Smart Transportation Alliance

Appraising the sustainability of infrastructure projects

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1. Introduction

Since the emergence of the concept of sustainability as an international priority in the 1980s and 1990s, there has been growing interest in the aspects of infrastructure sustainability; see Ashley and Hopkinson (2002); Meyer and Jacobs (2000); Rijsberman and van de Ven (2000). However, in practice, the introduction of multidimensional perspectives of sustainability in the appraisal of infrastructure projects is still an unresolved task. The problems are further compounded by the absence of a systematic, formally and commonly accepted method for the proper ex-ante sustainability appraisal of infrastructure projects. Furthermore, decision-making processes have put more emphasis on economic issues and might be politically biased.

Current approaches can be broadly grouped into **three main categories**. The first comprises traditional decision-making techniques and includes cost-benefit analysis (CBA), multi-criteria decision analysis (MCDA), among others. The second includes approaches to evaluating the environmental and social impacts of project alternatives such as life-cycle assessment (LCA) and social life-cycle assessment (SLCA). Finally, the third covers the frameworks, guidelines and models used to perform the sustainability appraisal and evaluate infrastructure assets, including sustainability rating systems that grade and score infrastructure projects depending on their sustainability performance.

From an overall standpoint, these tools are highly valuable for helping decision-makers meet some of their sustainability targets within their specific scope. However there is still room for improvement in the effectiveness of current assessment tools. Their main weaknesses are that they are biased towards either an environmental or an economic assessment, they fail to address sustainability thoroughly, and are overly focused on certain stages in the project life cycle.

This Discussion Paper has its origin in a research project supported by the European Investment Bank[1], published as full articles —see Bueno and Vassallo (2015) and Bueno et al. (2015). These studies: (i) provided a comprehensive review on the current assessment tools of sustainability applied to infrastructure projects to identify the limitations of existing approaches, point out new areas of research, and propose a sustainability appraisal agenda for the future, and (ii) presented a new methodology to set the weights of the sustainability criteria used in the multi-criteria decision analysis in order to reduce subjectivity and imprecision in the appraisal of infrastructure projects. On the basis of these analyses and the knowledge we were able to extract from reporting guidelines, frameworks, and more than 100 relevant academic studies, we propose a practical and novel approach to accurately appraise the sustainability of infrastructure projects.

This paper specifically integrates methodologies using the single-criterion and multiple-criteria approach in order to address all aspects of sustainability. This methodology responds to the current need to establish an appropriate ex-ante evaluation method for such projects, and supplements the relatively limited choice of real applications combining CBA and MCDA.

The tool designed in this research is expected to help decision-makers select the most adequate infrastructure design in terms of sustainability.

The paper is structured as follows. Section 2 summarises the literature review, aimed at identifying key aspects that are not included in current sustainability assessment methods and practices. The principles of the model are presented in Section 3. Section 4 discusses the methodological approach; and Section 5 provides a set of conclusions and final recommendations for additional research in this field.

[1] 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 (EIB).

2. Background

Several definitions of sustainability can be found in the literature and most of them focus on specific fields such as economy, ecology, and the environment (Gilmour et al. 2011; Parkin, Sommer, and Uren 2003; Radermacher 1999). However, as some authors admitted, despite sustainability becoming a fashionable word, it is far from being a well-defined concept. According to Gilmour et al. (2011), "it is generally accepted that the real challenge lies in understanding how to put it into practice: that is, to operationalise sustainability".

Since sustainable development is still seen as a complex issue that is hardly definable for practical conditions, there is no common understanding of what constitutes sustainability in real-life infrastructure projects both as a concept and in a practical sense. For the purpose of this discussion paper an infrastructure is considered sustainable when it contributes to favourable economic development and to the fulfilment of society's needs in a manner consistent with natural laws and human values. Beyond these key elements, we believe there are two other essential components when designing sustainable infrastructures. First, the context-sensitive nature of sustainability needs to be addressed; in other words, sustainability assessment should be adaptable and adjustable to the specific context of the project's location. Second, a proper definition must take account of the whole life cycle (from conception through construction, operation and maintenance).

On the other hand, infrastructure projects are appraised -in practice- through a number of tools or methodological frameworks that include the concept of sustainability to a greater or lesser extent. We classify the current tools and methods as follows:

- Project appraisal methods for decision-making such as cost-benefit analysis and multi-criteria approaches, which are the most commonly used techniques for decision-making;
- Techniques for assessing environmental/social impacts including life-cycle and social life-cycle assessment, which are often combined with other tools for a holistic sustainability assessment;
- Sustainability assessment methodologies such as rating systems, frameworks, and appraisal guidelines.

