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SUSTAINABLE PAVEMENT RATING SYSTEMS: AN INTERNATIONAL CRITICAL REVIEW

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Roads provide the network in which public development can take place and the economy can progress. Each year public entities invest significant amounts of economic resources for their maintenance and expansion. Coupled with the fact that the transportation sector accounts for 20% of all greenhouse gas emissions globally, it is necessary the resources invested in these networks are done so in the most effective and efficient manner possible. Tackling these issues, various institutions have established systems to quantify the sustainability of roads, such as GreenPave, Greenroads, CEEQUAL and BE2ST-in-Highways. The objective of this study is to establish an understanding of these systems to properly identify their effectiveness, their benefits and their limitations. This will be obtained via a systematic literature evaluation of all relevant academic publications and scheme manuals. The outputs of this study provide an in-depth understanding of these key rating systems, enabling project managers to better implement sustainability straight from the design stage of a project. Furthermore, sustainability is not a theme present in current pavement design manuals. From the evaluation and diffusion of these rating systems, sustainability can be incorporated and made mandatory in all pavement projects.

Keywords: *Pavements; Sustainability; Rating Systems*

SISTEMAS DE CERTIFICACIÓN PARA PAVIMENTOS SOSTENIBLES: UNA REVISIÓN CRÍTICA INTERNACIONAL

Las carreteras facilitan el desarrollo económico y social de los países que articulan. Cada año, las entidades públicas invierten importantes cantidades en primera inversión, mantenimiento y explotación de carreteras. El sector del transporte por carretera representa el 20% de todas las emisiones de gases de efecto invernadero en el mundo, por lo que se hace necesario que los recursos invertidos en estas redes se hagan de la manera más eficaz y eficiente posible. Abordando estas cuestiones, varias instituciones han establecido sistemas para cuantificar la sostenibilidad de las carreteras, como GreenPave, Greenroads, CEEQUAL y BE2ST-in-Highways. El estudio que aquí se presenta facilita la comprensión de estos sistemas para identificar adecuadamente su efectividad, sus beneficios y sus limitaciones. Para ello se ha llevado a cabo una revisión bibliográfica sistemática y un análisis pormenorizado de los sistemas citados. Los resultados apuntan a que los sistemas permiten a los directores de proyectos implementar mejor la sostenibilidad directamente desde la etapa de diseño de un proyecto. Se ha detectado también una deficiente utilización de la sostenibilidad como criterio de diseño pavimento. Desde la evaluación y difusión de estos sistemas de calificación, la sostenibilidad se puede incorporar y hacer presente en todos los proyectos de pavimentos.

Palabras clave: *Pavimentos; Sostenibilidad; Sistemas de Certificación*

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1 Introduction

The transportation sector is a key player in the production of greenhouse gases, where the sector accounts for 24% of all emissions in Europe and 28% in North America (Eurostat, 2018; IPCC, 2018; The World Bank, 2017). Furthermore, nearly all (95%) of the energy used in the transportation sector comes from petroleum based, non-renewable fuels (US EPA, 2014).

Roads account for a large percentage of land based passenger and freight travel (IRF, 2018). It is also proven that inefficient road construction can cause environmental degradation, loss of economic productivity and loss of time for road users (Anderson et al., 2011; Griffith and Bhutto, 2009). Road pavements are material intensive assets (Bryce et al., 2017) and in order to reduce their adverse environmental, economic and social effects, and enhance their benefit to society, various initiatives have come into play to provide leading sustainable best-practices which can guide project stakeholders in roadway projects.

These initiatives can be referred to as sustainable pavement rating systems (SPRS) and offer a pavement design and management best-practice platform, which in turn can evaluate and quantify the performance of a project. SPRS offer a key step towards more sustainable and responsible roads by affirming the sustainability credentials of a project and communicating them to stakeholders (Bryce et al., 2017; Rooshdi et al., 2014; Söderlund et al., 2007).

