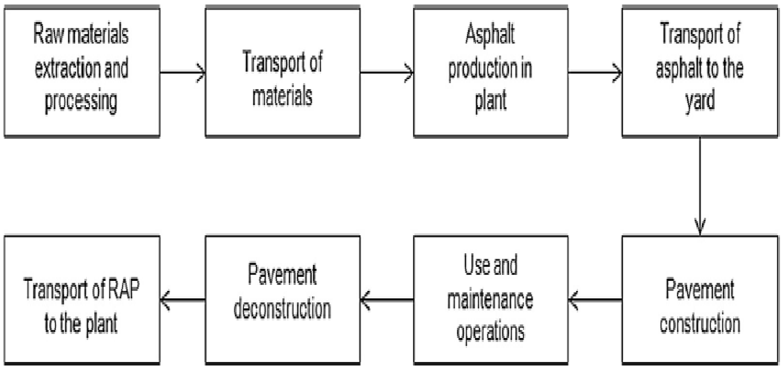

Figure 6: Processes related to the LCA study.

(Source: Adapted from Giani *et al.,* 2014)

These processes were then used to define the system boundary, as shown in Figure 7.

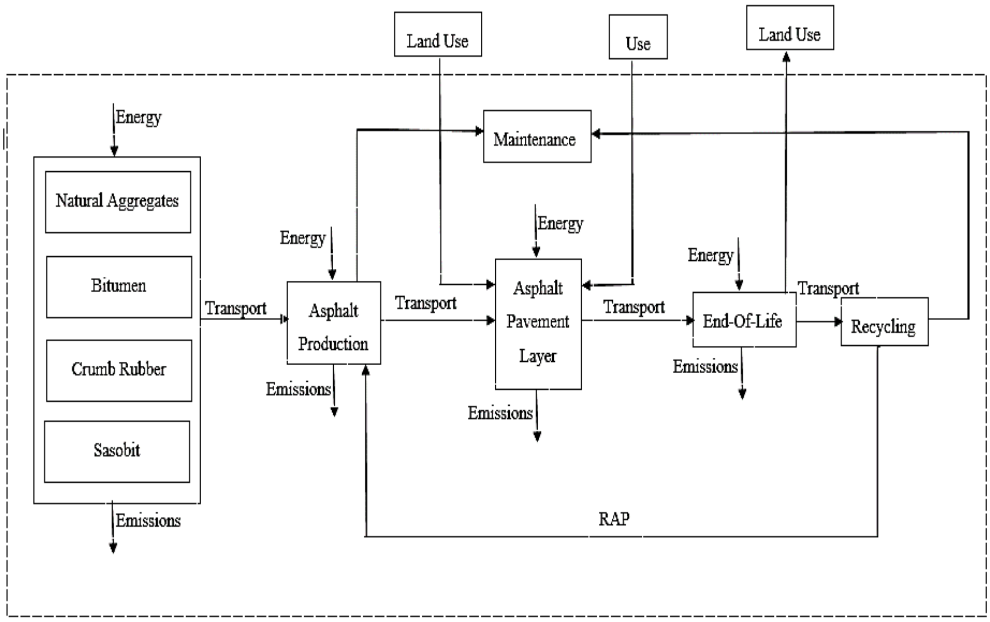

Figure 7: Proposed system boundary for LCA.

2.2 Functional Unit

Giani *et al* (2014) defined a functional unit as "*a unit of measure of the performance of the analysed product system and it is used as a reference to which all inputs and outputs are related.*" The present case study consisted that of a typical Mauritian B-type road, constituting of single lanes in both directions and having a total carriage way of 9.0 m.

Based on heavy traffic (Traffic Class T5, i.e. 3 to 6 ESA per year) (RDA, 2012), the following pavement cross-section was selected from ORN 31.

