Towards Developing Environmental Sustainability Performance Measures for Pavement Asset Management Practice

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Abstract

The functionality of performance measurement approach is valuable in Pavement Management Systems (PMSs) to account for different criteria in the decision-making process. However current paradigm of asset management decisions made within pavement management systems only prioritizes resource allocation polices that maximizes the serviceability performance of the road network with no consideration of the environmental sustainability. This is the essence of incorporating environmental sustainability into pavement management The reduction of material consumption and greenhouse gas emission when maintain and rehabilitating road networks can achieve added benefits including improved life cycle performance of pavements, reduced climate change impacts and human health effect due to less air pollution, improved productivity due to optimal allocation of resources and reduced road user cost. The growing awareness of the impacts of road transportation networks on the ecosystem, demands accountability for environmental performance, thus there is need to incorporate environmental performance measure into pavement asset management practices. To address this challenge, this present work focuses on developing a core set of environmental sustainability performance measures for pavement management. The ultimate goal is to develop a framework to incorporate environmental sustainability in pavement management systems for network-level maintenance programming. In order to achieve this goal, this paper present the first step, intention is to review the previous studies for environmental sustainability indicators, as well as the suitability of the indicators for the evaluation of the sustainability in pavement management. A next step will involve an industry and agency survey to identify the state-of-practice trends in environmental performance measurement, highlight data available and data needed, and propose the framework to incorporate measures into network-level sustainable maintenance and rehabilitation programming.

Keywords: pavement management, environment sustainability, network-level, performance measures

1. INTRODUCTION

Road infrastructure is critical to the quality of life of Canadians. Road pavement is part of the transportation system that provides mobility and access to various users. When Pavement road network are in good condition, an adequate level of service is provided and desired efficiencies achieved (Tighe and Gransberg 2011). However, construction and maintenance of road networks have undeniable impacts on the biophysical environment, which sustains human and non-human lives, and supports their wellbeing (Van Dam et al. 2015; Harvey et al. 2016). In 2015, the transportation sector was the second largest contributor to Canada's total Greenhouse Gases (GHG) emissions (Figure 1) with over 85% due to on road vehicle operations (ECCC 2017). Road Pavement is a part of the transportation system that can influence vehicle fuel efficiency depending on its surface design, characteristics and condition. Pavement can increase the environmental impact caused by cars and truck fuel combustion by 10% (Chester and Horvath 2009).

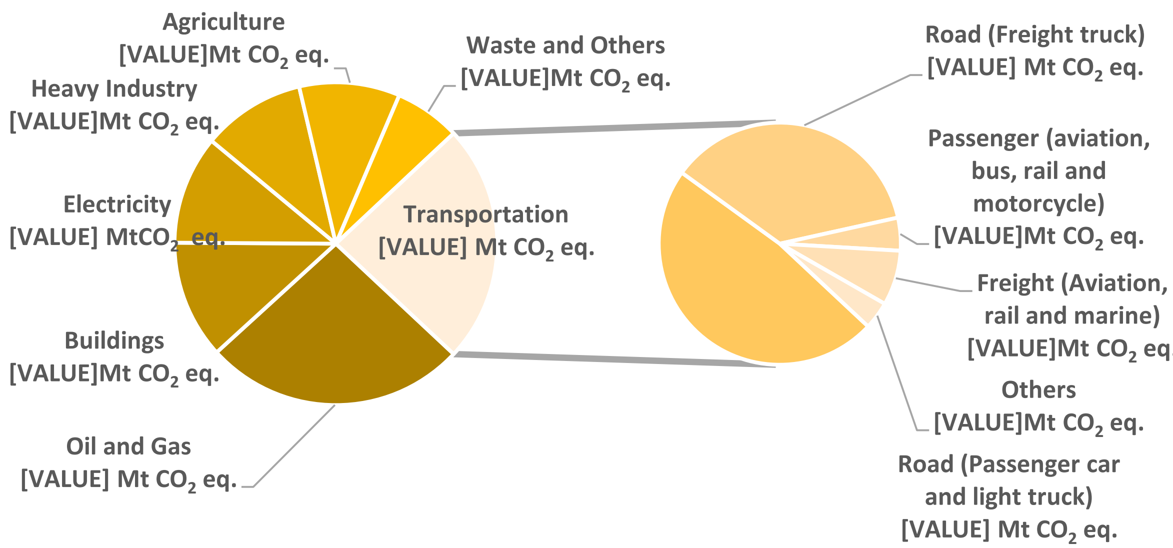

Figure 1. Greenhouse Gas Emission by Canadian Economic Sectors in 2015 and the Breakdown for Transportation section by use (ECCC 2017)