SPRS gained traction long after building rating systems, in the late 2010´s, compared to 1990´s, respectively (Farzaneh et al., 2012; McVoy et al., 2010). Hence why buildings have various sustainability construction standards (ISO 15392:2008, ISO/TS 12720:2014), but their base network of roads has largely been neglected (Clevenger et al., 2013; Rooshdi et al., 2014), and they have no direct standards, apart from general infrastructure standards (ISO/TS 21929-2:2015). Now that various systems are present in the market, a suitable time has arrived to critically review these rating systems and gain clarity on their functioning. Furthermore, given the youth of these systems and the roadway pavement being the key material consumer (Bryce et al., 2017), this study will pay special attention to pavement considerations within the whole roadway sustainability complex.

2 Review of Previous Studies

In general, a limited number of studies have been carried out which critically review the functioning of SPRS (Simpson et al., 2014). Many reviews have provided a brief insight into these systems in their own way, but a holistic study is still lacking for the proper evaluation of SPRS. In this study both peer-reviewed publications and public body reports by departments of transportation (DoT) have been included in order to maximise literature exposure.

Overall, of the key studies found, some reviews had the objective of providing information and clarity on SPRS. Zietsman et al. (2011) provides a guidebook for sustainability performance measurement for transportation agencies. A breakdown of eight SPRS is provided, in terms of creator, launch date, type of system, purpose, systems sustainability definition and weighting or scoring logic. Wu et al. (2015) evaluated the general structure of three infrastructure rating systems in order to explore their key elements. Clevenger, Ozbek and Simpson (2013) offer a solid background into six key SPRS and a more complex evaluation of sub-criteria than the previous studies according to environmental, water, energy and materials categories.

Furthermore, other studies focused their evaluation of SPRS as only part of a project, usually as a foundation for the development of a new sustainable pavement assessment method. Eisenman and Meyer (2013) evaluate eight rating systems and develop a new rating system for Georgia DoT, USA, through the evaluation of current practices and modifications for the Georgia region, but while various systems are included they are not critically compared.

Simpson et al. (2014: chap.2), provided a thorough evaluation of leading SPRS and took its evaluation of SPRS and applied it to identifying the best rating system for a specific DoT depending on its preferences (survey-based). The same results tables by Clevenger, Ozbek and Simpson (2013) are available in this study. Simpson et al. is the only study to evaluate the triple bottom line of the systems, although the methodology for this evaluation isn't explained. Bryce et al. (2017) provided a brief background into four SPRS. Using these systems, a new process was developed to evaluate sustainable pavements throughout the maintenance and rehabilitation stages of projects. Chang et al. (2018) briefly mentions a few SPRS and then applies the Greenroads indicators to a roadway project in China.

The work by Van Dam et al. (2015) can be considered to be one of the most complete references found. It is a reference document by the Federal Highway Administration (FHWA), USA, and provides sustainability best-practices for various aspects of pavements all throughout their life-cycle. This study is the only one which explores pavement related criteria in SPRS (chapter 10).

The findings of these studies display that: (i) in a critical review of SPRS there are some necessary aspects which must be considered (origin, launch dates, category comparison, scoring logic etc.), (ii) SPRS are rarely directly separated in terms of their varying focuses (i.e. infrastructure, roadway and pavement – they are generally bundled under the same group and referred to as transportation rating systems), (iii) the life-cycle applications and pavement-related criteria of SPRS has not been fully explored, and, (iv) not much SPRS literature has been published recently.

From the seven studies mentioned, four are public body reports and three are peer-reviewed publications. This displays a strong governmental desire for the development of a comprehensive sustainability assessment methodology (Böhringer and Jochem, 2007). It can be seen that all systems aim to explore the various elements in SPRS, each with its own criteria on identifying which are the most prominent systems to evaluate. In addition, the majority of the systems evaluated from the USA, and by sources in the USA.

3 Objectives

The aim of this study is to critically review and provide clarity on SPRS in order to enable project managers to make informed decisions on SPRS. In order to achieve this, and fill the current gaps in existing literature, this study will adhere to the following objectives:

1. Identify and provide understanding on prominent and established sustainable pavement certification systems for new constructions, covering the minimum required topics already established in other SPRS literature.
2. Fill current research gaps for SPRS, critically comparing the systems according to their varying focuses (pavements, roadways and infrastructure), life-cycle considerations and pavement related criteria, in order to further develop SPRS review literature.