- 50 mm wearing course

- 150 mm bituminous base course
- 275 mm of granular sub-base

In order to produce a comparative LCA, the pavement sub-layers have been kept constant while only the properties of the materials making up the wearing course were varied. A pavement lifetime of 25 years was considered. Maintenance strategies were chosen according to the requirements of the RDA (Table 6). Following a personal communication with the General Manager of the latter, a maintenance period of 5 years was chosen for the traditional HMA while for the modified mixes, Angela *et al* (n.d) recommended a minimum of 8 years.

Table 6: Service Life and Maintenance Frequency.

Parameter	Control Mix- HMA	Modified Mix 1 (MM1)	Modified Mix 2 (MM2)
Service Life (years)	25	25	25
Maintenance Frequency (1/years)	1/5	1/8	1/8

The software used for the life cycle modelling was *Athena Pavement LCA©*, which is custom-made for pavements only.

2.3 Data Sources

Currently, there is no complete existing database which relates to LCI data concerning pavement materials and construction in the local context. Hence, LCI data used for this comparative LCA have been collected from available literature and from various stakeholders within the local road construction industry.

2.4 Factors considered

The proposed system boundary, illustrated in Section 3.6.1 of Chapter 3, looked at the energy requirements (GER) and the amount of emissions (GWP) at different stages. However, the software used groups these stages into 4 main components, as listed in Table 7.

Table 7: Customised system boundary as per software's specifications.

	Life Cycle Stage as per proposed system boundary	**Grouped under**
1	Materials' Extraction	Manufacturing
2	Asphalt Production	
3	Construction	Construction
4	Maintenance	Maintenance
5	Usage & End-of-Life	Roadway Operating Energy Operations
6	Waste Scenario (Recycling)	

2.5 LCA model and inventory data

The model used to quantify the GER and GWP of the control and modified mixes has been based on an environmental mechanism. The latter encompassed the following cycle within the mechanism, which allowed the impacts to be quantified:

- Flow of energy and raw materials to and from nature
- Environmental emissions to land, water and air.

This cycle has then been embedded into the internationally recognized ReCiPe methodology. The latter is recognized by ISO 14040 and can be described as a combined mid-point and end-point approach (PreSustainability Consultants, 2017), indicating that a lengthy list of inventory results are combined into restricted amount of scores, which reflect the global (mid-point) and net (end-point) effects. In the case of pavements, Huang (2007) critically pointed out that mid-point indicators are more suitable for decision-making at the design stage, thereby confirming the validity of the GER and GWP indicators used by Angela *et al* (n.d).

2.5.1 LCI data

As previously mentioned, there are no LCI databases specific for Mauritius. Hence, the international database *Eco Invent 2.2*© and the *EuroBitume*© report were consulted. The inventory data used have been included in Appendix E.

3. Results

3.1 Gross Energy Requirements

Gross Energy Requirements (GER) reflects the total primary energy required throughout a product's life cycle. Figure 8 illustrates the variation of the GER for each mix, with the control HMA mix being used as the baseline.