GHG emission is one major cause of climate change, a critical challenge to global sustainable development. Mitigating GHG emissions is top priority globally, Canada alongside other 50 nations declared intentions and commitment to reduction of GHG emissions at the Conference of the Parties (COP) 21 under the United Nations Framework Convention on Climate Change (UNFCCC) 2015 Paris Agreement (Government of Canada 2017). GHG emissions associated with pavement management activities span at least four of five major sectors. Pavement construction and maintenance demands material and energy products, for example asphalt which is a product of the oil and gas sector is a major material for pavement construction in Canada. Cement, lime and steel are also vital materials in pavement construction that are part of the heavy industry sector. The energy demand for material production and construction work can increase GHG emissions from the energy sector depending on energy source (Van Dam et al. 2015).

Beyond the common proxy to define environmental sustainability performance, i.e. GHG emission, management activities throughout the pavement lifecycle have other impacts on the environment and human health. Environmental aspects of pavement management activities may lead to resource depletion due to construction and maintenance material demand, noise disturbance from construction site and tire-pavement interactions, pollution from hazardous chemicals and particulate matter release (Harvey et al. 2016). These aspects can drastically change water, soil and air quality; with direct impacts on climate change, biodiversity loss and resource availability. There is great awareness of these sustainability issues, yet the environmental aspects and impacts of pavement management activities are often overlooked in many highway investment decisions (Tighe and Gransberg 2011). In the recent edition of the Ontario Ministry of Transportation (MTO) RoadTalk, the agency stressed the need to foster sustainability in road asset management "by seeking opportunities to mitigate environmental impacts in the highway right-of-way (ROW) during highway planning, design, construction, and maintenance operations" (MTO 2017).

Incorporating environmental criteria into pavement engineering and management decision making can enhance long term economic viability of pavement systems. Road pavements deteriorate over time as the road ages underneath the growing traffic and effects of climate change is worsening pavement performance and durability (Mills et al. 2007). The Government of Canada allocates over 25 billion dollars annually to pavement maintenance and capital projects (Thompson 2013), yet deplorable state of Canadian municipal infrastructure asset reveal maintenance backlogs due to funding gaps (CIRC 2016). Roads in bad condition over a long term will not only lead to substantial future rehabilitation and reconstruction cost, but will also lead to more pollutants emissions and traffic noise, due to effects of vehicles travelling over rough road pavements (Zaabar and Chatti 2010; Pellecuer, Assaf, and St-Jacques 2014). An important element in improving the environmental sustainability of road transportation is the use of new technologies and products that directly enhance the roadway environmental and economic sustainability through reduced consumption of energy and material (Montgomery, Schirmer, and Hirsch 2015).

Pavement Management Systems (PMSs) is a mainstream infrastructure asset management decision support tool widely used among transportation agencies, in which effects of various criteria and performance measures and targets that link agency strategic goals with decisions about how to best allocate resources and funding to influence desired outcomes like adequate level of service and efficiencies (Haas, Hudson, and Falls 2015). PMSs rely on the functionality of performance measures to that account for different criteria in the decision-making process and assess the level of achievement of management objectives. Technical and economic performance indicators of transportation infrastructure assets are well established, however, many variations of environmental sustainability performance indicators have been developed and no standardized measurement method available that can be applied to pavement management activities (Uddin, Hudson, and Haas 2013). Environmental performance indicators should be defined to operationalize environmental sustainability objectives directly aligned with the broad institutional goals of the agency addressing sustainability of transportation infrastructure assets (Cornet, Gudmundsson, and Leleur 2016).Thus, there is need to identify appropriate environmental performance measures for assessing environmental impacts of pavement management decisions in order to inform progress towards pavement sustainability. This paper presents a review of recent efforts towards incorporating sustainability into pavement management decisions by considering environmental objectives. The objective is to identify the environmental impact categories, performance indicators and measurement methods adopted in previous environmental sustainability evaluation of pavement management practice as well as evaluate the suitability of these indicators employed for sustainable pavement management systems.