On the basis of the literature review conducted, we were able to recognise a set of essential requirements for sustainability assessment of infrastructure projects in order to identify whether they are satisfied or not by the methods and techniques previously mentioned.

The key requirements for a tool to become suitable when appraising sustainability of infrastructure projects are the following:

1. *Life-cycle view*: Sustainability appraisal tools should be based on a life-cycle perspective. They should be able to capture all the sustainability impacts over the lifespan of the infrastructure, from conception through construction, operation and maintenance.
2. *Full perspective*: Sustainability appraisal tools should take into account all the criteria that may influence sustainability including equity over generations.
3. *Rigorous trade-offs*: Sustainability appraisal tools should use rigorous mechanisms for comparing all trade-offs among economic, environmental and social aspects.
4. *Transparent approach*:. Sustainability appraisal tools should be transparent, rational and formal in order to minimise ambiguity and ensure consistency and accuracy.
5. *Adaptability to the context*: Sustainability appraisal tools should be able to address the context-sensitive nature of sustainability by identifying the particular relevance of each impact within the specific characteristics of the social and geographical context of the project's location.

A detailed description of this analysis is beyond the scope of this discussion paper, and the reader is referred to Bueno et.al (2015). The main finding of this evaluation is that, despite the availability of numerous sustainability tools, none appears to be useful for providing a thorough appraisal of sustainability. While there are positive characteristics associated with each tool, some practical issues remain unsolved.

The tools analysed in this research do not satisfactorily fulfil the requirements cited above. On the basis of the missing requirements and considering the state of the art, we conclude that there is still room to improve current tools. The following section discusses some practical actions to overcome obstacles for effectively handling sustainability in the ex-ante appraisal of project alternatives.

3. The need for a proper sustainability method for appraising infrastructure projects

This section outlines the most significant challenges revealed by the review that must be satisfied to improve the sustainability appraisal of infrastructure projects, and ensure a proper method.

- It is vitally important to build a clear definition and a widely-accepted list of sustainability items for infrastructure projects. There is no broadly agreed standard list of sustainability criteria against which to compare project alternatives.
- One of the most important challenges for improving life-cycle evaluation is to define an accepted approach for inter-temporal aggregation of environmental, social and economic impacts. Current methods and tools do not fully ensure the proper inter-temporal aggregation of environmental and social aspects.
- A transparent approach must be defined to determine the relative impact of each sustainability item. To guarantee a correct sustainability assessment, priorities for sustainability items (called criteria weights) must be established based on a standard, transparent and consistent methodology.
- Since decision-making processes demand a commonly accepted, comprehensive and reliable appraisal method, existing tools and methods must also be combined in order to assess the sustainability of infrastructure projects. As none of the tools and methods analysed are suitable for a holistic assessment, further research is recommended to explore existing tools that can be more efficiently used for sustainability appraisal.

4. Proposed methodological approach

After strengths and weaknesses of sustainability assessment tools have been identified, and a number of methodological issues have been revealed; this discussion paper proposes a **methodological approach to accurately appraise sustainability of infrastructure projects**.

The method is structured in three steps; briefly described in the following paragraphs—see Figure 1.