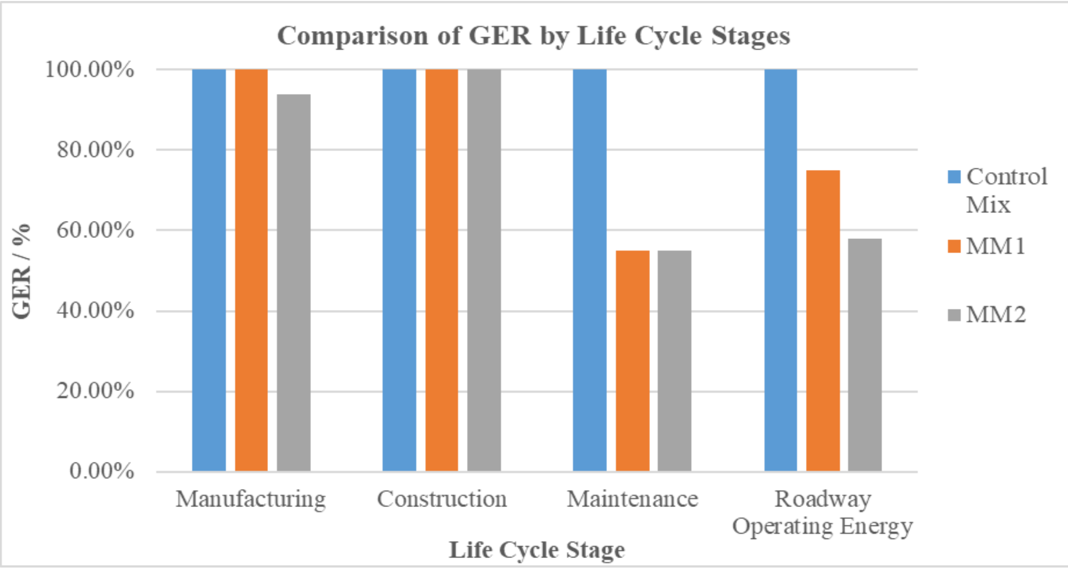

Figure 8: Comparison of GER by Life Cycle stages.

According to ISO standards, a weighting factor can be assigned to each life cycle stage to indicate its relevance. The weighting factor, which is subjective, normally ranges from 0 to 1. According to Huang (2007), for asphalt products, the highest weighting factors are allocated to the manufacturing, maintenance and, in this case, the roadway operating energy stage. The construction process is usually the same for all types of asphalts and was thus considered to be less relevant. A weighted average was then be determined for a global comparison of the GER between each asphalt mix, as in Figure 9.

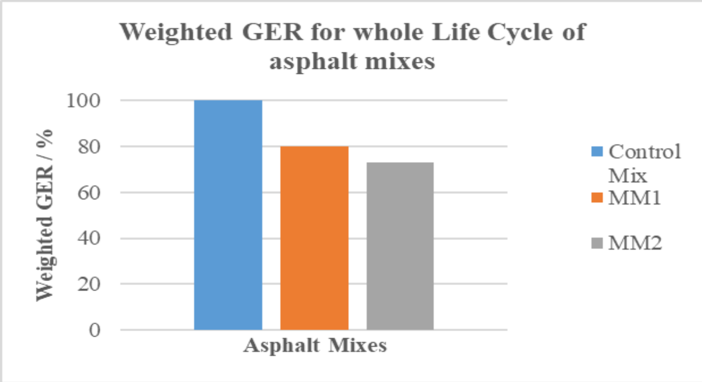

Figure 9: Weighted GER for whole Life Cycle of asphalt mixes.

3.2 Global Warming Potential

Global Warming Potential (GWP) is the amount of equivalent carbon dioxide emissions. It quantifies the effects of climate change. Figure 10 illustrates the variation of the GWP for each mix, with the control HMA mix being used as the baseline.

