ROAD INFRASTRUCTURE DESIGN FOR OPTIMIZING SUSTAINABILITY

LITERATURE REVIEW

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Any errors remain those of the authors. The findings, interpretations and conclusions presented in this article are entirely those of the authors and should not be attributed in any manner to the European Investment Bank.

# Acronyms and abbreviations

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# Acronyms and abbreviations

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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>AGR:</td>
<td>The European Agreement on Main International Traffic Arteries</td>
</tr>
<tr>
<td>AASHTO:</td>
<td>The American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>CBA:</td>
<td>Cost-benefit Analysis</td>
</tr>
<tr>
<td>CEA:</td>
<td>Cost-effectiveness Analysis</td>
</tr>
<tr>
<td>CEN:</td>
<td>European Committee for Standardization</td>
</tr>
<tr>
<td>CEPS:</td>
<td>Centre for European Policy Studies</td>
</tr>
<tr>
<td>CIB:</td>
<td>International Council for Research and Innovation in Building and Construction</td>
</tr>
<tr>
<td>CSD:</td>
<td>Commission on Sustainable Development</td>
</tr>
<tr>
<td>DfT:</td>
<td>The UK Department for Transport</td>
</tr>
<tr>
<td>DS:</td>
<td>Decision Support</td>
</tr>
<tr>
<td>EIA:</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>EU:</td>
<td>European Union</td>
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<tr>
<td>FHWA:</td>
<td>The US Federal Highway Administration</td>
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<tr>
<td>FIDIC:</td>
<td>International Federation of Consulting Engineers</td>
</tr>
<tr>
<td>FP6/FP7</td>
<td>The Sixth Framework Programme and the Seventh Framework Programme</td>
</tr>
<tr>
<td>IAIA:</td>
<td>International Association For Impact Assessment</td>
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<td>IETC:</td>
<td>International Environmental Technology Centre</td>
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<tr>
<td>LCA:</td>
<td>Life Cycle Assessment</td>
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<tr>
<td>MCDA:</td>
<td>Multi-criteria Decision Analysis</td>
</tr>
<tr>
<td>NEPA:</td>
<td>National Environmental Policy Act</td>
</tr>
<tr>
<td>OECD:</td>
<td>Organization of Economic Cooperation and Development</td>
</tr>
<tr>
<td>PSR:</td>
<td>Pressure -State-Response Model</td>
</tr>
<tr>
<td>SAFESTAR:</td>
<td>Safety Standards for Road Design and Redesign project</td>
</tr>
<tr>
<td>SDIs:</td>
<td>Sustainable Development indicators</td>
</tr>
<tr>
<td>SDM:</td>
<td>Sustainability Decision Model</td>
</tr>
<tr>
<td>SDS:</td>
<td>Sustainable Development Strategy</td>
</tr>
<tr>
<td>SEA:</td>
<td>Strategic Environmental Assessment</td>
</tr>
<tr>
<td>SETAC:</td>
<td>Society for Environmental Toxicology and Chemistry</td>
</tr>
<tr>
<td>SIA:</td>
<td>Social Impact Assessment</td>
</tr>
<tr>
<td>SLCA:</td>
<td>Social Life Cycle Assessment</td>
</tr>
<tr>
<td>TEP:</td>
<td>The Evaluation Partnership</td>
</tr>
<tr>
<td>TERN:</td>
<td>Trans- European Roadway Network</td>
</tr>
<tr>
<td>UN:</td>
<td>United Nations Organization</td>
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<tr>
<td>UNCED:</td>
<td>United Nations Conference on Environment and Development</td>
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<tr>
<td>UNEP:</td>
<td>United Nations Environment Programme</td>
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<tr>
<td>WSSD:</td>
<td>The World Summit on Sustainable Development</td>
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</tbody>
</table>
1 Introduction

Although there are many approaches aimed at assessing the socio-economic and environmental feasibility of surface transportation projects such as roads and railway infrastructure, presently there is no standardised or commonly accepted methodology to assure sustainability in the appraisal and evaluation of road projects over the life-cycle. Current approaches could be broadly grouped into three categories: (1) traditional decision-making process techniques including cost-benefit analysis (CBA), multi-criteria decision analysis (MCDA), and others; (2) road design process including standards and codes, and (3) sustainability rating systems and models for assessing sustainability of infrastructure design and construction.

However, these methods do not seem to apply for all the sustainability drivers of road projects. The main weakness of these tools is that they are either weighted towards environmental or economic assessment, do not address sustainability in a thorough way, or may be overly focused on certain stages of project development. CBA still has serious defects, especially when evaluating incommensurable goods. MCDA can introduce a subjective qualitative assessment, especially in the criteria weighting. Conversely, rating systems and models are useful to score and compare projects but are mostly focused on environmental aspects, are focused more on the construction stage of projects, and are not based on standardised methods of performance measurement. Finally, up to now little has been done to incorporate sustainability criteria into the engineering design standards of linear infrastructure projects.

This research contributes to fill this gap by developing an approach to introduce sustainability criteria in the appraisal of road projects. The tool developed in this research is expected to help decision-makers select the most adequate road infrastructure design from the point of view of sustainability – recognising as far as possible the limitations and constraints placed by local planning systems, design standards and codes of practice. This will require a comprehensive understanding of the complexity of sustainability principles when selecting design criteria for highways.

Since sustainability is a broad concept, we explore terminology and explain what sustainability means in this context. After that, we follow a systematic approach aimed at identifying key aspects that are not being incorporated in current methods and practices for sustainability assessment. The assessment model developed by this research describes the way to incorporate the sustainability elements in project appraisal, in order to identify the trade-off between social, environmental and economic issues, to ensure that each road project is undertaken in the most sustainable way.
2 Literature review

2.1 Sustainability concept

2.1.1 Evolution of the concept

The history of the concept of Sustainability started in 1972 with the United Nations Conference on the Human Environment held in Stockholm, the first international symposium aimed at discussing exclusively environmental issues. Consecutively, the Brundtland Commission provided the most widely used of all definitions of sustainable development: “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). After the emergence of the concept, it acquired political acceptance “through rising public concern in the developed countries over the new and alarming phenomenon of global environmental change, and in some ways it replaced fears of nuclear war that had prevailed in the early 1980’s” (Vogler, 2007).

Later, other important conferences and events associated with the United Nations Organization (UN) were held. Two of the more important are: the first UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 and the World Summit on Sustainable Development (WSSD) convened in Johannesburg in 2002. In this period the concept began to go beyond the environmental aspect and started to include economic and social elements. Additionally, the adoption of the Kyoto Protocol by 84 countries in 1997 and the introduction of the concept of sustainable construction in 1994 for making construction more sustainable without compromising conventional construction goals –see Fernández (2010)– established key milestones in recent sustainability history.

By following all the UN conferences from 1972, it is possible to note that “there was the shift in the political debate from a primary emphasis on environmental issues at the 1972 Stockholm Conference, through a shared focus on environmental, social and economic development at the Rio de Janeiro Earth Summit in 1992, to arguably a primary emphasis on poverty alleviation at the Millennium Summit in 2000 and at the Johannesburg World Summit in 2002” (Paul, 2008).