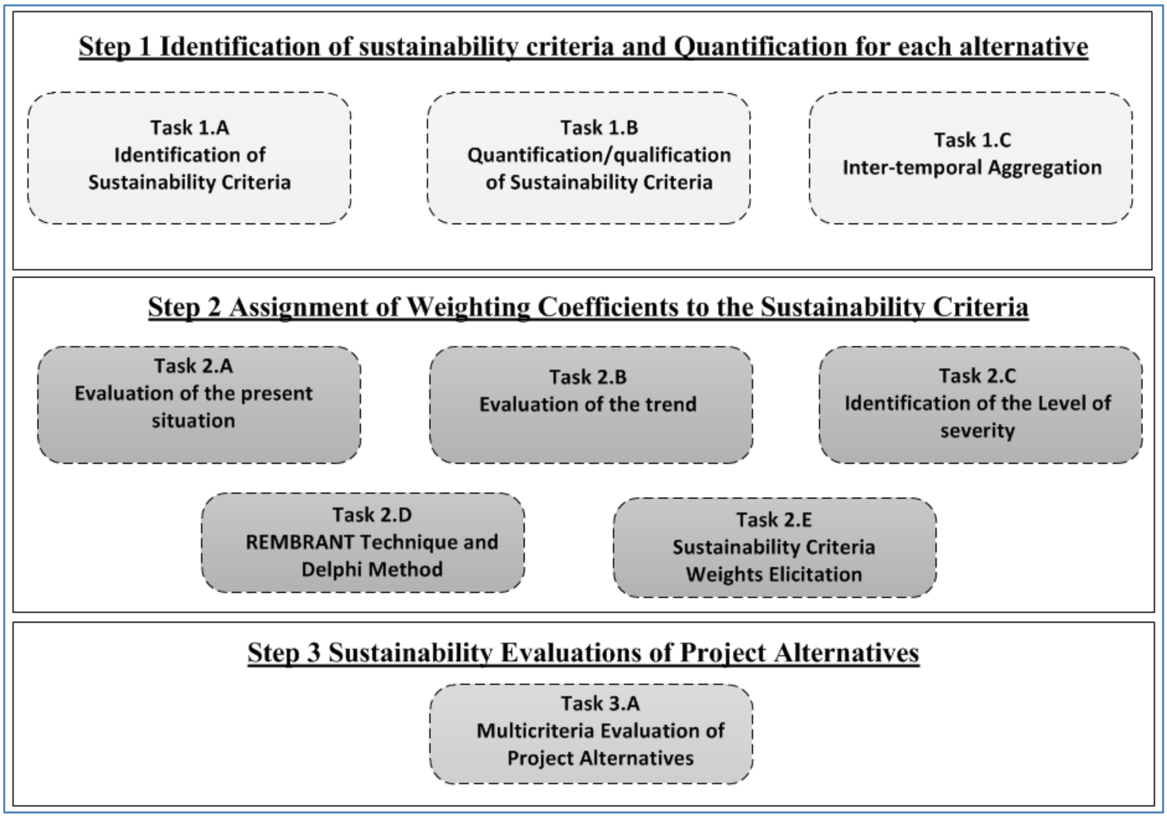

Figure 1: Structure of the Appraisal approach
Source: Authors' own elaboration

4.1. Step 1: Identification of sustainability criteria and evaluation for each alternative

Step 1 consists on identifying sustainability criteria –defined as the basic fundamentals or principles used to judge the sustainability of infrastructure projects–, and quantifying them for each alternative. Criteria can be grouped into different sustainability components (economic/social/environmental). Depending on their specific characteristics, each criteria is evaluated for each alternative in quantitative –either monetary or other– or qualitative units. This step is subdivided into three tasks, described in more detail below.

4.1.1. Task 1.A Identifying sustainability criteria throughout different project stages

In this task, decision-makers should identify a set of major sustainability items to be considered for infrastructure projects over their life cycle. Appropriate criteria to measure sustainability should not only take into account economic efficiency and environmental protection, but also social aspects such as equity, which is ambiguously considered in current project appraisals. These criteria should be evaluated at each stage of the project (construction, maintenance and operation). In this step it is essential to distinguish which criteria can be monetised and which ones measured qualitatively.

4.1.2. Task 1.B Quantification/qualification of sustainability criteria: identifying impacts for each alternative

In this task, designers should quantify/qualify each sustainability criterion for each alternative to obtain the specific project impacts. Decision-makers should calculate the differential annual value (do-nothing scenario vs. do-something scenario) for each sustainability criterion. In particular, the following aspects must be evaluated:

- *Impacts that can be quantified*. Practitioners should quantify these impacts in monetary or other units. We recommend using shadow prices in monetary terms that serve as a good proxy of the social cost (e.g. investment costs, vehicle operating cost and maintenance/operating costs). We also suggest using physical units for most criteria not bought and sold in the market (e.g. travel time savings, air/noise pollution, energy use, etc.).
- *Impacts that cannot be quantified*. These should be evaluated through a qualitative approach based on the decision-maker's criteria. For our methodological approach, we recommend a "seven-point assessment scale", broadly used in most scheme appraisals.