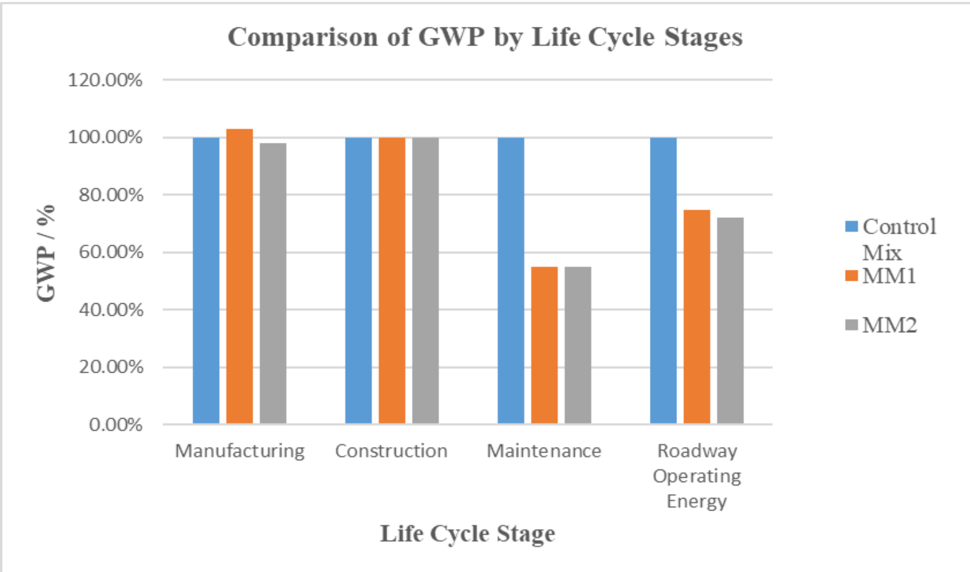

Figure 10: Comparison of GWP by Life Cycle Stages.

Similar to the GER, a weighting factor was allocated to each life cycle stage, enabling us to determine a universal GWP for each asphalt mix and to compare them. The weighted GWP for each mix was as shown in Table 8.

Table 8 - Weighted GWP score for each asphalt mix.

Asphalt Type	Weighted average for GWP / %
Control Mix	100.00
MM1	81.06
MM2	78.64

3.3 Life Cycle Stages

a) Manufacturing Stage

By considering Figure 9, it can be observed that, at manufacturing stage, both the control mix and MM1 had similar energy requirements while that of MM2 was 6 % less. As mentioned, the manufacturing stage consisted of raw materials' extraction and asphalt production. The aggregates and binder used for both mixes were the same. Although the production energy of MM1 is 15 °C lower than that of the HMA, the energy required to transport and convert waste tyres into crumb rubber, in addition to that of Sasobit©, brings its total energy requirements to that of the control mix. As for MM2, the use of RAP instead of natural aggregates seems to have a predominant impact on the energy requirements and can thus explain the difference as compared to HMA.

On the other hand, the GWP, in terms of carbon dioxide emissions, of MM1 was 3 % higher than the control mix while that of MM2 was 2 % lower. The higher environmental burden of MM1 can be attributed to the higher temperature used during the blending of crumb rubber and bitumen. As for MM2, the use of RAP predominates over the high blending temperature, causing an overall reduction in GWP.

b) Construction Stage

For the construction stage, no difference has been noted between either of the mixes for both GER and GWP. Provided that there is no significant difference between the Marshall Density of each mix, the amount of roller passes and other civil works required for compaction and finishing on site is fairly the same. Moreover, the transport requirements remain the same since each mix is being transported from a single plant. These factors explain the relative Stability of the GER and GWP between the asphalt types.

c) Maintenance Stage

Contrary to the initial life cycle stages, the maintenance stage shows a consequent decrease in the GER and GWP for both MM1 and MM2 as compared to the control mix. As stated in the Literature Review, warm mix asphalt rubber with and without RAP tends to have higher design lives with a smaller tendency to undergo permanent deformations. As a result, the maintenance frequency is much lower than HMA. Furthermore, with fewer deformations, maintenance operations are more likely to consist of asphalt patching at partial depths, while full depth asphalt reclamation is often required for the control mix, which is both energy and emission intensive.

d) Roadway Operating Energy Stage

This stage consists of the operations, end-of-life and waste scenarios of the LCA. While the latter two are similar for each asphalt mix, a lower maintenance frequency is reflected into a reduced consumption of fuel and carbon dioxide emissions by the operating equipment required to maintain the pavement made up of the 2 modified mixes. The results confirm the findings of the experimental tests whereby there is a continuous improvement in structural performance from HMA to MM1 and finally to MM2, resulting in the latter to have the lowest GER and GWP.

3.4 Weighted scores

There is no extensive and complete LCA carried out for warm-mix asphalt rubber with and without RAP till now. However, much focus has been placed on comparative LCAs between WMA and HMA and between asphalt rubber and HMA.

From the weighted scores, using the control mix as baseline, a reduction of 19.85 % in GER has been observed for MM1 while MM2 recorded a decrease of 26.82 %. On the other hand, a similar decreasing trend has been observed in GWP, whereby a reduction of 18.94 % was noticed for MM1 and that of MM2 was 21.36 %. These findings are perfectly in line with the results of Giani *et al* (2014), Anthonissen *et al* (2015), Farina *et al* (n.d.) and Bartolozzi *et al* (n.d), all of whom reported significant decreases in the above-mentioned environmental indicators when either of Sasobit©, crumb rubber and RAP were used.