2. ENVIRONMENTAL SUSTAINABILITY IN PAVEMENT MANAGEMENT

Pavements exist and function within transportation system that is responsible for over 25% of anthropogenic greenhouse gases exasperating the climate change problems (see Figure 1). It is inevitable that sustainable pavement engineering and management practices to minimize greenhouse gases should be a top agenda to fight a global issue such as climate change. Sustainable transportation refers to transportation that meets the three aspect of sustainability (Van Dam et al. 2015): (1) economic sustainability - affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy; (2) social sustainability - allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations; (3) environmental sustainability - limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise. On that note, it is important to recognize that sustainability is a context-specific and achieving pavement sustainability goes beyond the initial pavement material production or construction process but extends throughout the pavement whole lifecycle to the maintenance and operation activities, and pavement end-of-life.

2.1 Environmental Sustainability Factors of Pavement

Assessing environmental sustainability is an emerging field in transportation industry, and even more so in pavement management. Impact categories, impact factors and measure for environmental sustainability varies depending on approach and metric. Two main Approaches discussed below are commonly used to assess the sustainability of pavement.

2.1.1 Sustainability Rating Systems

Many transportation Sustainability Rating Systems (SRS) with similar models as LEED certification program have been developed with more focus on sustainability of construction and maintenance activities (Table 2). Pavement-related examples includes MTO's GreenPave, and INVEST, Greenroads and the GreenLITES programs. While implementation of sustainability factors in SRS has led decision makers to considering environmental values such as minimize wastage, efficient project delivery, avoid delays as well as minimize constructability related problems (Lew et al. 2016).

Table 0 Sustainability Rating Tools for Road Pavement

Tools	Owner	Major categories	Year Developed	Max Points (scale)	Points relevant to Pavement
GreenPave	MTO	Pavement technologies, material resources, energy & atmosphere, innovation & design process	2008	31 (1-5)	100%
Greenroad	Greenroads Foundation	Environment and Water, Access and Equity, Construction Activities, Materials and Resources, Pavement Technologies and Custom Credits	2009	118 (1-5)	49%
GreenLITE	New York State DOT	Sustainable Sites, Water Quality, Material and Resources, Energy and Atmosphere, Innovation /Unlisted	2008	60 (1-10)	10%
INVEST	Federal Highway Administration	Air Quality, Behavioral change & capacity building, Biodiversity, Cultural heritage, Energy, Noise management, Resource management, Road design, Stakeholder engagement, Urban design, Waterway and Water management	2011	118(1-15)	41%
BE2ST-In-Highway	Recycled Materials Resource Center	Greenhouse gas emission, Energy use, Waste reduction, Water consumption, Social carbon Cost saving, Life cycle cost, Traffic noise, and Hazardous waste	2010	10 (0-1)	100%
Envision	Institute for Sustainable Infrastructure	Quality of life, Leadership, Resource Allocation, Natural world, Climate change &risk	2011	809 (1-25)	31%

Major drawbacks are the scope and definition of reporting standards in SRS, summarized in Table 3. These standards are widely based on activity measures, not measuring the performance outcome which defines the impacts of carrying out those activities. For example, measures based on the use of 20% recycled material (GreenPave) or conducting an LCA (Greenroads), do not communicate nor account for resulting impacts. More so, high level of subjectivity in SRS often lead to different rating award to same project by different investigators using the same tool and scoring method. The sustainability scopes of projects evaluated by a SRS usually reflect a status quo of the specific sustainability values of the tool, implying that a project team will unlikely pursue a subset of goals outside sustainability scope of the SRS (Lew et al. 2016). A recent review of SRS for paving activities by Bryce et al. (2017) discussed in detail, these shortcomings of SRS indicators and their inadequacy to provide analytical sustainability performance measures for pavement management activities.

