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Sustainability Outcomes of Infrastructure Sustainability Rating Schemes for Road Projects

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Abstract

The construction and operation of infrastructure assets can have significant impact on society and the region. Using a sustainability assessment framework can be an effective means to build sustainability aspects into the design, construction and operation of infrastructure assets. The conventional evaluation processes and procedures for infrastructure projects do not necessarily measure the qualitative/quantitative effectiveness of all aspects of sustainability: environment, social wellbeing and economy. As a result, a few infrastructure sustainability rating schemes have been developed with a view to assess the level of sustainability attained in the infrastructure projects. These include: Infrastructure Sustainability (Australia); CEEQUAL (UK); and Envision (USA). In addition, road sector specific sustainability rating schemes such as Greenroads (USA) and Invest (Australia) have also been developed. These schemes address several aspects of sustainability with varying emphasis (weightings) on areas such as: use of resources; emission, pollution and waste; ecology; people and place; management and governance; and innovation. The attainment of sustainability of an infrastructure project depends largely on addressing the whole-of-life environmental issues.

This study has analysed the rating schemes' coverage of different environmental components for the road infrastructure under the five phases of a project: material, construction, use, maintenance and end-of-life. This is based on a comprehensive life cycle assessment (LCA) system boundary. The findings indicate that there is a need for the schemes to consider key (high impact) life cycle environmental components such as traffic congestion during construction, rolling resistance due to surface roughness and structural stiffness of the pavement, albedo, lighting, and end-of-life management (recycling) to deliver sustainable road projects.

Keywords: Road Infrastructure, Sustainability, Rating Scheme, Environment, Life Cycle Analysis (LCA), Life Cycle Environmental Component (LCEC)

1. Introduction

Various sustainability assessment rating schemes have been developed with a view to assess infrastructure projects for their sustainable development and operation. The schemes are primarily based on three broad dimensions of sustainability - environment, social wellbeing and economy, of which the environment dimension is the most important one for attaining sustainability (Stanners et al., 2007). Road is one of the extensive infrastructure assets with whole-of-life environmental consequences, that requires sustainable development and operation. Recent studies (Santero et. al., 2011b, Yu and Lu, 2012, Ting et al., 2012, and Alam et al., 2013) have identified that there is a need for the whole-of-life environmental impact of road infrastructure to be addressed by the rating schemes for sustainable delivery of road projects.

This study has analyzed five prominent sustainability rating schemes for their adequacy in addressing the life cycle environment components (LCECs) of road infrastructure. This analysis includes: identification of credits[1] from the schemes that are relevant to LCEC; and qualitative and quantitative analysis of the identified credits for their coverage to each of the LCECs.

2. Sustainability of roads

The development, use and maintenance of road network have multi-facet impact on the environment and the surrounding community. To attain sustainability, all phases of an infrastructure should be guided by the principles of sustainable development (Lim, 2009). These include: reduction in emission from the road during construction, maintenance and operation; and preservation of the roads from the impact of changing climate.

For road infrastructure, the conventional environmental factors are: energy consumption; emission during road construction and maintenance; and impact of road characteristics such as slope, curve, pavement stiffness, surface unevenness, and surface texture during operation. Traffic congestion during works (Lepert and Brillet, 2009) also adds to emissions. Some of the additional environmental factors are: biodiversity, habitat protection, sound and light pollution, air and water quality, land use and visual amenity, climate change considerations, resource conservation, source of materials, waste management and future proofing (Griffiths, 2008). Therefore, in the environment dimension of the road asset, sustainability is a “whole-of-life” assessment phenomenon. This has led to life cycle assessment (LCA) of road projects as a step forward from the traditional generic environmental studies. LCA can provide a scientific approach for whole-of-life optimization of resource and energy consumption, minimization of emissions and reduction of waste in road works (Stripple, 2001, Soderlund, 2008, Chan et al., 2011, Santero et al., 2011b, Santero et al., 2011a).

3. Life cycle assessment (LCA)

LCA is a systematic set of procedures for compiling and examining the inputs and outputs of materials, energy and associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle. LCA of road projects have been carried out since 1996. Santero et. al. (2011b) studied the system boundary considerations of 15 road LCA studies from 1996 to early 2010 and observed that they considered materials and construction phase environmental components, but generally ignored the high impact “use and maintenance phase” environmental components. They noted that inclusion of the environmental components of only selected phases of the life cycle in a given analysis limits the utility of the results, as the omitted components often contribute significantly to the overall life-cycle impact. Other recent studies (Zhang et al., 2010, Yu and Lu, 2012, Ting et al., 2012) also identified the lack of a comprehensive system boundary for conducting LCA of road projects. Alam et al. (2013) examined the published road LCA studies till 2012 and conducted a qualitative assessment of different environmental components under the different phases of road life to categorise them as “low impact” or

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[1] A credit is a sustainability factor that is included in an infrastructure rating scheme address sustainability impact. For example, ‘use of recycled material’ is a credit that addresses impact related to the use of virgin material processing and transportation.