As our aim is to understand the trade-off among the economy, the environment and social well-being by reviewing in first instance the evolution of the concept of sustainability, a brief history of the concept is set out in Table 1. The table is a summary of the key events and milestones that have guided the journey toward sustainable development.
<table>
<thead>
<tr>
<th>Event/Landmark</th>
<th>Year</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conference on Human Environment (Stockholm)</td>
<td>1972</td>
<td>The first international meeting for discussing environmental matters (e.g., regional pollution, acid rain, etc).</td>
</tr>
<tr>
<td>Brundtland Commission</td>
<td>1987</td>
<td>Brundtland report provided the most quoted definition in the literature, making popular the “sustainable development” term.</td>
</tr>
<tr>
<td>UNCED (Rio de Janeiro)</td>
<td>1992</td>
<td>Key important outputs: The Rio Declaration, Agenda 21 and the CSD.</td>
</tr>
<tr>
<td>The Concept of sustainable construction emerged</td>
<td>1994</td>
<td>Claims for making construction more sustainable without compromising conventional construction goals.</td>
</tr>
<tr>
<td>Kyoto conference on climate change</td>
<td>1997</td>
<td>The Kyoto protocol sets out obligations to reduce emissions of greenhouse gases. 84 countries signed the protocol, others refused to ratify it. The Kyoto Protocol entered in force in 2005.</td>
</tr>
<tr>
<td>Millennium Summit held in New York</td>
<td>2000</td>
<td>World leaders agreement “Millennium Development Goals” against poverty, environmental degradation, discrimination, etc.</td>
</tr>
<tr>
<td>WSSD in Johannesburg</td>
<td>2002</td>
<td>The Johannesburg Summit reconfirmed the Millennium goals and complemented them by additional ones.</td>
</tr>
<tr>
<td>UN Conference on sustainable Development. Rio+20</td>
<td>2012</td>
<td>Two main topics developed in the conference: a green economy in the context of sustainable development and poverty eradication; and the institutional framework for sustainable development.</td>
</tr>
</tbody>
</table>

2.1.2 Sustainability definitions

Since the concept of sustainability reached international priority in the 1980s and 1990s, there has been a growth of interest in infrastructure sustainability concerns; see Meyer & Jacobs (2000); Rijsberman & Van de Ven (2000); Deakin (2001) and Ashley & Hopkinson (2002). However, as some authors admitted, despite sustainability becoming a fashionable word, it is far from being a well-defined concept.

As Gatto (1995) investigated, sustainability has three rather distinct definitions (see FIGURE 1). Nevertheless, the author argued that all these definitions are inconsistent: “The notion of sustainability is a vague and elusive one, and attention must be directed to what it means before asking whether and how it might be achieved” (Levin, 1993).

![FIGURE 1 Distinct definitions of Sustainability](image)

Source: Authors’ figure based on Gatto (1995)

Until now, definitions of sustainability do not appear to diverge from this “old research gap”. Despite, the need to achieve economic and social development and to protect the environment seems to be a general consensus, there is no standard way in which sustainability is defined. In the face of this situation, there is a large body of work on the conceptualization of sustainability that also includes some definitions. After the definition given by the Brundtland Commission, many authors provided their own descriptions and connotation of the sustainability definition. For instance, Radermacher (1999) provided one of the broadest concepts of the evaluation of sustainability – according to Ciegis, Ramanauskiene, & Martinkus (2009). His study indicated that the definition of sustainability should include: a) globalization, b) a long period of time, d) external effects, e) environmental policy, f) the approach “from the cradle to the grave”.

In this sense there are a number of other definitions of sustainability—see Forum for the Future (2005), Gilmour, Blackwood, Banks, & Wilson (2011), Parkin, Sommer, & Uren (2003). However, most of these definitions focus on specific fields for example economy, ecology, and
environment. Consequently, definitions tend to differ and “not a single reference presented a feasible definition of sustainable development which could incorporate all aspects of the concept commission’s report under investigation and provide no ideal understanding of this concept” (Ciegis et al., 2009).

To sum up, sustainable development is still seen as a complex issue that is hardly definable for practical conditions. It is not clear whether sustainability requires a trade-off or whether an optimum level is achievable. In addition, there is no clear consensus on how to encourage convergence and divergence in sustainability elements and as Gilmour et al. (2011) found, “it is generally accepted that the real challenge lies in understanding how to put it into practice: that is, to operationalise sustainability”.

### 2.1.3 Sustainability accepted indicators

In its simplest form, a project appraisal is conducted by going through a list of indicators for each option. As Farsari & Prastacos (2002) found, some of the best known international efforts on the development of sustainable development indicators are:

1. **OECD Pressure-State-Response framework**: The PSR model –see FIGURE 2– claims that: human activities exert pressures on the environment and affect its quality and the quantity of natural resources “state”; society responds to these changes through environmental, general economic and sector policies and through changes in awareness and behaviour “societal response” (OECD. Organization of Economic Cooperation and Development, 2001).

This model provides indicators of environmental pressures (related to production and consumption), indicators of environmental conditions (for example population exposure to certain levels of pollution) and, indicators of societal responses (for example environmental expenditure, price structures and waste recycling rates).

![FIGURE 2 The PSR Model](source: OECD. Organization of Economic Cooperation and Development (2001))
2. World Bank: The World Development Indicators – see The World Bank (2012)– is a compilation of relevant, high-quality, and internationally comparable statistics about development and the quality of people’s lives. Indicators are organized around six themes: world view, people, the environment, the economy, states and markets, and global links. Table 2 shows examples of indicators by themes. This collection of development indicators aims to put data into the hands of policy makers, development specialists, students, and the general public. The dataset presents indicators for monitoring progress on goals and targets from the Millennium Development Goals. It represents a clear international effort on the development of sustainability indicators which contains more than 1,000 indicators for 216 economies, with many time series extending back to 1960.

**Table 2. Examples of World Development Indicators**

<table>
<thead>
<tr>
<th>Theme</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>World view</td>
<td>Poverty rates/ People living in extreme poverty/ Progress toward gender equality in education.</td>
</tr>
<tr>
<td>People</td>
<td>Population dynamics/ Unemployment/ Disease prevention coverage and quality/ Mortality.</td>
</tr>
<tr>
<td>The environment</td>
<td>Energy production and use/ Trends in greenhouse gas emissions/ Traffic and congestion.</td>
</tr>
<tr>
<td>The economy</td>
<td>Growth of consumption and investment/ Monetary indicators/ Balance of payments current account.</td>
</tr>
<tr>
<td>States and markets</td>
<td>Business environment: Doing Business indicators/ Transport services/ Financial access, stability, and efficiency.</td>
</tr>
<tr>
<td>Global links</td>
<td>Growth of merchandise trade/ Travel and tourism/ Primary commodity prices.</td>
</tr>
</tbody>
</table>

Source: Authors’ table based on The World Bank (2012)

3. United Nations – Commission on Sustainable Development Indicators

Agenda 21 calls on countries and the international community to develop indicators of sustainable development. Following this recommendation, in 1995, the Commission on Sustainable Development (CSD) encouraged work aimed at developing these indicators, which “serve as reference for countries to develop or revise national indicator sets, and are intended to be adapted to national conditions” (CSD. Commission on Sustainable Development, 2009).

There are 96 indicators organized into 15 themes and 44 subthemes. Table 3 shows examples of indicators by theme and subtheme.
### Table 3. Examples of CSD Indicators of Sustainable Development

<table>
<thead>
<tr>
<th>Theme</th>
<th>Subtheme</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poverty</td>
<td>Sanitation</td>
<td>Proportion of population using an improved sanitation facility.</td>
</tr>
<tr>
<td>Oceans, seas and costs</td>
<td>Coastal Zone</td>
<td>Percentage of total population living in coastal areas/Bathing water quality.</td>
</tr>
<tr>
<td>Land</td>
<td>Forests</td>
<td>Proportion of land covered by forests/Area under sustainable forest management.</td>
</tr>
<tr>
<td>Economic development</td>
<td>Employment</td>
<td>Employment population ratio/Vulnerable employment.</td>
</tr>
</tbody>
</table>

Source: Authors’ table based on CSD. Commission on Sustainable Development (2009)

4. **Barometer of Sustainability**

This model was developed in 1997 by Robert Prescott-Allen and is a visual tool of sustainability assessment. It measures the sustainability of a country and represents an aggregate index by combining indicators —scaled in [0, 100]. FIGURE 3 shows the barometer, which has two axes: one for human wellbeing and the other for ecosystem wellbeing. Each axis is divided into five bands. “The performance criteria enable indicator measurements to be given a score by converting them to the scale of the barometer. They define the rate of exchange between the indicator and the scale that is worth a given number of points” (Prescott-Allen, 2001).

Notwithstanding critiques concerning subjectivity of this methodology, in general, the Barometer is a useful and simple tool easy to understand and calculate and “gives an immediate easy to understand reflection of ecosystem and human well-being. Moreover, it allows the interested parties to define their own criteria for sustainability and thus the overall process to be participative” (Farsari & Prastacos, 2002).

