ENVIRONMENTAL INDICATORS FOR SUSTAINABLE ROAD DEVELOPMENT AND OPERATION

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ABSTRACT: Road construction, maintenance and operation are activities that impact the environment by way of energy use, resource consumption and emission. Components such as construction material, transportation, street lighting, rolling resistance, traffic congestion during works, albedo and end-of-life processing impact the environment at different phases of the life of a road. With a view to promote sustainable development, a few sustainability rating schemes, e.g. Infrastructure Sustainability and Invest (Australia), Envision and Greenroads (USA), and CEEQUAL (UK) have been developed, that can assess road projects. These schemes address environmental areas such as: energy and emission, land, water, materials, discharges into surroundings, waste and ecology as factors for sustainable development. This paper assesses different rating schemes based on a defined comprehensive life cycle assessment (LCA) system boundary for road projects to identify different environmental indicators that address sustainable road development and operation. The findings indicate that new indicators are required to address different environmental components during the operation phase of roads.

KEYWORDS: Road, sustainability, rating schemes, life cycle, environment, indicators

1. INTRODUCTION

Sustainable development is becoming increasingly important due to impacts of climate change, resource depletion and energy constraint. It is essential to optimize resource and energy consumption, and to minimize greenhouse gas (GHG) emissions. It generally needs to address three areas- environment, social wellbeing and economy, where environment is the most important element due to changing climate phenomena [1].

Sustainability in infrastructure can be measured by relevant sustainability factors known as 'sustainability indicators'. Roads constitute an important infrastructure asset with significant sustainability impact. A few infrastructure sustainability rating schemes are now available for the development and operation of sustainable roads. Identification of environmental indicators relevant to road infrastructure considered in the schemes is important to see their adequacy to address the whole-of-life environmental complications of road infrastructure. In this study, the indicators considered in different rating schemes are identified and summarized following a qualitative research procedure.

2. SUSTAINABILITY INDICATORS

Sustainability indicators are indicative variables used to provide indication of the variables of a system or product when it is difficult to estimate them by direct measurement or by simulation modelling. They can be simple or composite. A simple indicator originates from a direct measurement or from an estimate obtained by modelling of the value of a single indicative variable. A composite indicator is obtained by the ''aggregation'' of measured or estimated variables [2].

Indicators may result from a set of measurements, from calculated indices, or may be based on expert systems. The popular methodologies involve assimilation of common perceptions and expectation of different stakeholders towards achieving sustainability [3]. The process generally includes interviews, workshops, surveys and case studies to gather structured information on some specific areas of influence based on present level of scientific and social understanding. It often fails to extract some vital issues due to gaps in common understanding in present day practices. Dahl [4] stated that indicators are only as good as the data behind them. As a result, scientific approach of indicator search of any system is important to assess completeness of the indicators in addressing sustainability of the system.

3. SUSTAINABILITY OF ROADS

The sustainability aspect of road infrastructure has a two-way challenge. It is the reduction of emission from road construction and maintenance to minimise the contribution to climate change; and also to minimise the impact on roads from the effect of changing climate.

The environmental aspect of road infrastructure is a "whole-of-life" phenomenon. It includes: energy and resource consumption, and emissions during road construction and operation activities; impact of road characteristics (e.g. slope, curve, pavement stiffness, surface unevenness, surface texture) on vehicle use, sound and light pollution, air and water quality, land use, resource conservation, source of material, waste management, and impact on local flora and fauna [5]. This wide spectrum of environmental factors has led to the concept of life cycle assessment (LCA) of road projects instead of traditional generic environmental studies. The LCA can give a scientific approach for whole-of-life optimization of resource and energy consumption, minimization of emissions and reduction of waste in road works [6-10].

Road life cycle primarily includes five different phases: construction material (pre-construction), construction, use, maintenance and end-of-life (EOL). The former two phases can be combined as the "development phase" and the later three phases can be combined as the "operation phase". LCA of road projects has been carried out since 1996, but most of them considered the environmental components associated with the development phase and generally ignored the operation phase which has high impact [9]. Researchers have highlighted the absence of a comprehensive system boundary for conducting LCA of road projects [11-13]. The authors of this paper studied published road LCA studies till 2012 and have proposed a comprehensive LCA system boundary for carrying out future road LCA studies [14]. This system includes seven high impact life cycle environmental components such as material, transportation, traffic congestion, rolling resistance, albedo, lighting and end-of-life (EOL) processing. The high impact road LCA environmental components are defined below:

> *Material: Total upstream supply chain required to deliver processed materials for road construction and maintenance activities including extraction and production, but excluding transportation.*
>
> *Transportation: Carrying materials from the extraction sources to the production plants and then to the construction sites. The factors to be considered are: mode of transportation (road, rail or water), location of the project, and the mass of material to be transported.*
>
> *Traffic Congestion (Delay): Implementation of road works under safe and efficient conditions often needs closure of one or several lanes; such situation temporarily disrupts traffic flow and may cause congestion during peak periods [15].*
>
> *Rolling Resistance: Pavement surface roughness and structural properties cause rolling resistance and increase fuel consumption and emissions of vehicles significantly [16]. The impact of rolling resistance becomes significant as it affects every vehicle using the pavement [13].*
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> *Albedo: The solar radiation reflected off the surface is known as "albedo", every 0.01 unit increase of which can offset 2.55 kg of emitted CO_2 for every square meter of the earth surface [17]. The solar radiation absorbed by road pavement increases ambient temperature, resulting in urban heat island effect and increases the energy demand for cooling devices in urban areas.*
>
> *Lighting: Roadway signage and lighting is usually used in urban roads. The amount of lighting required varies based on the reflective properties of the surface material.*

End-of-life (EOL) Recycling: Environmental burdens of dismantling old pavement, processing materials for reuse and transportation [12].

4. ROAD ENVIRONMENTAL INDICATORS

Policy support by governments has assisted in the development of various infrastructure sustainability rating schemes to facilitate sustainable development and operation of the infrastructure sector. There are rating schemes for all-infrastructures (general) as well as for individual infrastructure class. The “all-infrastructure” type schemes have a more general approach, while the “individual infrastructure” class schemes have a specific approach. Infrastructure Sustainability (Australia)[18], Envision (USA)[19], CEEQUAL (UK)[20], Invest (Australia)[21], and Greenroads (USA)[22] are some schemes relevant to road infrastructure [14].

To identify the present generation road environmental indicators, two general schemes and two road specific schemes were reviewed for the relevant LCA environment credits or issues. The design phase of the schemes were considered in this assessment, as it includes credits relating to all the phases of infrastructure life and is a crucial phase for decision making on any project. The LCA system boundary proposed by Alam et al. [14] was considered for this assessment to identify indicators relating to whole-of-life environmental components of roads infrastructure because of its generalized and comprehensive structure.

4.1 Indicator Identification

Four of the five infrastructure rating schemes mentioned earlier, randomly named as Scheme A, B, C and D, were studied to identify road environmental indicators. The sustainability rating schemes in general comprise environmental credits under several thematic areas. These are: energy and emissions, land, water, materials, discharges into surroundings, waste and ecology. The environmental credits under different thematic areas were identified and assessed for their coverage to different road life cycle environmental components (LCECs) for two environmental concerns such as energy consumption and GHG emissions. The guidance and explanation about the credits in the respective manual were studied to classify the credits. The findings from the identified credits were then assessed to find the credits’ coverage to different LCECs. Based on the coverage of the credits for different LCECs and credit description in the manual, generalized environmental indicators were selected. The study was conducted following Seidel’s noticing, collecting and thinking model for qualitative data processing [23].

The indicator identification process of different rating schemes is presented in Tables- 1 and 2. Credits addressing same areas were collectively considered for selecting their generalized indicators. For example, as seen in Table- 1 the first two credits of Scheme- A: ‘Energy and carbon monitoring and reduction’ and ‘Energy and carbon reduction opportunities’ were collectively studied for identifying the environmental indicators. The identified indicators are: reduce energy use, use renewable energy, energy efficiency, and reduce emissions.

Credits addressing different areas may also have same indicators. For example (Table- 2), Scheme C and D have ‘pavement performance tracking’ and ‘incorporating future maintenance requirements’ credits respectively. These credits are provided for the operation phase of roads to minimize rolling resistance of pavement, which increase energy use and consequent emissions. The relevant indicators are – ‘Reduce energy use’ and ‘Reduce emissions’. These indicators are also addressed by credits, such as ‘Fossil fuel reduction’, and ‘Equipment emissions reduction’ etc. of Scheme- C, and ‘Reduction of electrical energy consumption’, and ‘Substitution of electrical energy sources’ etc. of Scheme- D.