4 Methodology

This study used a three-step approach to systematically review sustainable pavement rating systems.

(a) Initially, a systematic literature review was carried out via the Web of Science (WoS) and Springer peer-review databases, along with US Department of Transport (DoT) sources, to identify relevant literature on the review of these rating systems. Elsevier's WoS and Springer are seen as the most widespread scientific journal databases (Guz and Rushchitsky, 2009). Search keywords included: "sustainable" AND "pavement" AND "rating system". Upon the review of this literature, a second search phase was carried out including the names of SPRS.

(b) Once the prominent SPRS were identified from reviewing the literature, a criterion was applied for their selection in this study. This criterion was influenced by the key points and gaps found in previous reviews. The criterion was as follows: i) from the collected systems, at least one system will be selected to represent a key focus group (pavements, roadways and infrastructure) of SPRS; ii) each system must have undergone scientific review; iii) systems are found to be context sensitive (Van Dam et al., 2015), therefore the SPRS elected will need to account for this. Context is found to provide systems with different approaches in their evaluation of sustainability; different regions will provide different approaches. For the scope and depth of this study four SPRS were evaluated.

(c) In the final step, the manuals of the selected systems were examined to determine similarities and differences between their background info, rating criteria, life-cycle considerations and pavement related criteria. For the citation evaluation of the systems, both WoS and Springer were considered with the search criteria: "[name of SPRS]" AND "sustainable" AND "pavements". In the assessment of pavement related criteria, the same considerations as made by Van Dam et al. (2015:chap.10) were made.

Comparison tables were provided in chapter 5 in order to provide an improved system comparison. Throughout this study the rating systems will be referred to as SPRS, but it is fully understood that these systems do not solely concentrate on roadway pavements.

5 Results and Discussion

5.1 System Selection

The key systems identified in this study are displayed in table 1. Along with the most prominent SPRS being identified, the focus of the systems has been established too (pavement, roadway and infrastructure). From the evaluation of literature reviews in chapter 2, key gaps in current studies were identified. As a result, the selection criteria in chapter 4 was established.

Table 1: Prominent SPRS and their focuses.

Application	Most Prominent Systems	Origin	Sources
Infrastructure	CEEQUAL	United Kingdom	4, 7
	Envision	USA	2, 4, 5, 6
	IS	Australia	6
	LEED ND	USA	5
Roads	BE^{2}ST-in-Highways	USA	1, 2, 3, 4, 7
	GreenLITES	USA	1, 2, 3, 4, 5, 7
	Greenroads	USA	1, 2, 3, 4, 5, 6, 7
	I-LAST	USA	1, 2, 3, 4
	Invest	USA	1, 2, 4, 7
	STARS	USA	1, 4
Pavements	GreenPave	Canada	1, 4, 7

Sources: Zietsman et al., 2011[1]; Clevenger, Ozbek & Simpson, 2013[2]; Eisenman & Meyer, 2013[3]; Simpson et al., 2014[4]; Van Dam et al., 2015[5]; Wu et al., 2015[6]; Bryce et al., 2017[7].

As stated in chapter 2, the main focus of SPRS reviews thus far has primarily been based in the USA and on USA rating systems, hence, as a first step, the selection of the only two non-

USA systems selected in table 1 (criterion c): *CEEQUAL* and *GreenPave*. As it turns out, these two systems represent both infrastructure and pure pavement SPRS (criterion a). Following on, and given that road SPRS represent the bulk of available systems, two further systems were selected for evaluation from the roads category (criterion a): *Greenroads* and *BE²ST-in-Highways*. Through the literature review, it was found that Greenroads is the most researched system (criterion b), and that the BE²ST-in-Highways system was unique in its approach to sustainability quantification (criterion c); while many SPRS are based on the LEED building system (Barrella et al., 2017), BE²ST functions through a variety of third-party apps, which through their analysis provide key data for system evaluation, hence offering the highest potential of variance for this study.