The rationale behind such reductions in GER and GWP for the modified mixes can be explained through the following factors:

i. Lower production temperature.
ii. Significant reduction in natural aggregates extraction and processing.
iii. Use of recycled aggregates instead of natural ones.
iv. No dumping of end-of-life tyres and RAP.
v. Higher structural performance and lower maintenance frequency.

These weighted scores reflect the significance of these indicators over the whole life cycle. If individual stages are further analysed, it can be observed that the manufacturing (materials) stage of the modified mixes prove to be a greater environmental burden than that of HMA, principally due to the production of the additives. However, this is significantly offset during the later stages of the life cycle. This observation was also reported by Shuang Wu and Shunzi Qin (n.d).

From the results obtained, it can now be confirmed that, on an environmental basis, warm-mix asphalt rubber with and without RAP are indeed sustainable alternatives to HMA. Significant savings in energy and lower emissions resulting from the modified mixes will undoubtedly enhance the attractiveness of these technologies to the various stakeholders within the local road construction industry, especially during an era whereby much focus is been laid on reducing the carbon and ecological footprint in Mauritius.

3.4 Contractors' opinion Evaluation of results

The different results obtained were exposed to 5 different contractors operating in the local asphalt industry. Each of the surveyed contractors agreed that the proposed modified mixes seemed to be better alternatives to HMA and were totally in line with the environmental policy goals attached with the strategic objectives of each company. However, as far as the implementation aspect was concerned, different issues were raised.

Table 9: Evaluation of results by major contracting firms in Mauritius.

Contracting Firm	Relative size of organisation	Proportion of operations dealing with road construction / %	Issues raised
A	Large	45	Being sustainable, A would have liked to obtain financial incentives from the Government to cover the initial capital costs while also questioning the availability of crumb rubber and RAP all year round.
B	Large	40	B would have liked to monitor the actual performance of the modified mixes subjected to traffic loading on a 2-year basis before implementing such a project. Issues about initial capital costs were also raised.
C	Large	90	C was totally in favour of such a project. The environmental policies of C was actually based on the use of recycled materials in asphalt.
D	Large	35	Similar to A.
E	Medium	45	Similar to C.
F (International)	Large	65	F would have liked to obtain an in-depth engineering consultancy report on the matter before reporting further.

From the survey, it was clear that the contractors saw this new technology as a business opportunity but the issues raised by them indicated that much more was required to be done by the RDA and Government in order to materialise this project.

4. Conclusion and recommendations

This research work was focused on the evaluation of the performance of warm-mix asphalt rubber with and without RAP, relative to HMA, in environmental aspect.

The main finding was that the LCA showed that WMA rubber with and without RAP had lesser environmental impacts that HMA in terms of GER and GWP, with the incorporation of RAP lessening the burden even more.

The following recommendations were:

i. Warm-mix asphalt rubber with and without RAP may effectively be used as a sustainable alternative to HMA for new road construction, rehabilitation purposes or for repairs.

ii. Resurfacing of wearing courses should be limited to one time only and milling of pavements should be encouraged prior to laying such layers.

iii. Amendments should be made to the legal framework such that contractors are able to incorporate waste materials such as crumb rubber and RAP into asphalt mixes without compromising their performance by limiting the dosages of the different additives to the ones mentioned previously.

iv. The use of WMA additives should be strongly encouraged by relevant authorities in an attempt to reduce the emission of greenhouse gases within the local road construction industry.

v. Further performance testing of asphalt mixes using crumb rubber, WMA additives and RAP should be carried out by local authorities such that adequate design guidelines can be set up for Mauritius.