Table 1. Indicator Identification of two General Rating Schemes

Credits	Road Life Cycle Components							Addressed Indicators
	Material	Transportation	Congestion	Rolling Resistance	Albedo	Lighting	EOL Processing	
Scheme – A (General)								
Energy and carbon monitoring and reduction.	√	√	√	√	√	√		Reduce energy use. Use renewable energy. Energy efficiency. Reduce emissions.
Energy and carbon reduction opportunities.	√	√	√	√	√	√		
Materials lifecycle impact measurement and reduction.	√	√						Use regional material. Reduce net embodied energy.
Deconstruction/Disassembly/Adaptability							√	Use recycled materials. Reuse of material.
Waste management.	√							Reduce waste. Earthwork balance.
Scheme – B (General)								
Reduce energy consumption.	√	√	√	√	√	√		Reduce energy use.
Reduce greenhouse gas emissions.	√	√	√	√	√	√		Reduce emissions.
Commission and monitor energy systems.		√				√		Energy efficiency.
Reduce net embodied energy.	√	√						Reduce net embodied energy.
Use recycled materials.	√							Use recycled materials. Reuse of material.
Provide for deconstruction and recycling.							√	
Use regional materials.	√	√						Use regional materials.
Divert waste from landfills.	√							Reduce waste.
Reduce excavated materials taken off site	√	√						Earthwork balance.

Table 2. Indicator identification of two Road Specific Rating Schemes

Credits	Road Life Cycle Components: Material	Transportation	Congestion	Rolling Resistance	Albedo	Lighting	EOL Processing	Addressed Indicators
Scheme – C (Road Specific)								
Fossil fuel reduction.	√							Reduce energy use. Use of renewable energy. Reduce emissions. Reduce net embodied energy.
Equipment emissions reduction.	√							
Long-life pavement.	√							
Warm mix pavement.	√							
Cool pavement.					√			
Life cycle assessment.	√	√	√	√	√	√	√	
Energy efficiency.						√		Energy efficiency.
Regional materials.	√	√						Use regional material.
Pavement reuse.	√						√	Reuse of material.
Earthwork balance.	√	√						Earthwork balance.
Recycled materials.	√						√	Use recycled materials.
Pavement performance tracking.				√				Reduce energy use. Reduce emissions.
Waste management plan.	√							Reduce waste.
Scheme – D (Road Specific)								
Reduction in electrical energy consumption.						√		Reduce energy use. Use of renewable energy. Energy efficiency. Reduce emissions.
Substitution of electrical energy sources.						√		
Purchase green power for non-office use.						√		
Installation of road energy system.					√			
Use of products and materials with greater environmental benefits.	√							Reuse of material. Use recycled materials. Reduce net embodied energy.
Reuse contaminated fill material.	√	√						
Coordination of off-site recycling/reuse of excess material.	√						√	
Use of existing infrastructure.	√	√						
Incorporating future maintenance requirements.				√				Reduce energy use. Reduce emissions.
Balancing of earthworks.	√	√						Earthwork balance.
Reuse waste material from local sources.	√	√						Reduce waste. Use regional material.
Considering constructability and construction planning to avoid re-work, wastage and delays.	√	√	√					

4.2 Environmental indicators

The environmental indicators that address various road life cycle environmental components were selected through assessment of environmental credits of different rating schemes as detailed in Tables- 1 and 2. These include:

a) Reduce energy use.
b) Use of renewable energy.
c) Energy efficiency.
d) Reduce emissions.
e) Reduce net embodied energy.
f) Use regional material.
g) Use recycled material.
h) Reuse of material.
i) Earthwork balance.
j) Reduce waste.

4.3 Indicators' Significance

This study identified ten environmental indicators by analyzing the credits of four sustainability rating schemes. It is seen that all the schemes addressed the same indicators. The only difference between the general and road specific schemes is that the road specific schemes addressed a little about the operation phase environmental components, while the general schemes did not address them. The inclusion of a few credits to address rolling resistance and albedo components by the road specific schemes provided some additional consideration to the two major environmental indicators- 'Reduce energy use' and 'Reduce emissions' only. It did not include any other "component specific" indicators.

The rating schemes generally can increase credits, which can address road life cycle environmental components (LCECs) as observed from Tables- 1 and 2. Scheme- A has 5 LCEC relevant credits out of total 51 credits, Scheme- B has 9 LCEC relevant credits out of total 55 credits, Scheme- C has 13 LCEC relevant credits out of total 48 credits, and Scheme- D has 12 LCEC relevant credits out of total 44 credits. Frontal construction components, material and transportation have got high consideration. Of the ten identified environmental indicators, six (e-j) cover the material and transportation components. The other four (a-d) indicators on energy and emissions cover all the components including the material and transportation components, since material extraction, production and transportation involve energy uses and emissions.