This, in turn, correlates to the following systems being selected (in alphabetical order): BE²ST-in-Highways; CEEQUAL; GreenPave; Greenroads.

5.2 Introduction to Selected SPRS

From the systems selected, two originate from different US states; one from the west side and one from the central-eastern side. Both US systems in this study consider the roadway system (Anderson et al., 2017; UWM, 2010). The origin of the purely pavement systems can be found a little further north in Canada (Lane et al., 2017). Finally, from the European continent the CEEQUAL system can be found (BRE, 2012), which evaluates all forms of infrastructure projects.

Overall, the majority of the SPRS offer rating only in their local region, whereas the Greenroads system spans further and covers North America, Australasia, Africa, the Middle East and Asia. This reinforces the superior number of citations which Greenroads has. Furthermore, GreenPave and Greenroads provided updated manuals in 2017, counting as the most recent systems. On the other hand, BE²ST and CEEQUAL (despite being at version 5) haven´t updated their manuals since 2010 and 2012, respectively. Sustainability measurement evolves over time, therefore systems must be updated accordingly (Zietsman et al., 2011).

Table 2: Introduction to Sustainable Pavement Rating Systems.

	BE²ST-in-Highways	**CEEQUAL**	**GreenPave**	**Greenroads**
Origin	Wisconsin, USA	United Kingdom	Ontario, Canada	Washington State, USA
Dispersion	Wisconsin, USA	UK & Ireland	Ontario, Canada	USA, Canada, Australasia, Africa, Middle East and Asia
Start – Latest Release	2010 – N.A.	2003 – 2012	2010 – 2017	2010 – 2017
Citations	2 (WoS) 1 (Sp)	5 (WoS) 2 (Sp)	3 (WoS) 2 (Sp)	20 (WoS) 11 (Sp)
Rating Type	Self-Assessment	Third-Party	Self-Assessment	Third-Party
Cost	N.A. - Internal	Based on project cost and award type[1].	N.A.- Internal	Based on project cost. Discounts for members.

With regards to the cost of the rating systems, this can be seen as linked to the rating type a system has chosen. For the BE²ST and GreenPave systems, they can be seen as internal rating tools for DoT application, whereas CEEQUAL and Greenroads have taken a more

commercial approach and rate external projects via a third-party, in turn, charging for the rating of projects. Projects to be evaluated by CEEQUAL and Greenroads have similar pricings when project budgets are around 5 million, but upon reaching budgets of 300 million Greenroads is roughly three times more expensive (CEEQUAL Ltd., 2017; Greenroads, 2019). Neither system will exceed 1% of project budget for rating. The more open approach of BE^{2}ST and GreenPave is best as there is a growing adoption of rating tools in departments of transport (Eisenman and Meyer, 2013), especially considering CEEQUAL´s and Greenroads´ latest manuals are not publicly available.

5.3 Criteria and Method Evaluation

Briefly described in table 3, the criteria categories for each of the systems are displayed, along with the total number of categories available, the total number of indicators (Ind.) and whether the system demands any pre-requisites for evaluation (pre-req.). From the comparison of the categories of the rating systems, it can be found that all systems provide considerations for six key aspects: (i) *design process* (many mentioning relevant regulations), (ii) *energy and emissions*, (iii) *environment & land use*, (iv) *materials*, *resources* (including water) *and waste*, (v) *life-cycle considerations* (environmental and economic) and (vi) *social aspects*. These findings are similar to those of Clevenger et al. (2013).The authors would add two further categories for a more complete SPRS: *pavement technologies* (from GreenPave) and *construction activities* (Greenroads).

It is worth noting that the number of categories isn´t directly proportional to the complexity of the systems. For example, from table 3 we can see that BE^{2}ST and CEEQUAL offer the highest amounts of credit categories, however BE^{2}ST only offers two credits per category (excluding the pre-requisite, gives a total of 18 credits), whereas CEEQUAL offers a total of 5,010 credits in its system. In total, GreenPave offers 32 credits, and Greenroads offers 130 credits. With the exception of BE^{2}ST, it can also be seen that the number of indicators is directly proportional to the complexity of the system (more indicators with more complexity), as paving activities have narrower boundaries than road and infrastructure projects (Bryce et al., 2017). In general, there is a recognised difference between infrastructure and roadway rating systems (Zietsman et al., 2011).