"high impact" considering energy consumption and greenhouse gas (GHG) emissions as major environmental factors. Based on the study findings, they proposed a comprehensive system boundary for carrying out future road LCA studies. It included high impact life cycle environmental components such as: material processing, transportation, traffic congestion, rolling resistance, albedo, lighting and end-of-life (EOL) recycling. The use of this system boundary in road project assessment would assist in minimizing life cycle resource consumption and emissions. The high impact road LCA environmental components are defined below:

Material processing (Extraction and Production): Total upstream supply chain required to deliver processed material for road construction and maintenance activities.

Transportation: Carrying material 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 (Lepert and Brillet, 2009).

Rolling Resistance: Pavement surface roughness and structural properties cause rolling resistance and increase fuel consumption and emissions of vehicles significantly (Chupin et al., 2012). The impact of rolling resistance becomes significant as it affects every vehicle using the pavement (Ting et al., 2012).

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 (Akbari et al., 2009). 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 (Yu and Lu, 2012).

4. Sustainability rating schemes

Various sustainability rating schemes have recently been launched. The progress of the building industry in sustainability assessment since the development of UK based Building Research Establishment Environmental Assessment Method (BREEAM) Rating Scheme in 1990 (Lee and Burnett, 2008) has led to the development of sustainability assessment in the infrastructure sector. 'All-infrastructure' type schemes are: Infrastructure Sustainability (AGIC, 2012), Australia, Envision (2012), USA, and CEEQUAL (2012), UK; and 'road specific' schemes are: Invest (2011), Australia, and Greenroads (2011), USA (Alam et al., 2013).

Sustainability rating schemes, both 'all-infrastructure' and 'road specific', are based on their own standards, varying sustainability dimensions and generally exclude operation and end-of-life (EOL) phases (Soderlund, 2008, Shaw et al., 2012). This has resulted in the assessment of the sustainability outcome levels relevant to road infrastructure projects by different sustainability schemes. One approach is by identifying different environmental credits from the schemes that relate to road projects based on a comprehensive road LCA system boundary. The adequacy and appropriateness of the identified credits for each of the LCECs can give an indication about the sustainability outcome levels of the schemes for road projects.

The above mentioned five sustainability rating schemes have been assessed for their coverage to different high impact road life cycle environmental components (LCECs). It includes credits relating to all the phases of infrastructure life. The comprehensive LCA system boundary for road projects proposed by Alam et al. (2013) has been considered for this assessment.

4.1 Assessment of schemes based on LCA

The rating schemes have been developed on different credits or concerns that address different dimensions of sustainability. Each of the credits is assigned with a score point based on the weighting given to the credit. Under this study, the environmental credits of the sustainability rating schemes were identified and assessed for their coverage to different road LCECs, such as material processing, transportation, traffic congestion, rolling resistance, albedo, lighting and end-of-life (EOL) recycling as identified by the Alam et al.(2013) system boundary.

The credits of each of the rating schemes were studied separately based on the guidance and explanation given in the respective scheme manual to identify the environment related credits. The identified credits were then studied in detail to assess their coverage to different LCECs. This resulted in combination of both qualitative and quantitative assessment. Some of the credits cover multiple LCECs and the share of each LCEC in a particular credit was not feasible to separate. An example of credits' coverage to different LCECs is shown in Table-1. Here, 3 (three) LCEC related credits are taken from a typical "all-infrastructure" rating scheme, which has 9 (nine) LCEC related credits out of total 55 (fifty-five) credits for sustainability assessment.