![The five bands of the Barometer](image)

**FIGURE 3** Barometer of Sustainability

Source: Prescott-Allen (2001)
5. Ecological Footprint

The ecological footprint analysis is an area-based indicator which quantifies the intensity of human resource use and waste discharge activity in a specified area in relation to the capacity of the area to provide for that activity (Wackernagel & Yount, 1998). In this light, the measurement is made in land units. Researches have defined a nation’s footprint to correspond to the water and land area demanded by its population in order to produce consumed resources and to absorb generated wastes.

The ecological footprint is understood as a general measure of sustainability, focused on the “carrying capacity” of a region. Although in its calculations it does not incorporate the economic dimension, it is widely used to compare in a global scale the consumption patterns among different nations.

![The ecological footprint measures how much biological capacity people occupy. Some countries claim more biological capacity than there is within their boundaries. This means that they run a national ecological deficit. Consequently, they need to import their missing ecological capacity—or deplete their local natural capital stocks. Regions and countries with footprints smaller than their capacity are living within their territory's ecological means. Often, however, the remaining capacity is used for producing export goods rather than keeping it as a reserve. In contrast, a region’s 'global ecological deficit' refers to the gap between the average consumption of a person living in that region (measured as footprint) and the bio-capacity available per person in the world.]

FIGURE 4 National ecological deficit

On the other hand, the EU Sustainable Development Strategy (SDS), proposed by the Commission in May 2001, consists in a long-term strategy for ensuring economic, social and ecological sustainable development. This strategy singled out a number of objectives in four priority areas: climate change, transport, public health and natural resources, see European Commission (2009a).

The SDS requires the European Commission to “monitor the progress of the EU against the challenges laid out in the strategy and specifically to draw up a comprehensive set of Sustainable Development Indicators (SDIs)”. In order to accomplish this task, the Statistical Office of the European Communities (Eurostat) has developed a set of indicators, adopted by the Commission in 2005 and then updated in 2007.

The indicators are divided into ten themes, reflecting the ‘key challenges’ of the strategy: socio-economic development, sustainable consumption and production, social inclusion, demographic changes, public health, climate change and energy, sustainable transport, natural resources, global partnership and good governance. These themes are further divided into subthemes to reflect the operational objectives and actions of the SDS (European Commission, 2009a). Furthermore, there are three levels of indicators reflecting the structure of the SDS (overall objectives, operational objectives, actions). Table 4 shows examples of sustainable transport indicators, divided into two subthemes.
Table 4. Examples of Eurostat SDIs. Theme 7: Sustainable transport.

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Energy Consumption by transport mode</td>
<td><strong>Sub-theme: TRANSPORT AND MOBILITY</strong></td>
<td></td>
</tr>
<tr>
<td>3. Modal split of freight transport</td>
<td>5. Volume of passenger transport</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Investment in transport infrastructure by mode (not yet available)</td>
<td></td>
</tr>
<tr>
<td><strong>Sub-theme: TRANSPORT IMPACTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Greenhouse gas emissions by transport mode</td>
<td>8. People killed in road accidents</td>
<td></td>
</tr>
<tr>
<td>9. Emissions of zone precursors from transport</td>
<td>10. Emissions of particulate matter from transport</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11. Average CO₂ emissions per km from new passenger cars</td>
<td></td>
</tr>
<tr>
<td><strong>Contextual indicator</strong></td>
<td></td>
<td><strong>Contextual indicator</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Prices indices for transport</td>
</tr>
</tbody>
</table>

Source: European Commission (2009a)

Finally, several funded research projects on SDIs have been finalised. The most notable research projects which focus explicitly on SDIs are DECOIN, INDI-LINK under FP6 and SMILE (a follow-up project to DECOIN), POINT, OPEN-EU and INSTREAM, under FP7—for further information see European Commission (2009a).

Given the broad range of international sustainability accepted indicator schemes, it is hardly possible to cover all of them. However, as pointed out by Bartelmuther & Douglas (2008), despite there is no a definitive set of measures which everyone agrees, in general sustainability indicator schemes around the world include the following topics:

- Population (growth, migration, refugees),
- Human needs (health, food, housing, education, equity, security, etc.),
- Renewable and non-renewable natural resources,
- Environmental quality (air, water, land),
- Ecosystems (acidification, eutrophication, biodiversity),
- Economic sectors (and their impacts, including emissions, natural resource use, production and consumption patterns, technologies),
- Natural and man-made disasters,
- Global environmental problems (climate change, ozone layer depletion),
- Globalization,
- Institutions.
2.1.4 Sustainable construction and highways

Sustainable construction is defined as a construction process which incorporates the basic matters of sustainable development—see Parkin (2000) and Chaharbaghi (1999). Such construction processes should comply with the following principles to the fore in the built environment and facilities for the wider community: environmental responsibility, social awareness, and economic profitability objectives (Shelbourn & Bouchlaghem, 2006).

The International Council for Research and Innovation in Building and Construction (CIB) and The United Nations Environment Programme-International Environmental Technology Centre provided the following definition of sustainable construction: “...is a holistic process aiming to restore and maintain harmony between the natural and built environments, and create settlements that affirm human dignity and encourage economic equity” (CIB & UNEP-IETC, 2002).

According to the Federal Highway Administration (FHWA) sustainable highways are seen as an integral part of sustainable development. A sustainable highway should satisfy lifecycle functional requirements of societal development and economic growth while striving to enhance the natural environment and reduce consumption of natural resources. The sustainability characteristics of a highway or roadway project should be assessed and considered for implementation throughout its lifecycle, from conception through construction, operations, and maintenance (CH2M HILL, University of Washington, Texas Transportation Institute, High Street Consulting Group, & Webkey LLC, 2012).

Over recent years, a number of sustainability evaluation tools have been developed to evaluate sustainability of infrastructure projects, including ratings systems, checklists and different evaluation schemes. Transport sector rating and certification tools base their sustainability frameworks for road projects on their own sustainability definitions (for further information see section 2.2.4).

In general, a green highway can be defined by the following key areas (see FIGURE 5). By combining these key areas, a set of topics can begin to be assessed in the development of green highways. The focus areas presented are the foundation for the areas needed to develop green highways (Bryce, 2008).

![FIGURE 5 Five key areas for green highways](source: Bryce (2008))
From the aforementioned descriptions it is very important to point out that theoretically, sustainable highway principles are drawn during the lifetime of the infrastructure. However, up to now, the application of the sustainability concept to the roadway lifecycle is mostly based on energy and material perspectives. The evaluation of the sustainability of roads has been focused on the construction process. For example, the Guide from the Department for Transport (DfT) titled “Sustainable Highways: A Short Guide” –see Reid et al. (2008)– provides guidance on the choice of sustainable materials and techniques for use in highway and footway maintenance as well as new construction.

Research studies analyzing the design brief stage according to its positive or negative influence on sustainability are scarce. Consequently, the impact of road design parameters on highways sustainability has not been analyzed in a thorough way. Nevertheless, some studies had implicit recognized this link. For example, the influence of vehicle dynamics of road geometrics – see Reagan et al. (1998) and Sebsadji et al.(2008), and safety issues for geometric design of roads – see Cafiso et al. (2004), Lamm, Psarianos, Soilemezoglou, & Kanellaidis (1996), Sentouh et al. (2006) and Milliken and Pont (2004).

Finally, a road is sustainable if “it is able to reach, during the phases of construction, maintenance and operation, the objectives underlying the design (regulations observance, safety, fluidity of movement, maintenance, energy efficiency, transport capacity ...) in a self-sufficient way” (Corriere & Rizzo, 2012). The approach taken by these authors argues that the lack of adoption of sustainable practices integrated in the design of roads resulting in impossibility to make choices that lead to sustainable use of resources needed. Therefore, the impact geometric design of roadway facilities should be regarded with special emphasis when incorporating the principles of sustainability throughout the project lifecycle.