Above observations indicate that the operation phase components have got little consideration, which often possesses high environmental impacts [9]. Santero and Horvath [24] study (Figure- 1) shows possible impact levels of different road life cycle environmental components in terms of global warming potential (GWP) as a single concern for one lane-kilometer road with a standard lane width of 3.6m and an analysis period of 50 years based on findings of 15 important Road LCA studies from 1996 to 2010. The thick, gray bars represent the probable ranges and the thin, black lines represent the extreme ranges. This figure shows that components such as rolling resistance (roughness), rolling resistance (structure) and traffic delay (congestion) can have high impacts, which may together possess almost half of all the life cycle environmental impacts. It is to be noted that the impacts in Figure- 1 are presented in log scale.

Proper consideration to the material and transportation components provided them with six environmental indicators. These six indicators are explicit in addressing different material and transportation aspects such as: use of reclaimed (reuse), recycled and regional materials; reduction of net embodied energy i.e. consideration to frontal supply chain factors in material processing, waste reduction through maximized use of materials and 'cut and fill' balancing of earthwork. These indicators promote reduction of virgin materials in road works and therefore reducing the need of material transportation. However, the life cycle impact of the material and transportation components do not appear to be more than five percent (5%) of the total environmental impacts as approximated from Figure- 1. Therefore the other environmental components, which account for the remaining ninety-five percent (95%) of the road environmental impacts, require new indicators to address them properly towards sustainable road development and operation.

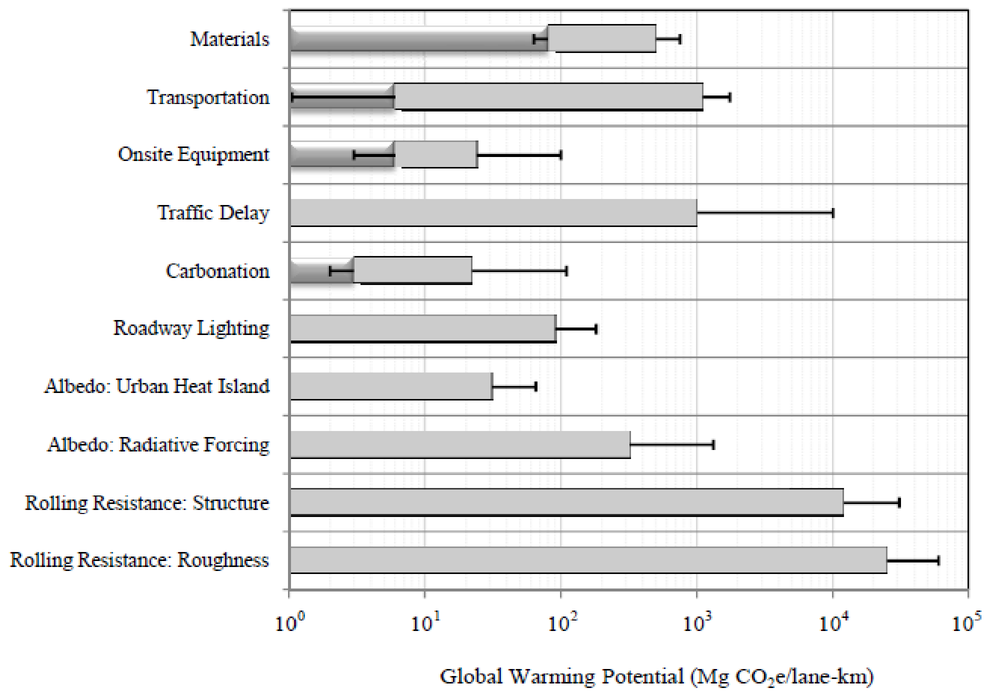

Figure 1: GWP impact ranges for components of road pavement life cycle [24].

5. CONCLUSION

Road development and operation activities possess significant environment impact. Traditionally the environmental issues during the development phase of roads are extensively studied, but those of the operation phase are relatively not considered as much. The uncertainties with future operation issues could be one of the reasons. To find the industry level application of whole-of-life environmental impact in delivering sustainable roads, this study identified different environmental indicators by analysing four popular infrastructure sustainability rating schemes that assess roads. It was observed that the development phase components material and transportation were addressed with a number of quality environmental indicators. It was identified that there is a need to include new environmental indicators to address different environmental components during the operation phase of roads. Further studies are, therefore, required for developing appropriate environmental indicators to address all the controlling environmental components of roads infrastructure.

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