5. Acknowledgements

Our deepest appreciations go to Transinvest Construction Co. Ltd, for always being available to guide me throughout the different laboratory tests and; Mr James Alexander Marais, Sales Executive of Sasol Co. Ltd (South Africa).

6. References

1. AASHTO. 2011. *AASHTO comments concerning FHWA's Sustainable Highways Self-Evaluation Tool.* Washington, D.C: AASHTO.
2. ANGELA, F., ZANETT, M., EZIO, S., BIENGINI, G., and LANOTTE, M. n.d. *Life Cycle Assessment of Road Pavements containing crumb rubber from end of life tyres.* Torino, Italy: Department of Environment, Land and Infrastructure Engineering, Politechnico di Torino.
3. ANTHONISSEN, J., VAN DEN BERGH, W. and BRAET, J. 2015. Life Cycle Assessment of Hot Mix Asphalt and Zeolite-based Warm Mix Asphalt with Reclaimed Asphalt Pavement. *Resource Conservation and Recycling.* 105(12), p. 78-83.
4. AUSTROADS. 2016. *Maximising the use of Reclaimed Asphalt Pavement in Asphalt Mix Design – Field Validation.* Sydney: Austroads Ltd.
5. BARTOLOZZI, I, RIZZI, F, BORGHINI, A and FREY, M. 2011. Life Cycle Assessment of Rubberized Asphalt Road Pavement in Lamia, Greece. In: *Proceedings of the 3rd International CEMEPE & SECOTOC Conference.* Albama, United States: EnviTech.
6. BEHZAD, B. 2012. *Fracture characterisation of asphalt mixtures with reclaimed asphalt pavement.* MSc. University of Illinois.
7. BERTHELOT, C. 2010. *Cement Stabilisation of Reclaimed Asphalt Pavement Materials.* MSc. University of Saskatchewan.
8. BOODHOO, S., 2009. *The changing Climate of Mauritius*. Available from: http://www.fao.org/fileadmin/user_upload/foodclimate/forum/Boodhoos.pdf [Last Accessed: 20 July 2018]
9. BRUNDTLAND COMMISSION. 1987. *What is Sustainable Development?* [Online] Available at: http://www.worldbank.org/depweb/english/sd.html. [Accessed 03 October.2016]
10. CENTRAL STATISTICS OFFICE. 2009. *Mauritius in Figures.* [Online] Available at: http://statsmauritius.govmu.org/English/Publications/Documents/MIF/mif09.pdf. Port Louis: Government of Mauritius. [Accessed on 18 October.2016]
11. STATISTICS MAURITIUS. 2009. *Digest of Environmental Statistics.* Port Louis: Government of Mauritius.
12. EUROPEAN ASPHALT PAVEMENT ASSOCIATION. 2015. *Asphalt in figures* [Online] Available at: http://www.eapa.org/promo.php?c=174. [Accessed 20 October.2016].
13. FARINA, M., ZANETT, H., EZIO, S., LANOTTE, M and BLENGINI, G. n.d. *Life Cycle Assessment of road pavements containing crumb rubber from end-of-life tyres.* Torino, Italy: Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino.
14. FENG MA, S., AIMIN, S, PANPAN, Y and HUANG, Y. 2016. Greenhouse Gas Emissions from Asphalt Pavement Construction: A Case Study in China. *International Journal of Environmental Research and Public Health.* 13(351), p. 1-15.
15. GIANI, M., DOTELLI, G., BRANDI, N. and LUCA,Z. 2014. Comparative Life Cycle Assessment of Asphalt Pavements using RAP, Warm Mix Technology and Cold in Place Recycling. *Resource Conservation and Recycling.* 104(43), p. 91-98.