2.2 Sustainability assessment: Methods and Techniques

2.2.1 Available sustainability evaluation tools: an overview

The International Federation of Consulting Engineers (2012) –FIDIC– has grouped sustainability tools currently available on the market into the four categories shown in FIGURE 6, depending on their origin and intended use. This report explains decision support tools as process tools that use sustainability guidelines and methodologies –such as multicriteria analysis methods and calculators– to provide expert consulting support to decision-making all along the project cycle. On the other hand, the FIDIC defined rating systems as tools intended to assess, rate and award a project, depending on its performance against relevant sustainability criteria. Finally, calculators are developed as isolated tools used to provide inputs to another sustainability tool and guideline documents typically inform other sustainability tools on sustainability quality, standards, indicators or methodologies.
Tools described by the International Federation of Consulting Engineers (2012) were provided concerning sustainable infrastructure projects in general. In particular, related to linear infrastructure projects, they are assessed in practice by a number of tools or methodological frameworks including to a greater or lesser extent the concept of sustainability. Current methodologies can be grouped in three major categories:

1. The main appraisal tools, as the decision-making process techniques: including cost-benefit analysis (CBA); cost-effectiveness analysis (CEA); multi-criteria decision analysis (MCDA) and others;
2. Road design process including standards, codes and agreements;
3. Frameworks, systems and models for sustainability assessment: including rating systems for civil infrastructure (e.g. CEEQUAL–UK, Envision –USA and IS –Australia); rating systems for evaluating sustainability of roads (e.g. Greenroads, GreenLITES, Greenways); and sustainability decision models to embed sustainability in the design process of road projects.

Highway-related sustainability studies, sustainable requirements initiatives and current methods and techniques are introduced in the following sections. Our aim is to identify strengths and weaknesses in current sustainability assessment methodologies and to describe to what extent they integrate sustainability into existing appraisal processes.

2.2.2 Main Appraisal tools

The objective of this section is to briefly examine and to compare the main techniques for project appraisal. First, we studied the CBA and the MCDA, the primary tools for comparing project alternatives. Subsequently, we included environmental and social assessments tools.

In this literature review, we give a general description of the main appraisal tools features, especially when assessing sustainability.

i. Cost-benefit analysis (CBA)

CBA is the most widely used tool to help decision making process. It is generally accepted in academia that CBA is the basic tool for appraising and evaluating infrastructure investments. As Browne & Ryan (2011) state, CBA is generally used in road construction investment analyses in
order to compare the financial costs of construction with long-term congestion reduction benefits such as travel time and vehicle operating cost savings (Owens, 1995).

Usually, CBA is studied as theoretical papers with empirical applications. Many textbooks and research papers have been developed in order to explore CBA perspectives, concepts and practice--see Adler & Posner (2001), Boardman, Greenberg, Vining, & Weimer (2006), Tudela, Akiki, & Cisternas (2006), Gühnemann, Laird, & Pearman (2012), Calthrop, De Borger, & Proost (2010) and Hyard (2012).

In addition, there has been active research activity regarding substantive problems when appraising projects with CBA--e.g. Beukers, Bertolini, & Te Brömmelstroet (2012) and Elvik, (2001). Mouter, Annema, & Wee (2013) mentioned problems with the estimation of the non-monetized project effects. By examining the prospect of CBA application in promoting or demoting sustainable development was found “abundant arguments disfavouring the application of CBA, represented by the problems of: (1) trying to evaluate what are often not ‘evaluatable,’ i.e., non-economic values; (2) limited considerations regarding distributional equity (including intertemporal equity); (3) political bias often present in the application of CBA” (Omura, 2004).

On the other hand, in the European context a number of official guidelines exist such as SafetyNet (2009), and the Impact Assessment Guidelines (European Commission, 2009b). The European Commission sets the CBA as the “common evaluation language” to compare projects. Consequently, CBA results are the ones that provide evidence that a major project is suitable for co-financing with European grants (European Commission, 2008).

ii. Multi-criteria decision analysis (MCDA)

Regarding MCDA, its use had been increasing in the literature. There are several papers in the field of transport, for instance Iniesta & Gutiérrez (2009), Cheng & Li (2005), Friesz, Tourreilles, Han, & Fernandez (1980), Frohwein, Lambert, Haines, & Schiff (1999), Giuliani (1985), Khorramshahgol & Steiner (1988). Beria, Maltese, & Mariotti (2012) offer a short definition for the multi-criteria method. According to these authors, the MCDA is a tool for selecting alternative projects, which have significant social, economic and environmental impacts. MCDA takes into account several criteria and the opinions of stakeholders. In this sense, a number of authors have suggested that MCDA is the most appropriate tool to adopt decisions--see Walker (2010), Tudela et al. (2006) and Janic (2003).

Furthermore, the extensive study of multi-criteria techniques for transportation projects has included issues that require further analysis. The main unresolved matter of this tool concerned with the aggregation of the individual criteria and transparency of judgements, usually called “the black box” (see FIGURE 7).
This concept and other inherent weaknesses have been subject to severe criticism by a number of studies. Particularly, Browne & Ryan (2011) found the three following limitations of the technique:

1. Subjective qualitative assessment and the imputation of value-laden weightings to assumptions, which may lead to subjective and non-transparent biasing—see Munda (2004) and White and G. J. Lee (2009);
2. Decision-aiding techniques do not overcome the problem associated with incomparable quantities;
3. They may lead to distrust or excessive faith in the results, due to the complexity and ‘black-box’ nature of the methodology.

As the literature has shown there is no simple solution for the appraisal of projects, specifically when tackling sustainability of transport projects. Each tool has its own advantages and disadvantages. In this sense, many studies aimed to compare the two approaches have been conducted. A strategic summary of these comparative analyses is set out in FIGURE 8. The objective is to present the characterization of the strengths and weaknesses of the tools discussed in this section described by a large number of authors as Beria et al. (2012), Omura (2004), Browne & Ryan (2011) and others.

However, there will always be some bias in project appraisal and selection as ultimately judgments have to be applied for certain items. There are constraints often set by political, planning and regulatory systems as well as local factors. Although some systems and tools try to present information as far as possible—towards making a good project, the decision maker has to take the final decision.

More recently, some authors have claimed the integration of the Multi-criteria and Cost-benefit methodologies to fully consider sustainability. Particularly, “MCDA is a good tool for the indirect actions—where soft and indirect effects prevail—while CBA for the direct ones—where monetizable costs and benefits prevail” (Beria, Maltese, & Mariotti, 2011). Barfod, Salling, & Leleur (2011) depict the above description by developing a composite decision support model based on combining cost-benefit analysis (CBA) with multi-criteria decision analysis (MCDA). Also, Gühnemann et al. (2012) developed a novel approach of combining both appraisal techniques within a road infrastructure development programme by incorporating CBA results into an MCA framework.
iii. Life-cycle assessment (LCA)

One available tool to assess the environmental effects of construction processes is the life-cycle assessment analysis. Life cycle assessment is an environmental methodology for assessing the environmental performance of a product, an activity or a process from ‘cradle to grave’. The Society for Environmental Toxicology and Chemistry (SETAC) defines life cycle assessment as a process to evaluate the environmental burdens by identifying and quantifying energy and materials used and waste released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to effect environmental improvement” (Consoli et al., 1993).

This technique has been widely used in decision making process and has been applied to a variety of fields including: energy and transport —see Tahara, Kojima, & Inaba (1997), Matsuhashi, Hikita, & Ishitani (1996) and Raluy, Serra, & Uche (2005); water —see Dennison, Azapagic, Clift, & Colbourne (1998); and chemical sectors —see Ophus & Digernes (1996); among others.

There are numerous available techniques for assessing environmental impacts, each of these tools with advantages and disadvantages. However, as Treloar, Love, & Crawford (2004) claimed there are several limitations with existing tools, as they have a “general objective of encouraging greater environmental responsibility within the construction industry, but not toward sustainability as a whole”.

In this light, LCA is considered by researchers to be the only legitimate basis on which to assess environmental impacts. Furthermore, as recognized by Azapagic (1999), it is important to
mention another objective of LCA: “provide a basis for assessing potential improvements in the environmental performance of the system. The latter can be of particular importance to engineers and environmental managers, because it can suggest ways to modify or design a system in order to decrease its overall environmental impacts”.