Table 3 Limitations of Pavement Sustainability Rating Systems

Limitations	Comment
High subjectivity in procedure and implementation	Points awarded for most indicators are based on analyst perspective of the project sustainability factors
Limited activity focus of pavement management	Focusing on select activities indicates biases in the opportunities identified to extend pavement sustainability
Indicators based on non-generalizable approaches and location-specific practices	Specifying benchmarks for indicators like 20% of recycled material limits innovative thinking
Indicators do not define performance outcome	Indicator such as conducting an LCA shows no evidence of a sustainable outcome
Criteria weight not well aligned to objectives	Rating systems provide an overall relative rating of the project but not precise values associated with environmental sustainability.

2.1.2 Lifecycle Assessment Methods and Tools

Lifecycle Assessment (LCA) is a comprehensive method for quantifying the environmental impacts of product, service or product system over its whole lifecycle from extraction and production of raw material, production of product, distribution and use/operation, maintenance to its end-of-life and final disposal in a cradle to grave perspective or recycling in a cradle to cradle circular economy view (ISO 2006). LCA can be used for a variety of purposes, including quantifying information concerning the environmental performance and identifying opportunities for improvement; selecting relevant indicators of environmental performance from a system-wide perspective; and informing decision makers in many purposes such as strategic planning, setting priorities, product or system design selection (Harvey et al. 2016). The LCA methodology provide that framework such holistic assessment. Since early 1990s, ISO has started publishing series of standards in their 14000 family of standards to ensure consistency of the procedure for an LCA. The most recent updates regarding LCA requirements and guidelines in ISO 14040 standards was published in 2006 (ISO 2006).

LCAs involve extensive data sets related to materials quantities, emission rates, environmental responses, different level of details (temporal and spatial), and other factors. Completing a holistic LCA is very challenging and ISO guidelines did not specify the exact approach to carry out task. As a consequence, LCAs tend to be time consuming and expensive to complete. Alternative procedure, termed “streamlined LCA”, seek to preserve the power of and confidence in the LCA approach in demonstrating environmentally-problematic attributes of a product system more quickly and cheaply but with some compromise (Rosenbaum 2017). Streamlining within the existing LCA framework can be accomplished by streamlining the methodology (what to do) or the process (how to do) for conducting an LCA. This can be done by limiting the scope of the study or simplifying the modelling procedures, thereby limiting the amount of data or information needed for the assessment. Depending of the purpose of study, commonly used LCA approach for assessing environmental impacts are show in Table 4. The differences in the approaches influences the inconsistencies in methodological choice and resulting outcomes of LCA studies. On the other hand, developing more readily available lifecycle data or tools, such as software with embedded databases can enable streamlining the process of conducting LCA.

Table 4 Variations of LCA Approaches

LCA Approaches	Orientation	Purpose
Attributional vs consequential	Defining boundary conditions	Intended to estimate impacts of a specific product system versus to assess impacts of changes to the evaluated system
Single vs comparative	Scenario building	Intended for disclosure of single product performance versus for comparison of alternative products
Static vs. Dynamic	Modelling approach	Differentiates an assessment of impacts at a point in time versus one that looks that impacts that evolves over time
Process vs Input-Output vs Hybrid	Data computation	A top-down data aggregation versus bottom-up process data aggregation
Substitution vs Allocation vs System expansion	Multi-functionality procedure	Differentiates how the environmental burdens should be assigned between co-products or systems
Mass vs economic	Allocation procedure	Differentiates how the environmental burdens can be allocation between co-products or systems

LCA study of pavements is a fairly new practice in evaluating the environmental performance of pavements. A critical review by Santero et al (2010) reveal that prior to 2010, only 15 studies were published on pavement LCA. The number of pavement LCA studies quadrupled in the past few years and currently over 300 studies have been published (Azarijafari, Yahia, and Ben Amor 2016). Earlier studies have focused on comparing the impacts of the two main types of pavement (concrete and asphalt), ignoring important aspects that promote achieving sustainability goals. Recent studies reveal variation of LCA methodological choice adopted in pavement LCA studies, which present evidence based on inconsistent functional unit and boundary definition, limited scope and environmental categories. There is a call for standardized functional units and system boundaries, and common set of guidelines for data collection and analysis to pave way for unification of pavement LCA procedures (Huang, Spray, and Parry 2013; Hamdar, Chehab, and Srour 2016).