4.1.3. Task 1.C Inter-temporal aggregation of economic, environmental and social impacts

One of the most important challenges for improving life-cycle evaluation is to define a standardised and accepted approach for inter-temporal aggregation of environmental, social, and economic impacts. Based on the assumption that MCDA and CBA can be used in tandem, we propose an alternative approach to discounting depending on the characteristics of the items:

- **For items that can be quantified and monetised with market prices** (shadow prices available), annual future impacts can be converted to present day values (hereafter named **aggregated impacts – *AI***) by using an appropriate discount rate. After aggregating impacts spread over time (i.e. after obtaining *AI*), *AI* are transposed to another qualitative assessment scale −which can be interpreted as shown in Figure 2− in order to obtain **homogenised aggregated impacts (*HAI*).** By using a homogenised scoring system rather than the monetised value, the cost-benefit analysis can be merged with the multi-criteria approach.

However, since preference does not necessarily increase with higher aggregated values, scale must be maintained consistent by specifying an ordinal correspondence between criteria values and preferences such as **"more is better" or "less is better"**, respectively known in the literature as "benefit and cost criteria". Thus before translating aggregated impacts, each sustainability criterion must be classified as a more/less is better criterion, based on the nature and the sign of each sustainability criterion. For example, "less is better" for infrastructure costs while "more is better" for vehicle operating cost savings.

In summary, Figure 2 presents the seven-point assessment scale for obtaining *HAI*. Since our aim is to select the best alternative, the concept used to obtain *HAI* is based on the comparison among the different alternatives, expressed as the average of the alternatives. To make it easier for designers to decide what is much/moderately/slightly better or worse, we propose the thresholds shown in Figure 2.

For example, for a "less is better" criterion, the $(AI)_i$ of the *a* alternative is considered much worse than the average of the alternatives $(AI)_i$ when it is 45% higher than this average, while it is much better when it is 45% lower.

- **For items that can be quantified and are not bought and sold in the market**, the aggregation of these impacts is still contentious, in that some authors suggest environmental discount rates, others apply monetary values and traditional discount rates, while others opt for simple aggregation, even though the impacts may extend over a long period of time. We suggest maintaining the original units and not discounting these non-market goods. Therefore, since there is no "well-known time preference", the *AI* should be obtained through a cumulative value to be converted from the original units –such as tonnes of CO_2 or number of accidents avoided– into the seven-point assessment scale –according to the criteria shown in Figure 2– in order to obtain the homogenised aggregated impacts (*HAI*).
- **For items that cannot be quantified**; similarly, the *AI* of qualitative impacts has no discounting technique. Decision-makers should be encouraged to aggregate by averaging the scores (points allocated according to Task 1.B) over different time periods. The final score allocated to each alternative (i.e. the *HAI*) is derived from the comparison of the *AI* of each alternative with the average *AI* of the project alternatives. Consequently, the seven-point assessment scale can be interpreted as shown in Figure 2.

Points to assign (HAI)		1 point	2 points	3 points	4 points	5 points	6 points	7 points
Description		If the obtained **AI** of the alternative is **highly worse** than the average of the alternatives	If the obtained *AI* of the alternative is **moderately worse** than the average of the alternatives	If the obtained *AI* of the alternative is **moderately worse** than the average of the alternatives	If the obtained *AI* of the alternative is **moderately worse** than the average of the alternatives	If the obtained *AI* of the alternative is **moderately worse** than the average of the alternatives	If the obtained *AI* of the alternative is **moderately worse** than the average of the alternatives	If the obtained *AI* of the alternative is **moderately worse** than the average of the alternatives
Numerical Interpretation (threshold)	**For a "Less is better" criterion**	AI>1.45*	1.30*<AI≤ 1.45*	1.15*<AI≤ 1.3*	0.85*≤ AI≤ 1.15*	0.7*≤ AI≤ 0.85*	0.55*≤ AI<0.7*	AI<0.55*
	For a " More is better" criterion	AI<0.55*	0.55*≤ AI<0.7*	0.7*≤ AI<0.85*	0.85*≤ AI≤ 1.15*	1.15*<AI≤ 1.3*	1.30*<AI≤ 1.45*	AI>1.45*

*times the average

Figure 2–Seven-point assessment scale for obtaining HAI
Source: Authors' own elaboration

4.2. Step 2: Assigning weighting coefficients to the sustainability criteria

Step 2 is aimed at determining the weights for *HAI* obtained from Step 1. We strongly recommend using analytical and rigorous methodologies for comparing all trade-offs among economic, environmental, and social aspects. Since so far there are no standardised methods for evaluating the trade-offs in a transparent and precise way, we propose to use a composite weighting model that allows the incorporation of consensus-based comparative judgments and preferences, along with the geographical and social context of the project. Essentially, it means that decision-makers should considering separately the sensitivity of the criteria in the geographical context where the project is situated, and the trade-offs among different criteria from expert's judgments and preferences.