Table 1: Typical environmental LCA related credits with their weighting and coverage

Credits				**Road Life Cycle Environmental Components (LCEC)**						
3 of 55 Credits	Name	Allocated Score	% Weighting	Material Processing	Transportation	Congestion	Rolling Resistance	Albedo	Lighting	EOL Recycling
1	Use recycled materials	14	1.66	√						
2	Use regional materials	10	1.18	√	√					
3	Provide for deconstruction and recycling	12	1.42							√
Total 55 Credits		**845**	**100**							

In Table-1, typical environmental credits of a scheme are presented that are associated with road LCECs. The weighting of each credit is based on percentage score of the credit relative to the aggregated scores of all the credits in the scheme. For example, the weighting 1.18 of credit '*2: use of regional materials'* is obtained as a percentage of its score of 10 with the total score of 845 ((10/845)*100). This weighting 1.18 relates to two LCECs- material processing and transportation as presented in Table- 1. This table shows that for the selected credits in the example, the ‘material processing’ component is covered by credits ‘1’ and ‘2’, the ‘transportation’ component is covered by credit ‘2’, the ‘EOL (end of life) recycling’ component is covered by credit ‘3’, and the other components (congestion, rolling resistance, Albedo and lighting) are not covered by any of the 3 (three) credits. The weightings for different LCECs obtained from the 3 (three) credits included in Table- 1 are presented in Table- 2.

Table 2: Weighting assessment of environmental credits of a typical infrastructure rating scheme based on Seidel (1998)

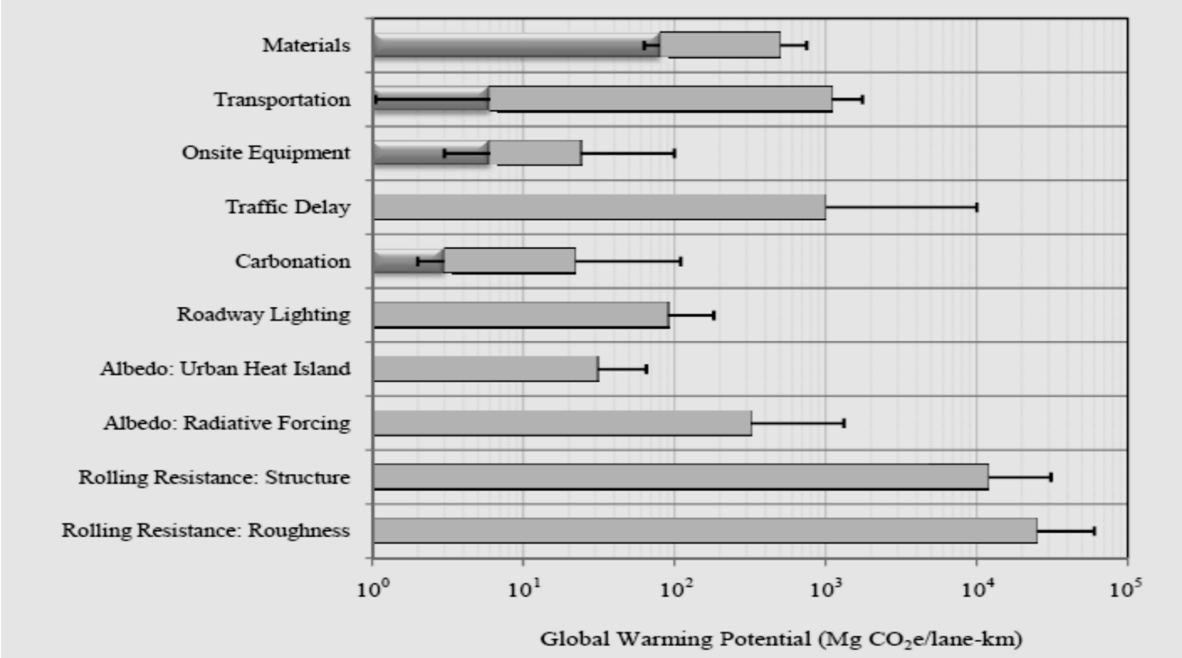
LCEC from Table-1	No. of credits covered	Total Weighting (Drawn from Table-1)	Remark
Material Processing	2	2.25 *	Covered
Transportation	1	0.59 **	Marginally covered
EOL Recycling	1	1.42	Partially covered
Congestion	-	0	Not covered
Rolling resistance	-	0	Not covered
Albedo	-	0	Not covered
Lighting	-	0	Not covered

* 2.25 = 1.66 +(1.18/2), ** 0.59 = 1.18/2

The reasoning behind using a 50:50 split (Reference: credit ‘2’, “use regional materials”, Table-1, weighting 1.18%) resulting in 0.59 weighting for “transportation”; and contribution of 0.59 to the “material processing” giving a value of 2.25 is based on Figure- 1 (Santero and Horvath, 2009). This figure (1) shows possible impact levels of different LCECs in terms of global warming potential (GWP) for one lane-kilometer road with a standard lane width of 3.6m and an analysis period of 50 years. This is based on the findings of 15 Road LCA (life cycle assessment) studies from 1996 to 2010. The distribution of the weighting point 1.18 of the shared credit ‘2’ between the two competing LCECs was done using a qualitative approach model proposed by Sidel (1998), which is explained below.