Currently, a number of methods and possibilities for the application of LCA in strategic environmental assessment of transport infrastructures have been developed, for example see Stripple & Erlandsson (2004). The LCA has been applied for road construction, road maintenance and road operation. It has also included the extraction of materials, the production of construction products, the construction process, the maintenance and operation of the road and finally the disposal/reuse of the road at the end of the life cycle (Stripple, 2001). A schematic figure of the life cycle of a road is presented in FIGURE 9.

In addition to vehicle life-cycle energy, the environmental impact of roads is focused on road surface materials (i.e. asphalt surfaces or concrete surfaces) and constructive techniques. As Treloar et al. (2004) claimed, when evaluating the potential environmental impacts for this kind of facility, the road construction process “is the most important, but in the long run the manufacture, use, and maintenance of vehicles using the road became paramount”.

Despite the use of LCA helping researchers to estimate environmental consequences related to facilities, this technique also presents some disadvantages. There are a number of advantages and disadvantages of the different types of LCA –see University of Washington (2011b). In general, the main criticisms towards LCA in the literature are the following:

1. Since the environmental preservation is not always the main objective of the decision-maker, the definition of the impacts and criteria generates very complex and incomprehensible models for them, especially when the evaluation is conducted for a private company;
2. Actually, the LCA methodology, as described in the ISO standards, doesn’t refer to very important notions in decision making which are uncertainty, validation and Robustness of solutions –see Mazri, Ventura, Jullien, & Bouyssou (2004);

FIGURE 9 Main structure of a Life Cycle Assessment for a Road
Source: Authors’ figure based on Stripple (2001)
3. There are some parameters such as biodiversity or biological barrier effects that are essentially difficult to handle and very difficult to quantify and therefore not possible to include in an LCA model—see Stripple & Erlandsson (2004);

4. Currently, there is not a generally acceptable LCA methodology. Furthermore, when applying the LCA for roads, it is usually confined to materials and engine alternatives for construction vehicles. However, they do not consider how energy consumption varies with different road design parameters. As a result, the significant changes in the environmental effects captured through the LCA, are roughly including the design phase of the facility.

Finally, these are several areas where recent developments in LCA have been strong during the last years. These include “a better understanding of the difference between attributional and consequential LCA, better models for impact assessment, and databases for the inventory analysis. There are at the same time several areas where further development would be useful. Examples of such areas include further development of tools for consequential LCA, of methods for assessment of impacts on ecosystem services from land use and impacts from water use, and weighting methods” (Finnveden et al., 2009).

**iv. Environmental impact assessments (EIA)**

In the International arena, some form of environmental impact assessment has been incorporated into legislation or formal guidelines by a number of countries. At the European level, one can point at the Strategic Environmental Assessment (SEA)—see Directive 2001/42/EC—and the Environmental Impact Assessment (EIA)—see Directive 2011/92/EU. The SEA is a mandatory regulation for some public plans/programmes which are likely to have significant effects on the environment. The EIA is a procedure that can be applied to a wide range of defined public and private projects. The SEA and EIA procedures are very similar, but there are some differences. The EIA is only undertaken for certain projects and at a more developed stage of feasibility study while the SEA is a process that applies further upstream in feasibility—hence less detail.

Environmental impact assessment emerged with the National Environmental Policy Act (NEPA) in 1969. The International Association For Impact Assessment - IAIA (1999) defines environmental impact assessment as “the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made”.

The IAIA, as the premier organization in the field, has also pointed out, in the principles of EIA, the following general objectives:

1. To ensure that environmental considerations are explicitly addressed and incorporated into the development decision making process;
2. To anticipate and avoid, minimize or offset the adverse significant biophysical, social and other relevant effects of development proposals;
3. To protect the productivity and capacity of natural systems and the ecological processes which maintain their functions;
4. To promote development that is sustainable and optimizes resource use and management opportunities.

For the European Commission (2013), the environmental assessment is a “procedure that ensures that the environmental implications of decisions are taken into account before the decisions are
The environmental impact assessment can be undertaken for individual projects on the basis of the EIA Directive of The European Parliament and The Council of The European Union (2012).

According to this directive, the EIA shall identify, describe and assess in an appropriate manner, in the light of each individual case, the direct and indirect effects of a project on the following factors:

1. Human beings, fauna and flora;
2. Soil, water, air, climate and the landscape;
3. Material assets and the cultural heritage;
4. The interaction between the factors referred to in points (1), (2) and (3).

On the other hand, “despite the methodological and administrative advances in EIA over the past two decades, recent experience in many countries confirms that there is still considerable scope for strengthening the process. Immediate and cost-effective measures could help improve the process in four key areas: scoping, evaluation of significance, review of EIA reports, and monitoring and follow-up” (Morgan, 2012). Moreover, as Hollick (1986) mentioned, detailed environmental information is not always available to decision makers because of failure to apply EIA to all relevant decisions. According to this author, the success of EIA depends on adequate monitoring, reassessment, and enforcement over the life of the project. An EIA states what needs to be done but no checks on how a project actually followed through when comes to construction.

FIGURE 10 shows a summary of the strengths, weaknesses, opportunities and threats for the EIA set out in the environmental impact assessment –state of the art– conducted by Morgan (2012). Regarding sustainability, current practice provides minimal level of ‘sustainability assurance’ because the sustainability aims and criteria are not fully incorporated in the technique itself. There is a need for integrating the EIA with other impact assessment tools. The EIA and the SEA are seen by many as first steps towards a sustainability impact assessment.
v. Social assessment approaches

The evaluation of social impacts has been implemented by using several different approaches. In this light, one study conducted by Jørgensen, Bocq, Nazarkina, & Hauschild (2007) found that the perception of social impacts is very variable across the social life cycle assessment (SLCA) approaches. Furthermore, these authors recognized “SLCA is in an early stage of development where consensus building still has a long way. Nevertheless, some agreement regarding which impacts are most relevant to include in the SLCA in order to cover the field sufficiently seems paramount if the SLCA is to gain any weight as a decision support tool”.

On the other hand, The Evaluation Partnership (TEP) and the Centre for European Policy Studies (CEPS) (2010) developed a study for the European Commission (Directorate General Employment, Social Affairs and Equal Opportunities) aimed to describe, compare and analyse the different ways in which social impact assessment (SIA) was currently carried out in the EU and to identify recommendations for the implementation of effective social impact assessment systems and for effective social impact assessment analysis (Centre for European Policy Studies (CEPS), 2010). The main conclusion of this study was that “that social impact assessment is still in its infancy in most European impact assessment systems. Where it takes place at all, the assessment
of social impacts is often less well developed than the assessment of economic or financial impacts.”

Finally, this study found some challenges that have to be addressed in order to set up an effective social assessment. The most important challenges are the following:

1. The term “social impacts” is potentially broad and has not been well-defined yet;
2. The lack of appropriate tools to assess social impacts quantitatively is one of the most frequently cited challenges to effective social IA. Most social assessments remain purely qualitative, and often very superficial.

Regarding the arguments listed above, scholars admit that the social impacts and the study of their distributional effects have traditionally received less attention than economic and environmental aspects. Presently, there is no standardized method to evaluate social and distributional effects of transport projects. One of the difficulties of including social impacts within the appraisal of major projects is that there remains a considerable uncertainty surrounding what a social impact is and how to estimate it.

In conclusion, social assessment is under development and has not been well integrated into decision making process. Even social impacts are considered within the scope of an impact assessment –see European Commission (2009b) – there is still focus on economic impacts (Key challenge number 3 “Commitment to consider social impacts”).

2.2.3 Road design process including standards, codes and agreements

At the European level, civil engineering works are obliged to comply with some requirements and standards. There are also a number of voluntary standards in the field. As shown in FIGURE 11, the study of the published literature and norms establishes that engineering design standards of civil works can be studied from the following perspectives:

1. From a general perspective, concerning European structural design codes and European standardized methods for the assessment of the sustainability aspects of civil engineering works;
2. From a specific point of view, related to road design standards and practices in Europe.

The objective of this section is to provide a general overview of the procedures and norms in the European context. Our aim is to identify limitations set by codes and standards and to describe to what extent they include sustainability.
i. European structural design codes

Regarding the general aspect, we studied two specific existing sources. One is the CEN/Technical Committee involved in the construction sector. The second source consists of the Structural Eurocodes for building and civil engineering structures.