Table 3: SPRS Criteria Categories.

System	Criteria Categories	Total	Ind.	Pre-req.
BE^{2}ST-in-Highways	Regulation & local ordinances (pre-requisite); Greenhouse gas emissions; Energy use; Waste reduction (ex-situ); Waste reduction (in-situ); Water consumption; Hazardous waste; Life-cycle cost; Traffic noise; Social carbon cost saving.	10	9	✓
CEEQUAL	Project environmental management; Land use; Landscape; Ecology & biodiversity; Archaeological & cultural heritage; Water issues; Energy; Use of materials; Waste transport; Nuisance to neighbours; Community relations.	12	179	**X**
GreenPave	Pavement technologies; Materials & resources; Energy & atmosphere; Innovation & design process.	4	14	**X**
Greenroads	Project requirements; Environment & water; Construction activities; Materials & resources; Utilities & controls; Access & liveability; Creativity & effort.	7	61	✓
Common Criteria	Design process management (inc. regulations); Energy & emissions; Environment & land use; Materials, resources (inc. water) & waste; Life-cycle; Social aspects.			

With regards to the methodologies of the systems considered GreenPave and Greenroads are notably influenced by LEED in their methodology (Anderson et al., 2017; Lane et al., 2017). On the other hand, BE²ST doesn´t follow a similar credit criteria method, but rather awards points depending on a project´s target reductions (between 10-20% in comparison to another project which has passed the same pre-requisite screening phase). CEEQUAL´s methodology differs greatly from the other systems evaluated as it presents its credits in the form of questions. However, these questions are left very open and do not always provide the best-practice guidance it should pragmatic solutions or ideas.

As seen in table 4, all systems incorporate regional considerations into their system, to make the assessment best suited for the area of evaluation. Regional considerations are very important in terms of sustainability and render each project unique (Van Dam et al., 2015; Zietsman et al., 2011), and they are recognised as a limitation to SPRS in the work of Bryce et al. (2017). Furthermore, all systems should explicitly state why type of road project is being evaluated. This is required as different road types have different road design considerations; an urban road is not the same as a highway. GreenPave and Greenroads shows considerations for the pavement type and CEEQUAL considers all projects in general. Although, no system explicitly states the road type it is understood to be incorporated into the boundary conditions of a LCA, which is considered in various SPRS.

Another important consideration is innovation recognition in a project, which helps promote new technologies into pavements and the development of the sector. Only GreenPave and Greenroads consider innovation as part of their criteria, offering up to 12.5% and 12% of the total criteria, respectively. Innovation is seen as a core element for all sustainability strategies, improving project adaptability, and the incremental improvement of a system (Gleich, 2007).

Table 4: Criteria Breakdown of SPRS.

	BE²ST-in-Highways	**CEEQUAL**	**GreenPave**	**Greenroads**
Assessment Type	Target Reductions compared to Reference Project	In form of Questions	Credit criteria	Credit criteria
Regional Consider.	✓ – through assessment tools.	✓ – ecologically & socially.	✓ – PT-3, 4, MR-1, 3, EA-1 & EA-2.	✓ – ecologically & socially.
Inn. Con.	**X**	**X**	✓ – 12.5%.	✓ – 12%.
Road Type Considerations	**X**	Relative – considers all inf.	✓ – PT-2.	✓
Rating Mechanism	Bronze (50%); Silver (75%); Gold (90%).	Pass (25%); Good (40%); Very Good (60%); Excellent (75%).	Certified (10 pts) Silver (15 pts) Gold (20 pts) Trillium (Future Development Stage).	*All P.R., plus*: Certified (40 pts); Silver (50 pts); Gold (60pts); Evergreen (80pts).
Mandatory Criteria	✓ – Initial project screening required for assessment.	✓ – 39% of points.	**X**	✓ – 20% of indicators (no points available).