A number of pavement LCA tools have been developed to ease the rigorous task of pavement LCA modelling, some major challenges exits including considering only select pavement lifecycle phases, pavement type, materials and processes. Supposedly, most pavement LCA tools cater to the conditions in specific regions where they were developed (Santero, Masanet, and Horvath 2011; Huang, Spray, and Parry 2013). Standards of practice in roadway development differ regionally, there are variations in primary data source varies and indicators measured by the tools. Use phase of the pavement lifecycle is has been lest attempted amongst available tools. Huang et al (2009) claimed that pavement LCA tools developed prior to 2007, for example Pavement Life Cycle Assessment Tool for Environmental and Economic Effects (PaLATE) and DuboCalc are currently not suitable for conducting LCAs mainly because these tools use outdated data. However PaLATE presents some important features that represents practicality relevant for any new improved LCA tool development, evident in its application in recent pavement LCA studies (Celauro et al. 2017). PaLATE is based on an easy to use micro-soft excel workbook and has the information of recycled materials and on-site recycling processes, also users can adjust all detailed information such as characteristics, emissions, equipment, and activities in the data worksheets according to the actual conditions (Nathman, McNeil, and Dam 2009). Many LCA tools do not provide these features. The Athena Highway Impact Estimator developed by the Canadian Athena Institute is considered the most comprehensive North American LCA tool (Ahammed et al. 2016), however the tool does not investigate some salient environmental impacts. Noise and water quality, water consumption or land use are not evaluated. Thus tools might not accurately present comprehensive environmental performance measures for innovative practices in pavement management. Larger variation in environmental impact estimates has been reported when pavement LCA tools were compared (Santos et al. 2017). It is important to recognize the limitation of data, as well as the database in available LCA tools can limit applicability in certain region. This reflects conclusions of previous pavement LCA reviews that there is need for localized region specific database for pavement environmental sustainability assessment (Santero, Masanet, and Horvath 2011; Hamdar, Chehab, and Srour 2016). Considering that sustainability is context specific, different impact factor will be of concern for different agencies depending on the institutional sustainability objective. Thus, a suitable tool for an agencies should address the important impact categories which can be characterized into select set of relevant indicators of pavement lifecycle environmental impacts.

2.2 LCA of Innovative HMA Mixture

2.2.1 Introduction

This section presents a preliminary assessment conducted with a focus to understand the challenges with available LCA tools and also to highlight the importance and need for tools to adequately account the environmental performance of innovative materials and techniques in pavement engineering and management. This preliminary study is based on a current project on an innovative hot-mix asphalt (HMA) mixtures produced by substituting natural aggregate with coarse recycled concrete aggregate (CRCA) at various proportions (0%, 15%, 30% and 60%). Technical performance of constituent materials and the new mix designs have been extensively investigated, and the most recent publication on this project included an economic analysis of the production of 1 m3 of HMA mix design blends considered to meet the volumetric properties was conducted as part of a sustainability assessment (Al-Bayati, Tighe, and Achebe 2018) In this preliminary assessment is conducted to determine environmental impacts of CRCA usage in asphalt mixtures and to show how available LCA tools differ in impacts calculation for an innovative HMA mixes, thus to support understanding of limitations already discussed in literature review and illuminate the gap that any new tool will need to overcome.

2.2.2 Methods

The three tools used include PaLATE, ECORCE M, and Athena pavement LCA. The differences in their databases and modeling approaches are highlighted in the results. A current work in another research at CPATT is updating the data of the original PaLATE (2004), this version is also considered here and the results compared with results from the original PaLATE highlight differences in outcomes as a result of the changes in database. The updated data are available for CO2 [Mg], SO2 [kg], NOx [kg], PM10 [kg] and CO [kg], and data for energy consumption. Six HMA mix design with different proportions of CRCA (0%, 15%, 30%, 60%) with two of the mixes containing heat treatment and acid treatment of CRCA. The mix designs investigated are shown in table 5 with the material content of each constituent.