> *In Figure- 1, the highest possible impacts of the two LCECs are almost similar, but the range of possible impact for the ‘transportation’ LCEC is much bigger than that of ‘materials’ LCEC. For the transportation LCEC, it can be as low as ‘0’ and can be as high as 10^3 Mg Co^2e/lane-km. For the ‘materials (material processing)’ LCEC, the range of possible impacts is limited in between 10^2 Mg Co^2e/lane-km and 10^3 Mg Co^2e/lane-km. The highest value of transportation shown in Figure- 1 was obtained for extreme situation like 300km of ground transportation after shipping from remote location (Santero and Horvath, 2009). The scheme considered soils and aggregates within 80km, and concrete within 160km as regional materials under this credit. As a result, for this credit the environmental impact in terms of GWP for the transportation LCEC would be significantly lower than the extreme level of 10^3 Mg Co^2e/lane-km. Again, as stated in the scheme manual, this credit is included to reduce environmental impact caused by transportation of construction materials; which means the transportation LCEC should get the larger share of the weighting point 1.18. In addition, there are issues like low quality and less durable materials from regional sources with higher environmental consequences. Under these circumstances, the credit weighting is equally distributed between the two LCECs. This is a qualitative assumption, which may not differ significantly in case of a real life road project.*

Figure 1: GWP impact ranges for components of road pavement life cycle (Santero and Horvath, 2009)



The thick, gray bars represent the probable ranges and the thin, black lines represent the extreme ranges.

Three 'all-infrastructure' schemes- Infrastructure Sustainability, Envision, and CEEQUAL; and two road specific schemes- Invest, and Greenroads were assessed under this study. The credits of each scheme were studied separately and summarized for their general findings following the methodology discussed above and are presented in Table-2. It was observed that the findings of the three 'all-infrastructure' schemes are similar, and the findings of the two 'road specific' schemes are also similar within the group. The coverage of the credits related to LCEC is less in 'all-infrastructure' type compared with 'road specific' type. These are presented in Table- 3.

Table 3: Infrastructure rating schemes' coverage of life cycle road environmental components

Scheme Type	LCECs Covered	LCECs Partially Covered	LCECs Marginally Covered
All-Infrastructure	• Material • Transportation	• EOL recycling	• Congestion • Rolling Resistance • Albedo • Lighting
Road Specific	• Material • Transportation	• Albedo • Lighting • EOL recycling	• Congestion • Rolling Resistance

4.2 Key findings

The rating schemes in general have included some environmental credits which relate to the life cycle impact of road projects. All schemes have included a number of credits related to the material processing and transportation LCECs. The schemes have also included a few credits relevant to the end-of-life (EOL) phase of road, which results in "partial coverage" consideration to the EOL recycling component by all the schemes. However, the schemes differ in considering other LCECs based on their type.

"All-infrastructure" type schemes have given "marginal coverage" to the traffic congestion, rolling resistance, albedo and lighting components. The "road specific" schemes have given "marginal coverage" to the traffic congestion and rolling resistance components, but "partial coverage" to the albedo and lighting components. The difference in coverage to the albedo and lighting components comes as a result of inclusion of findings from some road LCA studies by the road specific schemes (Greenroads, 2011).

The Santero and Horvath (2009) study (Figure- 1) shows that LCECs such as rolling resistance (roughness), rolling resistance (structure), and traffic delay (congestion) can have "high" impact, which may collectively possess nearly half of all the life cycle environmental impacts. The impacts shown in Figure- 1 are presented in log scale. Therefore, the impact of rolling resistance (both roughness and structure) is very high, while the impact of traffic congestion is second among all the components. As observed in this study, the rating schemes have not included enough credits to address these possible high impact LCECs of road projects.

5. Conclusion

The purpose of the infrastructure rating scheme for roads is to assess the level of sustainability accomplishment in road projects. This study identified that the infrastructure rating schemes generally used for sustainability assessment of road projects do not address all the high impact road life cycle environmental components (LCECs). LCECs such as material and transportation are better addressed, but LCECs such as traffic congestion during re-construction, rolling resistance of the pavement, albedo, street lighting, and end-of-life management (recycling) are partially or marginally addressed. In general, 'road specific' schemes' have better indicator coverage to the LCECs than the 'all-infrastructure' schemes. It is inferred that the sustainability outcomes of the infrastructure rating schemes- both 'all-infrastructure' and 'road specific' can be improved further for road projects by incorporating all the LCECs with component specific indicators.

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