Some systems require mandatory criteria to be completed for certification too: BE^{2}ST (initial screening of project for regulation adherence), CEEQUAL (39% of all points) and Greenroads (20% of total indicators, act as pre-requisites and no points available). GreenPave has no mandatory criteria. Mandatory criteria is recommended in order to ensure minimum sustainability requirements are met (Sharifi and Murayama, 2013).

The rating mechanisms were also evaluated, but are recognised as subjective to the desires of the SPRS establishment, and a score of 55% e.g. in one system is not corresponding to 55% in another. In general, the consensus is that the higher the score of a project, the more the project developers have gone in exceeding all regulatory requirements (Anderson et al., 2017; BRE, 2012; Lane et al., 2017; RMRC, n.d.).

5.4 Sustainability Considerations

Taking a brief glance at the sustainability of the tools evaluated in this study, all tools include a LCA (environmental), where Greenroads states it as a prerequisite. All systems also require a LCCA (economic), except CEEQUAL, where Greenroads states it again as a prerequisite. BE^{2}ST carries out LCA and LCCA through University of Wisconsin and FHWA tools (*PaLATE* & *RealCost*). Social metrics for rating tools are harder to define, and generally neglected in the appraisal of pavement projects (Sierra et al., 2018). Overall Greenroads and CEEQUAL have the highest social focus. With both considering workers´ health and sustainability education and non-motorised transport methods amongst other social impacts. CEEQUAL focuses heavily on ensuring a life-cycle focus and sustainability communication to all stakeholders throughout a project. CEEQUAL is the only system which considers the sustainability of the materials provider.

Table 5: LCA and LCCA SPRS considerations.

	BE^{2}ST-in-Highways	**CEEQUAL**	**GreenPave**	**Greenroads**
Perform LCA	✓– *PaLATE* tool.	✓– section 8.2.	✓– PT-1 & EA-1.	✓– prerequisite (PR-2).
Perform LCCA	✓– *RealCost* tool.	**X**	✓– PT-1.	✓– prerequisite (PR-6).

This study has only briefly considered the direct sustainability considerations, and in future work a more in-depth triple bottom line assessment will take place.

5.5 Pavement Related Criteria

Through a quantitative assessment, the percentage of total criteria specifically relevant to pavements was assessed; similar to the work of Van Dam et el. (2015:chap.10). While all these systems consider pavements in one way or another, only GreenPave makes it its primary focus (100%). With regards to the roadway systems, BE^{2}ST is considered to be very dedicated to pavements (89%), and Greenroads has a more expanded focus for the roadway system (48%), considering road surroundings, road lighting, electric vehicles, access and non-motorised vehicle considerations (from these results, BE^{2}ST could actually be considered very close to a pavement rating system, as it does not provide considerations for these aspects). Road geometry and access routes e.g., are not relevant to pavement processes (Van Dam et al., 2015). CEEQUAL´s focus is naturally even wider (45%) as it considers sustainability for all infrastructure projects. CEEQUAL´s criteria is interesting as it is not directly relevant to pavements, but considers project management, site considerations and material considerations which would all be necessary in a pavement project. Overall, many SPRS are found to be overly general in their pavement assessment (Bryce et al., 2017).

Table 6: Pavement related criteria in SPRS.

	BE²ST-in-Highways	CEEQUAL	GreenPave	Greenroads
Pavement Credit Criteria	✓– 89%.	✓– 45%.	✓– 100%.	✓– 48%.

5.6 Evaluation Summary

In table 7 a summary of the findings can be found for the SPRS evaluated. The key benefits and limitations are displayed for each type of SPRS: pavement, roadway and all infrastructure. A fine balance is required between detail and simplicity in SPRS. Creating consensus on what to include is a difficult and extensive task. Through research and review, SPRS can overcome their current criticisms (Eisenman and Meyer, 2013; Simpson et al., 2014) of being too general, not including the entire scope of sustainability and encouraging point mongering without actually understanding good design and construction practice (Bryce et al., 2017; Van Dam et al., 2015). It can be seen that each manual has created its own unique methodology for rating projects, and there is not one unique definition for sustainability (Van Dam et al., 2015; Zietsman et al., 2011). Through the better understanding of SPRS, their improvement and implementation will be easily facilitated to help stakeholders on their road to sustainability.