According to the European Committee for Standardization, the CEN/TC 350 is the one responsible for the development of voluntary horizontal standardized methods for the assessment of the sustainability aspects of new and existing construction works and for standards for the environmental product declaration of construction products.

This committee is divided into seven working groups, one dedicated to Civil Engineering works. Nevertheless, this working group (CEN/TC WG6) is new and has not written standards for...
sustainability assessment of civil engineering works. To date no norms at the European level have been produced by the CEN/TC 350. However, we found that currently, the Spanish Technical Committee for the sustainability in construction works—equivalent to the international CEN/TC 350 (AEN/CTN 198)—is developing a literature review of the methodologies for the sustainability assessment of infrastructure projects at the European level.

Finally, we want to point out that the Committee itself has provided standards for the environmental product declaration of construction products and for the sustainability assessment of buildings using a life cycle approach. However, the progress regarding civil engineering works has been limited. Last, we want to mention that these standards are not mandatory methods.

Concerning Structural Eurocodes for building and civil engineering structures, there is a clear difference: it is mandatory that European Members accept designs to the Eurocodes. There are ten Structural Eurocodes (see FIGURE 11): EN1990-EN1999. Regarding the key head Eurocode EN1990, it sets fundamental requirements for the construction (safety, serviceability, robustness and fire) and establishes principles for the design of buildings and other civil engineer works. This code is not related to road design but is focused on buildings, structures, earthworks and bridges—some of which are relevant for road projects.

In conclusion, the Structural Eurocodes do not go beyond the structural requirements of civil engineering work. Sustainability principles are not being incorporated in the broad sense because the code is focused on conventional construction standards and structural requirements. In this particular sense, the code does not limit the introduction of sustainability in the design process of road projects.

ii. Road design standards and practices in Europe

National Standards

Regarding the specific point of view, it is well know that road design standards and traffic regulations have been a matter of national interest in Europe (Wegman, 1998). Up to now, the situation has not changed and therefore fundamental characteristics of road design are still treated on a national level.

Most countries have their own road design standards. Table 5 shows different design guidelines in different European countries as described by the "Geometric design practices for European roads" report, sponsored by the Federal Highway Administration (USA Department of Transportation) and aimed at reviewing and documenting European procedures and practices in roadway geometric. However, this study found the guidelines issued by the national highway authorities are usually considered as recommendations for any projects under the authority of local governmental agencies. This provides great flexibility in designing to meet the local needs and conditions—see Brewer, German, & Krammes (2001).
Table 5. Design guidelines and standards in European countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Title</th>
<th>Publisher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>Swedish guidelines for state roads</td>
<td>Swedish National Road Administration</td>
</tr>
<tr>
<td>Denmark</td>
<td>Guidelines for Geometric Design of Roads and Paths in Urban Areas</td>
<td>Danish Road Directorate</td>
</tr>
<tr>
<td>Germany</td>
<td>Guidelines for the Construction of Roads Part: Manual for the Functional Structuring of the Road System</td>
<td>Forschungsgesellschaft für Strassen und Verkehrswesen</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>Road Design Manual</td>
<td>Centrum für Regelgeving en Onderzoek in de Grond-, Water-, en Wegenbouw en de Verkeerstechniek</td>
</tr>
<tr>
<td>England</td>
<td>Design Manual for Roads and Bridges (DMRB)</td>
<td>The Highways Agency</td>
</tr>
<tr>
<td>Spain</td>
<td>Regulation 3.1-IC</td>
<td>General Directorate for Roads of the Ministry of Public Works</td>
</tr>
</tbody>
</table>

Source: Authors’ table based on Brewer et al. (2001)

Finally, the mentioned report states that:

1. “All countries utilize design guidelines for roadway design that are considered central to their design philosophy;
2. European countries adjust the roadway design to the specific local requirements;
3. Each country has customized this design to conform to its design guidelines and safety goals, including use of varied roadway widths, lengths of passing lanes, median cable guardrail, and end treatment of passing lanes”.

Then, highway design practices and parameters present numerous differences among countries – see Hall & Powers (1995). As a general rule, most countries follow the practice of developing road projects while integrating these facilities into the environment. Furthermore, strong consideration is given to “the desires and needs of the community by inviting the appropriate stakeholders to participate in the development of the project and thus shape some of the solutions that are acceptable to the community (Brewer et al., 2001).

Design guidelines and road standards across different European highway authorities includes sections on most technical aspects and also on environmental and economic assessment. Nevertheless, no social assessment per se is included in these standards. For example, the Highways Agency DMRB contains, besides general requirements, rules for the structural design and the environmental design and assessment of road schemes (EIA). It also includes guidance on economic assessment of road projects (using a CBA). Nevertheless, this Design Manual does not cover the social assessment in relation to all trunk road projects and does not provide a way of
assessing and reporting these effects. However, the Department for Transport’s website for guidance on the conduct of transport studies includes social aspects to a certain extent.

On the other hand, the Regulation 3.1-IC (Spain) states “the required specifications to draft road design studies in order to achieve the adequate characteristics regarding driving functionality, safety and comfort and to make them compatible with the current financial and environmental circumstances”. Once again, the social assessment of roads still remains limited.

**International Standards**

In the international field, the American Association of State Highway and Transportation Officials (AASHTO) has established different standards and guides relating to geometric design of highways. These documents have been widely adopted by a number of countries as approved references to be used in conjunction with their own particular standards.

At the European Level, we found some international agreements and other cooperation forms. These international standards are voluntary guidelines to help with geometric design. In this sense, there is a need to mention two relevant agreements for road design: (1) the European Agreement on Main International Traffic Arteries (AGR) and; (2) the Safety Standards for Road Design and Redesign project (SAFESTAR).

The AGR (United Nations Economic and Social Council, 2008) establishes the international E-road network and provides recommendations about road geometric characteristics (design speed, horizontal and vertical alignment, cross section, etc). Nonetheless, this agreement consists on general rules of design mostly based on safety and traffic flow conditions applied on the basis of economic evaluation. Consequently, sustainability is not being incorporated in a wide and strict way.

On the other hand, on the SAFESTAR report (Institute for Road Safety Research, 2002) we found some recommended geometric characteristics for the ‘Trans-European Roadway Network’ (TERN) that links the major European centres. However, suggested parameters are focused on traffic safety.

Finally, the main conclusions and lessons of this section are the following:

1. Presently there is no Eurocode or standard directly linked with the sustainability of road projects. Standards in the field are focused on bridges, buildings and materials;
2. Regarding geometric characteristics and its connection with sustainability issues there is no standard or code at the European level. Voluntary standards provided by international agreements take into account various criteria including traffic safety, traffic flow, comfort of road users and environmental protection (in theory) but they do not address sustainability in a thorough and comprehensive manner;
3. Further to road design standards, they are treated on a national level. There is no standardization of road geometric characteristics.
2.2.4 Rating Systems and models