Table 5 Material content of mix design blends

	0%	15% Untreated	30% Untreated	30% Heating	30% Soaking	60% Untreated
Asphalt binder	4.83	4.90	5.31	5.31	5.31	5.71
Natural Course Aggregate (NCA)	96.17	87.5	79.54	79.54	79.54	64.12
Dust Plant	2.38%	2.50%	2.94%	2.94%	2.94%	2.94%
CRCA	0	7.6	15.15	15.15	15.15	30.17

2.2.3 Findings and Discussion

For climate change impacts, the Global Warming Potential (GWP) is the performance indicator used, general measure by the Kg CO2 equivalent of GHG emissions. Figure 2 shows that the difference in GWP values of mixes containing CRCA compared to the control mix range approximately from -10% to

23%. Similarly to energy consumption results, Athena tool accounts for benefits of using CRCA. PaLATE results show that energy and climate change impacts increase with increased quantity of NCA substituted with CRCA in HMA mixes.

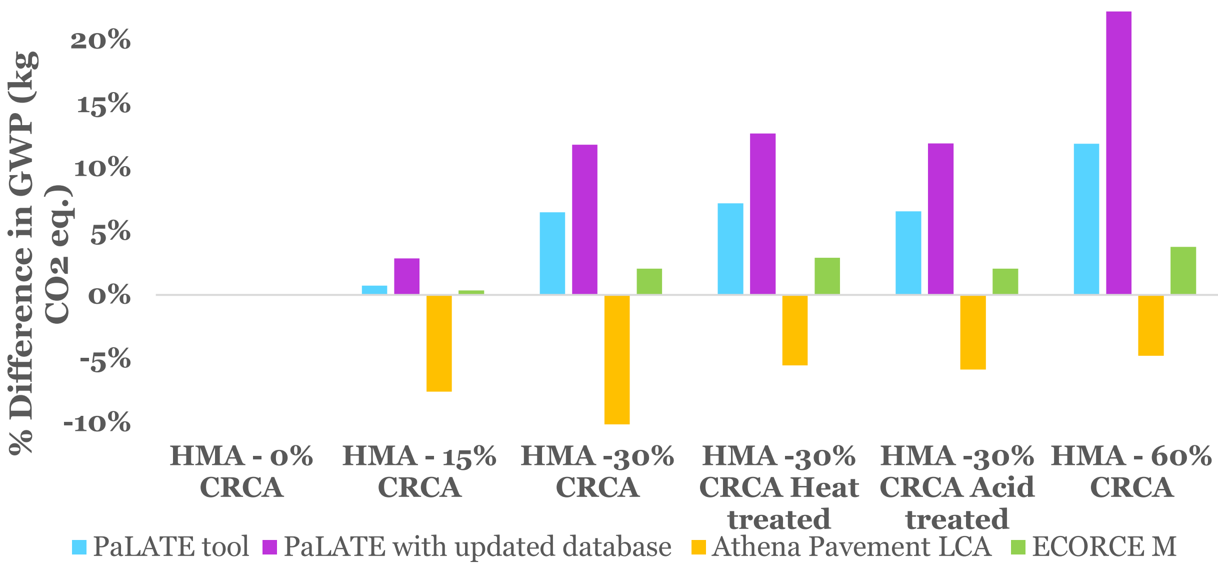

Figure 2. Climate Change impact (Global Warming potential (kg CO2 eq.) estimates of 5 HMA mixes with varying proportions of CRCA compared to control mix with 0% CRCA

Figure 3 shows the potential energy consumption of the HMA mixes evaluated in this case study and calculated using different tools. At first glance, it is clear that the impacts for each mix differ largely among the tools. The 60% CRCA as an example, the results from Athena are much higher compare to PaLATE and ECORCEM at approx. 250% and 600% respectively. Athena and PaLATE tools show large difference in energy consumption for mixes depending on the proportion of CRCA while ECORCEM show rather comparable impacts.