In this respect, the weighting approach adopted in this discussion paper represents an appropriate method for effectively assisting decision makers in determining the criteria weightings for infrastructure project appraisal. A detailed description of composite weighting model we recommend is beyond the scope of this discussion paper, and the reader is referred to Bueno and Vassallo (2015).

4.3. Step 3: Sustainability evaluation of project alternatives

The purpose of this step is to establish a procedure for assessing infrastructure projects according to their sustainability performance. The idea is to compare alternatives to help select the optimal design in terms of sustainability.

4.3.1. Task 3.A Multi-criteria evaluation of project alternatives

Since at this stage of the methodology all economic, environmental and social items are expressed through homogenised aggregated impacts (*HAI*) on a seven-point assessment scale, a sustainability evaluation must be done to obtain the ranking order of alternatives.

We suggest a weighted sum method, as the most widely used approach for this type of analysis. The global sustainability evaluation of alternative *a* is calculated as shown in equation (1). The resulting score for each alternative can be used to rank and choose the alternative with the highest sustainability performance.

$$\text{Sustainability Performance}_{\text{a}} = \sum_{\text{i}=1}^{\text{n}} \text{SW}_{\text{i}} \; . \; \text{HAI}_{\text{i}} \qquad (1)$$

Where,
Sustainability Performance$_a$ = Sustainability performance of alternative *a*
SW_i = Sustainability weight for sustainability criterion *i*
HAI_i = Homogenised aggregated impact for sustainability criterion *i*
n = Total number of sustainability criteria in alternative *a*

The **best alternative would be the one with the highest score**. However, the analyst should explore the potential compensation of impacts by means of a descriptive analysis in addition to the process above, by comparing each evaluation criterion across the alternatives.

After decomposing the *sustainability performance*, these results are presented to the decision-makers together with the global evaluation. Finally, the decision-makers can prioritise infrastructure alternatives on a sustainable basis. The effective incorporation of all sustainability drivers in the decision-making process is thus assured.

5. Applications and Conclusions

Although the concept of sustainability has assumed increasing importance, the question of how to incorporate sustainable concepts into the decision-making process remains unresolved. Planners and designers often strive to apply sustainability in the decision-making process, despite the current lack of a standardised or commonly accepted methodology for assessing the sustainability of infrastructure projects such as roads and railway infrastructure, especially in the appraisal process.

Although there are numerous sustainability tools available, none of them addresses all aspects of sustainability as a whole. While there are positive characteristics associated with each one, some practical issues remain unsolved. On the basis of the gaps identified in the literature, we identified a set of essential requirements to assess the sustainability of infrastructures. In this context, this Discussion Paper shares ground with the Smart Transportation Alliance's (STA) stand towards the deployment of Sustainable and Smart Transportation Infrastructures.

An "ideal tool" should be able to integrate in a single framework the widest possible range of impacts – economic, environmental, social and distributional– and take a life-cycle perspective. It should also take a rigorous approach to analysing the balance between "triple bottom line" aspects, and include the context-sensitive nature of sustainability.

This Discussion Paper describes a new methodological approach formulated to tackle previously identified and recurrent methodological issues in the sustainability assessment of available appraisal methods and techniques. The methodology provides a practical approach that considers all aspects of sustainability by combining cost-benefit analysis and multi-criteria decision analysis.

To validate the approach discussed in this paper, it is necessary to apply it to real projects. Despite we have a long way to go before sustainability assessment is widely and appropriately practiced, we have made a beginning by developing: (i) a complete review of the corresponding literature review, (ii) a novel methodological approach to accurately appraise the sustainability of infrastructure projects; and (iii) a new methodology to set the weights of the sustainability criteria used in the MCDA in order to reduce subjectivity and imprecision.

In particular, we are able to contribute to the general understanding of this field by continuing exploring future research areas on the basis of our know-how. We also could take advantage of our experience and previous results (http://www.starebeiupm.transyt-projects.com/).

Further research areas include: (i) continuous improvement and enhancement of existing tools and techniques, (ii) more research about the combination of these tools for the sustainability assessment of projects in order to reinforce their strengths and address their weaknesses, and (iii) greater sharing of knowledge regarding the environmental and social impacts of roads -including the quantification of the trade-offs, the inter-temporal aggregation of effects, and the treatment of future uncertainties.

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