i. Rating systems and certification tools

As mentioned by the International Federation of Consulting Engineers (2012), rating systems and certification tools are typically produced by reputable governmental or non-governmental institutions, sometimes in collaboration with academia. They are intended to assess, compare and award a planned or existing facility, depending on its performance against relevant sustainability criteria. Table 6 shows most important sustainability certification tools in the fields of transport, buildings and infrastructure in general. Details relating to the area of provenance are also defined in the table.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Certifying body</th>
<th>Sector</th>
<th>Country of origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEEQUAL</td>
<td>Institution of Civil Engineers (ICE)</td>
<td>All Infrastructure</td>
<td>UK</td>
</tr>
<tr>
<td>ENVISION</td>
<td>Institute of Sustainable Infrastructure (ISI) &amp; Harvard University</td>
<td>All Infrastructure</td>
<td>US</td>
</tr>
<tr>
<td>IS</td>
<td>Australian Green Infrastructure Council (AGIC)</td>
<td>All Infrastructure</td>
<td>Australia</td>
</tr>
<tr>
<td>BEAM</td>
<td>Hong Kong Green Building Council</td>
<td>Buildings</td>
<td>Hong Kong</td>
</tr>
<tr>
<td>BERDE</td>
<td>Philippines Green Building Council</td>
<td>Buildings</td>
<td>Philippines</td>
</tr>
<tr>
<td>BREEAM</td>
<td>Building Research Establishment (BRE)</td>
<td>Buildings</td>
<td>UK</td>
</tr>
<tr>
<td>CASBEE</td>
<td>Japan Sustainable Building Consortium</td>
<td>Buildings</td>
<td>Japan</td>
</tr>
<tr>
<td>GBI</td>
<td>Association of Consulting Engineers Malaysia &amp; Malaysian Institute of Architects</td>
<td>Buildings</td>
<td>Malaysia</td>
</tr>
<tr>
<td>GreenMark</td>
<td>Building and Construction Authority of Singapore</td>
<td>Buildings</td>
<td>Singapore</td>
</tr>
<tr>
<td>Green Star</td>
<td>Green Building Council of Australia</td>
<td>Buildings</td>
<td>Australia</td>
</tr>
<tr>
<td>Green Star SA</td>
<td>Green Building Council South Africa</td>
<td>Buildings</td>
<td>South Africa</td>
</tr>
<tr>
<td>Rating Tools</td>
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<tr>
<td>LEED</td>
<td>US Green Building Council</td>
<td>Buildings</td>
<td>US</td>
</tr>
<tr>
<td>Sustainable community Rating</td>
<td>Government of Victoria</td>
<td>Buildings</td>
<td>Australia</td>
</tr>
<tr>
<td>GreenLITES</td>
<td>New York State Department of Transport</td>
<td>Transport</td>
<td>US</td>
</tr>
<tr>
<td>Greenroads</td>
<td>University of Washington &amp; CH2MHIll</td>
<td>Transport</td>
<td>US</td>
</tr>
<tr>
<td>I-LAST</td>
<td>Illinois Department of Transportation</td>
<td>Transport</td>
<td>US</td>
</tr>
</tbody>
</table>
As Gambatese & Rajendran (2005) found, highway construction consumes large amounts of energy and natural material; produces waste and generates greenhouse gases, with effect to the environment. Consequently, there has been an increasing interest in introducing sustainability on road projects. In this sense, rating systems that evaluate the sustainability of road construction are currently being developed and include Greenroads, GreenLITES (Green Leadership In Transportation Environmental Sustainability), INVEST (Infrastructure Voluntary Evaluation Sustainability Tool), I-LAST (Livable And Sustainable Transportation) and STARS (Sustainable Transportation Analysis & Rating System).

As mentioned in the previous section, transport sector rating and certification tools base their frameworks for roads on their own sustainability definitions. Table 7 provides a brief summary of different sustainability definitions among different tools that are most relevant to roadways. These definitions might be useful to understand what certification tools mean by “sustainability”, especially when defining roadway projects.

**Table 7. Different Sustainability definitions among different sustainability tools**

<table>
<thead>
<tr>
<th>Sustainability tool</th>
<th>Definition of sustainability/ sustainable road-infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>GreenLITES</td>
<td>A transportation system which supports a sustainable society is one that (i) allows individual and societal transportation needs to be met in a manner consistent with human and ecosystem health with equity within and between generations; (ii) is safe, affordable, accessible, operates efficiently, offers choice of transport mode, and supports a vibrant economy; and (iii) protects and preserves the environment by limiting transportation emissions and wastes, minimizes the consumption of resources and enhances the existing environment as practicable. (<a href="https://www.dot.ny.gov/programs/greenlites">https://www.dot.ny.gov/programs/greenlites</a>)</td>
</tr>
<tr>
<td>Greenroads</td>
<td>Sustainability is a system characteristic that reflects its capacity to support natural laws and human values. “Natural laws” encompass the essential idea of Ecology, which is the study of ecosystems. Similarly, “human values” include both equity and economy. (University of Washington, 2011a).</td>
</tr>
<tr>
<td>INVEST</td>
<td>The goal of sustainability is to meet basic social and economic needs, both present and future, and the responsible use of natural resources, all while maintaining or improving the well-being of the environment on which life depends. Sustainability in highways should be addressed with the understanding that highways are one part of transportation infrastructure, and transportation is one aspect of meeting human needs.</td>
</tr>
</tbody>
</table>
I-LAST uses the United Nations Bruntland Commission definition of sustainability. Specifically, the I-LAST identifies the following goals for providing sustainable features in the design and construction of highway projects: (1) minimize impacts to environmental resources, (2) minimize consumption of material resources, (3) minimize energy consumption, (4) preserve or enhance the historic, scenic and aesthetic context of a highway project, (5) integrate highway projects into the community in a way that helps to preserve and enhance community life, (6) encourage community involvement in the transportation planning process, (7) encourage integration of non-motorized means of transportation into a highway project, (8) find a balance between what is important: to the transportation function of the facility, to the community, to the natural environment, and is economically sound and (9) encourage the use of new and innovative approaches in achieving these goals.

Sustainable transportation (i) allows the basic access needs of individuals and society in general to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations; (ii) is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy; and (iii) 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.


Source: Authors’ table

Available definitions tend to be focused on the same principles. The tipple bottom line is used by different sustainability evaluation tools to identify key aspects which enable road projects to support sustainability. As shown in Table 7, it is traditionally accepted for sustainability tools that have to be applied to roadway projects, that a sustainable highway infrastructure design requires a good balance between environment, cost and social aspects. Theoretically, a highway project should include these principles to be considered a “green design”. In this light, as pointed out by the FHWA, a sustainable road must incorporate diverse concepts such as environmental protection, judicious use of funds, air quality improvement, construction quality incentives, recycling promotion, social equity, and environmental management system use.

Then, there are specific rating schemes for evaluating sustainability of buildings, road construction projects and civil engineering works. The civil engineering rating systems were based on the building rating schemes, which are more established. The philosophy of rating systems is based on different categories, each of which explains one sustainability attribute and covers different topics in subcategories.

In general, for a project to be able to be considered for evaluation under a rating system, it is necessary to meet some minimum and mandatory prerequisites. If the project does not meet all these requirements the certification will not be awarded. Then, the project can earn optional
credits or points associated with each subcategory. Each rating system decides the overall weight for each category and subcategory. The percentage of sections and subsections are aggregated and proportioned. Therefore, the project can be certified depending on the percentage of earned credits (Total project score).

As explained above, from FIGURE 12 it can also be seen how a rating system works. We used as an example the categories and fundamentals for the Greenroads rating system, but in general all the sustainability assessment and award schemes studied works in the same way. For further information see the report of the International Federation of Consulting Engineers (2012), which explains in detail the typical process for obtaining sustainability certification for an infrastructure project.

![FIGURE 12 How a rating system works. Greenroads example.](Image)

### Problems associated with rating systems

1. There is not a common set of criteria for comparison among rating systems
2. The weighting processes lack of objectiveness and transparency
3. They are more used as "certification tools" rather than "sustainable tools".

In general, as we can see in FIGURE 13, the above mentioned rating tools had “similar” categories even though there were differences in weighting systems and indicator values. Even so, rating systems contain some common issues that can be grouped into the following sections: environment, water, energy, material, and technological and strategic innovation to improve the environmental performance. The following figure shows how, despite assessment tools have fixed
weights and benchmarks reflecting their own criteria, at the end they are based on similar methodological approaches.

As we can see in this literature review, over recent years a number of sustainability evaluation tools have been developed and applied to infrastructure projects. Despite the proliferation of rating systems throughout the civil engineering field, some authors have criticized its use by indicating that “they lack transparency and objectiveness in the criteria selection and weighting process and are not based on a standardized methods of performance measurement” (Lee, Edil, Benson, & Tinjum, 2011).

In line with the literature reviewed, we can conclude that rating systems are mostly restricted to environmental issues related with construction processes and materials. Each rating system sets its own weighting process. In this sense, each rating system works as an independent performance metric, with a particular general philosophy when evaluating sustainability. In spite of this, there will have to be some reasonably subjectivity due to the wide nature of projects, there location, externalities and other aspects.