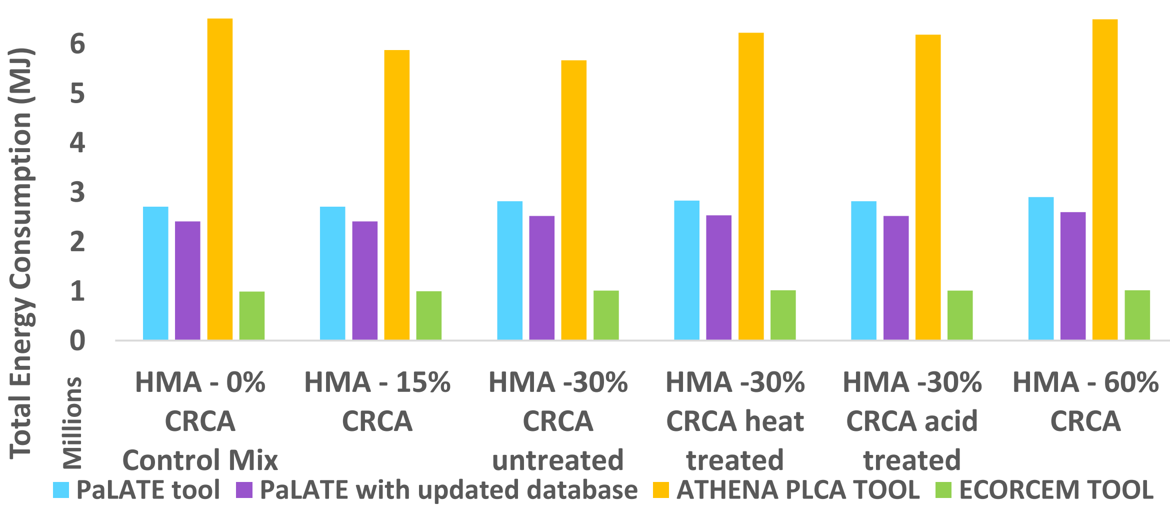

Figure 3. Total Energy Consumption (MJ) of Construction of pavements with six different HMA mix designs with varying proportions of CRCA (0%, 15%, 30% and 60%)

The results above reveal the following points:

- Environmental performance evaluation of HMA design mixes with CRCA with three pavement LCA tools reveals the following challenges and opportunities:
- Variability in the environmental impacts results reflects the influence of inconsistent modelling approaches and discrepancies in data adopted in these tools
- There is need to enhance the quality of data based on regional practice to better understanding of impacts

Future work should include developing a core set of environmental performance measures and sustainability assessment framework considering all aspects of the pavement lifecycle.

3. CONCLUSION AND FUTURE WORK

Canadian transportation agencies generally recognize the need to include environmental aspects in management decisions.The systematic review of environmental sustainability in the context of environmental performance measures and assessment tools is presented. Pavement sustainability represents a very important concept underpinning complexity of pavement asset management. Successful and sustainable pavement asset management requires performance measures that are objectively based, consistent, quantifiable and responsive to all aspects of sustainability. Specifically, decision support tools should incorporate institutional objectives for environmental factors to benefit the economic vitality and technical and functional efficiencies of pavement management. Pavement management decision making is guided by its performance measures and the associated targets or thresholds. A critical step towards incorporating environmental sustainability into pavement management framework is to identifying relevant environmental impact factors and appropriate performance measures and reliable metrics.

Sustainability rating tools were found not suitable for integrating environmental performance measure into network-level pavement management. LCA modelling is of particular importance to future research as it is used as basis to develop and evaluate the environmental performance measures of pavement lifecycle as well as integration in development of optimized sustainable maintenance and rehabilitation policy. Available LCA tools are able to measure select impact factors within limited scope of pavement lifecycle. Each method requires different set of data, investigates select measures and result in different estimates. It is recognized that there is no universally accepted LCA approach. However, adopting localized database and impacts factors is found to be crucial for a comprehensive consideration the environmental aspects of pavement engineering and management practice in a region by any pavement LCA tool and applicability of the LCA result in decision making. These findings will be guide future research work to define a core set of relevant environmental performance indicators/measures to capture the aspects and needs of sustainable pavement management at network-level and develop analysis tool based on LCA methodology to measure selected environmental measures. Next step in research work will involve an industry and agency survey to identify the state-of-practice trends in environmental performance measurement, highlight data available and data needed, and propose the framework for incorporate measures into network-level sustainable maintenance and rehabilitation programming.

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