Table 7: Summary of SPRS.

	Key Benefits	Key Limitations
Pavements: GreenPave	Best criteria focus for pavements. Simple and pragmatic, does not get lost in applying sustainability.	Limited social considerations. No mandatory criteria.
Roadways: BE²ST & Greenroads	Provides quantification for whole road project. Extra sustainability ideas (lighting, bicycle routes etc.).	No in-depth criteria for pavements.
Infrastructure: CEEQUAL	Enforces a Life-Cycle mindset and community incorporation. Considers supplier sustainability.	No specific criteria for pavements. No pragmatic solutions & ideas for credits. No innovation considerations.

Sustainability is now necessary in all aspects and for all stakeholders in the pavement sector (Simpson et al., 2014; Van Dam et al., 2015) and is a key issue recognised by chief highway administrators and transportation departments (Zietsman et al., 2011).

As displayed throughout this work, many interpretations of SPRS exist, and in order to understand sustainable pavement analysis holistically future work will dedicate itself to exploring further systems under more complex evaluation metrics (including the evaluation of the triple bottom line).

6 Conclusion

The increasing global interest in sustainability has now made its way into the road pavement sector. This, in turn, has caused various departments of transport and establishments to publish their own interpretations of how to measure sustainability in pavement systems. With varying interpretations in the industry, and no unified method being developed, this study has critically reviewed and provided clarity on sustainable pavement rating systems in order to enable project managers to make informed decisions. In order to achieve a systematic evaluation, key themes were recognised and included from previous review literature, and research gaps identified and assessed in order to further develop rating system review

literature. The BE^{2}ST-in-Highways, CEEQUAL, GreenPave and Greenroads systems were found to best meet the criteria established from the literature review of this study. They were evaluated against their origin, criteria, methodology, sustainability aspects and pavement focus.

The technical instruments presented in this study, just like the majority of rating systems, were primarily from North America and most systems only offer rating in their local regions. Greenroads breaks this trend by offering certification in various continents, linking to why it is also the most researched system in peer-review databases. GreenPave and Greenroads are the most up-to-date systems, both having updated their manuals in 2017. BE^{2}ST-in-Highways and GreenPave were developed for internal department of transportation use, whereas CEEQUAL and Greenroads have focused on a more commercial application and charge for use of their systems.

Between the systems, six common criteria category themes are found: design process management; energy and emissions; environment and land use; materials, resources and waste; life-cycle considerations; social impacts. All systems provide regional considerations in their criteria and all, except GreenPave, offer mandatory criteria. Half of the systems considered provide innovation considerations, with an average of 12% of total criteria dedicated to it. Furthermore, all systems include an environmental life-cycle assessment in their criteria, and all, except CEEQUAL, require a life-cycle cost analysis.

Throughout this work, the authors have described these systems as sustainable pavement rating systems, therefore logically the systems considered were also evaluated against their specific pavement considerations. GreenPave being a pavement rating system received the highest score, followed by BE^{2}ST-in-Highways (which is very close to being a pure pavement system). The Greenroads system received around half of its credits relevant to paving activities, given its large social focus and considerations for external road factors. CEEQUAL also scored below half of its credits, and while not specifically related to paving activities, many criteria were applicable as related to project management, and site and material considerations.

Overall, pure pavement rating systems are found to be the simplest and easiest to implement, but not be very specific for social considerations. Roadway systems offer the possibility to include exterior sustainable practices (lighting, bicycle paths etc.), but are do not go very in-depth with pavement considerations. And finally, infrastructure systems strongly enforce a life-cycle mindset, but are very general in their application and, while relevant, do not provide specific considerations for pavements.

Future research will explore more rating systems, of all focuses, and provide more complex rating metrics including the triple bottom line.

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