Limitations in the available sustainability evaluation tools for linear infrastructure projects are not fundamentally different from constrains presented by sustainability indicator systems for buildings. As Fernández (2010) claimed, despite sustainable construction being traditionally focused on buildings; these rating systems also present considerable problems such as:

1. Uncertainty and subjectivity when selecting criteria, indicators and dimensions (Hueting & Reijnders, 2004; Seo, Aramaki, Hwang, & Hanaki, 2004);
2. The predomination of environmental aspects when evaluating the sustainability of buildings;
3. The lack of participation of all the stakeholders involved in the project life cycle;
4. The number of indicators that generally should be small and in the existing systems of indicators is very high (Alarcón Núñez, 2005).
ii. Models and other sustainability decision tools

On the other hand, the literature also provides some methods and analytical calculations to introduce sustainability into infrastructure projects. The International Federation of Consulting Engineers (2012) defined these models as “Decision Support (DS) tools” –see FIGURE 6– and claimed that they are characterized by assessment frameworks which use multicriteria analysis methods to assess the sustainability performance of different design options during the appraisal of design options stage.

A number of decision support tools can be listed according to the group/category of sector they cover. The following table shows some available DS tools for infrastructure, water, building and transport sector, among others.

**Table 8 Example of Available Decision Support Tools**

<table>
<thead>
<tr>
<th>Tool</th>
<th>Certifying body</th>
<th>Sector</th>
<th>Country of origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPIRE</td>
<td>ARUP &amp; Engineers Against Poverty</td>
<td>All Infrastructure</td>
<td>UK</td>
</tr>
<tr>
<td>HalSTAR</td>
<td>Halcrow</td>
<td>All Infrastructure</td>
<td>UK</td>
</tr>
<tr>
<td>INDUS</td>
<td>Mott MacDonald</td>
<td>All Infrastructure</td>
<td>UK</td>
</tr>
<tr>
<td>SPeAR</td>
<td>ARUP</td>
<td>All Infrastructure</td>
<td>UK</td>
</tr>
<tr>
<td>Tandem Empreinte</td>
<td>Egis</td>
<td>All Infrastructure</td>
<td>France</td>
</tr>
<tr>
<td>Sustainability Matrices</td>
<td>Max Fordham</td>
<td>Buildings</td>
<td>UK</td>
</tr>
<tr>
<td>SPRing</td>
<td>University of Manchester in collaboration with City and Southampton Universities</td>
<td>Nuclear Energy Sector</td>
<td>UK</td>
</tr>
<tr>
<td>MAESTRO (Arrival Departure Manager)</td>
<td>Egis Avia and French Civil Aviation SNA</td>
<td>Transport (Aviation)</td>
<td>France</td>
</tr>
<tr>
<td>Scottish Transport Appraisal Guidance (STAG)</td>
<td>Transport Scotland</td>
<td>Transport</td>
<td>Scotland</td>
</tr>
<tr>
<td>Sustainability Decision Model (SDM)</td>
<td>Mott MacDonald</td>
<td>Transport (Light rail projects)</td>
<td>UK</td>
</tr>
<tr>
<td>Transport Analysis Guidance (WebTAG)</td>
<td>DFT</td>
<td>Transport</td>
<td>UK</td>
</tr>
<tr>
<td>Symbio City Approach</td>
<td>SWECO</td>
<td>Urban Planning</td>
<td>Sweden</td>
</tr>
<tr>
<td>Sustainable Water Engineering Opportunity Tool</td>
<td>Mott MacDonald</td>
<td>Water &amp; Wastewater Sector</td>
<td>UK</td>
</tr>
<tr>
<td>SWARD Guidelines</td>
<td>Ashley, R. (University of Bradford),</td>
<td>Water &amp; Wastewater</td>
<td>UK</td>
</tr>
</tbody>
</table>
Based on the FIDIC report, these tools offer support to the appraisal of the design phase. Particularly the main contributions are the following:

1. “Involvement of experts in advising on specialized studies and detailed weightings for performance assessment;
2. Assessment of each design option against sustainability criteria;
3. Calculators to provide useful values needed for the assessment Participatory assessment which brings stakeholders, experts and planning authorities together to decide on final weightings, materiality and performance of each option;
4. Comprehensive performance mapping of each option enables selection of best performing option;
5. Sensitivity analysis inspires confidence in results”.

Since a lot of effort has already been expanded on the sustainability of projects through decision tools, it therefore made no sense to deepen the particular approaches developed by different studies. Our aim is to outline the basic and general characteristics of the models associated with highway construction projects and to explore how far they go with respect to sustainability.

To accomplish this goal, an exhaustive review of the major publications was conducted including a review of the following models:

1. The BE2ST-in-highwaysTM system (Lee et al., 2011);
2. The methodological approach for sustainable design (Corriere & Rizzo, 2012);
3. The Sustainability Decision Model SDM (Leather & Parker, 2009);

After this explorative study we found that despite some models intend to consider design, construction, operation and maintenance, they are generally understood as quantitative methodologies for rating the benefits of sustainable highway projects. Thus, broadly speaking, these models are not fundamentally different from the philosophy of a multicriteria analysis and therefore, they have the same limitations listed for this main appraisal tool –see section 2.1.1.

Particularly, the SDM and the BE2ST are fundamentally based on methodological approaches as those developed for rating systems. These methodologies use a set of categories or layers with specific weights/points. Finally, the total score is the sum of points awarded by the design alternative. In addition, in theory these models can be used to evaluate sustainability, but in practice they mostly focus on environmental aspects.

Regarding the sustainability framework developed by the Department for Transport, it does not apply weights. This methodology consists on summarizing all relevant impacts (social environmental and economy impacts), without calculating a final “score” for an alternative. The outcomes of this methodology can be based on subjective judgments since it does not provide a final aggregated sustainability assessment.
3.1 Comparative analysis of evaluation tools

As pointed out in this literature review, some practical issues remain unsolved in methods and techniques for sustainability assessment. This issue is amplified when focusing on road projects, because it is not a clear definition in attempting to conceptualise the sustainability being addressed.

By accepting economic development, equity, social community, health and vitality, environmental and ecological systems as basic principles of sustainability -see Ramani, Zietsman, Potter, & Reeder (2012); the literature review process suggest that:

1. Traditionally accepted quantitative methods -such as the CBA and the MCDA- do not address all sustainability components. Particularly, the evaluation of incommensurable goods including social (as distributional equity/intertemporal equity) and environmental aspects were identified as unresolved CBA problems. On the other hand, despite the MCDA including multiple criteria in its analysis (social, environmental and economic), it is not able to remove subjectivity in the process, making the technique highly susceptible to manipulation. On the other hand, there is a considerable scope for strengthening LCA and social assessments towards sustainability as a whole.

2. With respect to the standards and codes it was found that European requirements do not constitute a limitation regarding sustainability, but they neither provide guidelines for incorporating sustainability in the design process of road projects. Currently standards for road design are voluntary and are not directly linked with sustainability.

3. Rating systems are useful to rank, score and compare projects, but since they are focused on environmental aspects and usually limited to the construction process, it can be assumed that they do not apply for all the sustainability drivers of road projects. Moreover, models are not based on standardized methods of performance measurement. Each method incorporates its own criteria. Broadly speaking, in frameworks and systems the whole-life approach is rarely considered -except in material management. Items such as operation and maintenance and carbon over the life cycle are less well developed. Furthermore, none of them is socially specific, although social aspects are relevant to a greater or lesser extent.

It can, therefore, be concluded that as concerns the definition of sustainability the way of putting economic, environmental and social aspects together is uncertain. Although in theory it is broadly recognized that there should measures to introduce sustainability criteria in the evaluation of investment projects (triple bottom line), in practice sustainability is a far reaching subject since there is no consensus on how to apply it, particularly on road projects. As Mihyeon & Amekudzi (2005) found despite “several frameworks were found in the literature for measuring progress toward sustainability in transportation and other infrastructure systems, as with the definitions of transportation sustainability, a standard framework for evaluating progress toward sustainability does not exist”.

The above sections have detailed different evaluation techniques and applications to sustainability assessment of road projects. However, currently projects continue to be mainly compared according to their benefit and costs and sustainability criteria are not part of the “common evaluation language”.

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