16. HUANG, Y. 2007. *Life Cycle Assessment of Use of Recycled Materials in Asphalt Pavement.* PhD. University of Newcastle.
17. HUANG, Y., BIRD, R., and HEIDRICH, O. 2009. A review of the use of recycled solid waste materials in asphalt pavements. *Resources Conservation and Recycling.* 52(1), p. 58-73.
18. INTERNATIONAL STANDARDS ORGANISATION. 2006. *ISO 14040 – Environmental Management – Life Cycle Assessment* [Online]. Available at: https://www.iso.org/standard/37456.html [Accessed 13 February. 2016].
19. MC CLENDON, E. 2012. 6 Signs That Mark The Path To Sustainable Road Design. *Environmental Leader.* 5 January.2012, p. 34.
20. MINISTRY OF ENVIRONMENT AND SUSTAINABLE DEVELOPMENT. 2011. *Mauritius Environmental Outlook Report.* 1st Edition. Port Louis: Government of Mauritius.
21. OVERSEAS ROAD NOTE 31. 1993. *A Guide to the Structural Design of Bitumen Surfaced Roads in Tropical and Sub-Tropical Countries.* 4th Edition. London: Transportation Research Laboratory Ltd.
22. PRE SUSTAINABILITY CONSULTANTS. 2017. *ReCiPe Method* [Online]. Available at: https://www.pre-sustainability.com/recipe. [Accessed 02 March. 2017].
23. PROAG, V. 2006. Water Resources Management in Mauritius. *European Water Publications*, 16(8), p. 45-57.
24. ROAD DEVELOPMENT AURHORITY. 2012. *Maintenance and Minor Works (Final) – Section V – Employer's Requirements – Part 2.* Mauritius: Road Development Authority, p. 29-32.
25. SOUTH AFRICAN INSTITUTE OF CIVIL ENGINEERS. 2010. Road Surfacing Industry Suggests Greening its Footprint for Sustainable Development. *Magazine of the South African Institute of Civil Engineers.* 12(4), p. 64.
26. STATISTICS MAURITIUS. 2015. *Digest of Road Transport and Road Accident Statistics.* Port Louis: Government of Mauritius.
27. T & DI / ASCE. 2010. Sustainability and Pavements: Are we focussing on the right things? *T&DI/ASCE Green Streets and Highways Conference.* Denver: ACPA.
28. THWINK. 2014. *Environmental Sustainability.* [Online] Available at: *http://www.thwink.org/sustain/glossary/EnvironmentalSustainability.htm* [Accessed 20 July 2018].
29. UNITED NATIONS ENVIRONMENT PROGRAMME. 2010. *Cleaner, More Efficient Vehicles*. [Online]. Available at: http://www.unep.org/transport/gfei/autotool/case_studies/africa/mauritius/cs_af_mp_O.asp [Accessed 13 October.2016]
30. UNITED NATIONS ENVIRONMENT PROGRAMME. 2016. *Rutting Behaviour of Asphalt Pavements* [Online]. Available at: http://www.unep.org/transport/gfei/autotool/case_studies/asphaltpavement/rutting/cs_af_mp_O.asp [Accessed 13 October.2016]
31. UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. 2000. *Documentation for Greenhouse Gas Emission and Energy Factors used in the Waste Reduction Model.* [Online] Available at: https://www3.epa.gov/warm/pdfs/WARM_Documentation.pdf. [Accessed 10 October.2016]

32. US NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION. 2016. *What is Climate Change?* [Online] Available at: http://www.noaa.gov/climate [Accessed 18 October.2016].
33. WATHNE, L. 2010. Sustainability and Pavements: Are we focussing on the right things? *Green Streets and Highways Conference.* Denver. 23. September.2010. New York: T&DI/ASCE, p. 23-52.
34. WORLD HIGHWAYS. 2015. *Sustainable road construction: current practices and future concepts.* [Online] Available at: http://www.worldhighways.com/categories/asphalt-paving-compaction-testing/features/sustainable-road-construction-current-practices-and-future-concepts/ [Accessed 20 July 2017]
35. WORLD BANK. 2010. *Infrastructure and Growth in Africa.* South Africa: World Bank, p. 67-68.
36. WU, S. and QIAN, S. n.d. Comparative study of warm mix asphalt and hot mix asphalt pavement based on LCA. *Life Cycle of Structural Systems*. London: Taylor and Francis Group.