Tesis Doctoral / PhD Thesis

DESARROLLO Y APLICACIÓN DE UN NUEVO SISTEMA DE RATING PARA LA EVALUACIÓN DE LA SOSTENIBILIDAD DE LOS PROYECTOS DE INFRAESTRUCTURAS EN PAÍSES SUBDESARROLLADOS (SIRSDEC)

DEVELOPMENT AND APPLICATION OF A NEW SUSTAINABLE INFRASTRUCTURE RATING SYSTEM FOR DEVELOPING COUNTRIES (SIRSDEC)

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“The word impossible is not in my dictionary”

Napoleón Bonaparte

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RESUMEN

La mejora de las infraestructuras en países subdesarrollados se ha vuelto una prioridad para las economías más avanzadas, ya que representan la principal vía para acelerar el balance entre los aspectos económicos, ambientales y sociales que constituyen el desarrollo sostenible en estos países. Bajo esta premisa, la tesis tiene como objeto el desarrollo y aplicación de un nuevo sistema de rating para la evaluación de la sostenibilidad de los proyectos de infraestructuras en países subdesarrollados que se denominará SIRSDEC (acrónimo en inglés de Sustainable Infrastructure Rating System for Developing Countries).

La evaluación de los tres sistemas existentes de rating de la sostenibilidad de los proyectos de infraestructuras en países desarrollados, Envision de USA, Civil Engineering Environmental Quality (CEEQUAL) de UK e Infrastructure Sustainability (IS) Rating Tool de Australia, confirmó que sus indicadores están orientados fundamentalmente a cuestiones medioambientales en detrimento de las sociales y económicas, cuya importancia es mayor en los países más pobres. La conclusión principal de este análisis determinó la necesidad de desarrollar un nuevo sistema contextualizado a los países subdesarrollados en el que los temas sociales, económicos y medioambientales fueran valorados equitativamente. Asimismo, se consideró que los principios de la Agenda 21 y los objetivos de desarrollo definidos por las Naciones Unidas también debían ser contemplados.

A continuación, se estableció la metodología a seguir para el desarrollo del nuevo sistema, incluyendo la definición de un árbol de decisión cuyos elementos considerasen equitativamente los tres pilares de la sostenibilidad y los principios de la Agenda 21. Un cuestionario on-line distribuido entre diversos expertos internacionales en la evaluación de la sostenibilidad permitió utilizar las respuestas recibidas relativas a la comparación de pares de los elementos de SIRSDEC para el cálculo de sus factores de ponderación utilizando el método de análisis multi-criterio para la toma de decisiones Analytic Hierarchy Process (AHP). El tratamiento de las inconsistencias encontradas en algunas respuestas del cuestionario se llevó a cabo a través de la aplicación de un algoritmo no lineal llamado Generalized Reduced Gradient (GRG). El Modelo Integrado de Valor para Evaluaciones de Sostenibilidad (MIVES) complementó el método AHP mediante la caracterización pormenorizada de las funciones de valor de los indicadores utilizados por el nuevo sistema.

El proyecto para la construcción de una balsa de lixiviados en una mina peruana fue utilizado como caso de estudio para la aplicación de SIRSDEC, lo que sirvió para validar la metodología desarrollada en la investigación. Este ejemplo también enfatizó la necesidad de cumplir los requisitos obligatorios establecidos por el sistema para superar la evaluación del proyecto. Finalmente, el nuevo sistema contribuyó a identificar acciones complementarias que permitirían mejorar la aceptación del proyecto inicialmente rechazado por la comunidad de la zona.

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1. INTRODUCCIÓN

1.1. Marco de la tesis

1.1.1. Antecedentes

El informe final de la Comisión Brundtland de 1987 definió el concepto de Desarrollo Sostenible como "el desarrollo que satisface las necesidades del presente sin comprometer las necesidades de las generaciones futuras" (WCED, 1987). La Sostenibilidad está basada fundamentalmente en el equilibrio de los 3 pilares esenciales de la sostenibilidad (Triple Bottom Line o TBL en inglés): social, económico y medioambiental (Elkington, 1997).

Entre los 27 principios proclamados en la declaración final de la Conferencia de Desarrollo Sostenible celebrada en Rio de Janeiro en junio de 1992 destacó el tercero, que afirmaba que "el derecho al desarrollo debe de satisfacer las necesidades en materia de medioambiente y de desarrollo de los países para las presentes y futuras generaciones" (UN, 1992). Este principio ratificaba el papel transcendental que la sostenibilidad juega en la sociedad actual, así como la imperiosa necesidad existente para el desarrollo de herramientas eficaces que permitan evaluar de una manera equitativa las cuestiones sociales, económicas y medioambientales de los proyectos de construcción.

Se define sistema de rating de la sostenibilidad como el conjunto de buenas prácticas asociadas a una serie de indicadores (Hart, 2006), que evalúan la sostenibilidad de los proyectos mediante la asignación de puntos de acuerdo al grado de cumplimiento de los objetivos establecidos por dichos indicadores, que pueden incluir una gama de variables muy diversas, tales como: proporción de elementos contaminantes / CO_2 emitidos a la atmósfera, porcentaje de uso de energías renovables y materiales reciclables, consumo de energía, conservación de los ecosistemas, etc.

En las últimas décadas, diversos sistemas de rating de la sostenibilidad fueron desarrollados para el sector de la edificación en todo el mundo (Häkkinen, 2007), como consecuencia del rápido crecimiento económico y de los daños medioambientales provocados por el sector de la construcción. Sin embargo, hasta hace unos pocos años, los proyectos de infraestructuras no han atraído la atención ni de los investigadores ni de los principales agentes involucrados en el sector para desarrollar sus propios sistemas de rating. Aunque la creación y aplicación de estas herramientas están fundamentalmente orientadas a los países más desarrollados, las crecientes preocupaciones medioambientales de la sociedad actual plantean la necesidad de utilizar estos nuevos sistemas en los países menos desarrollados.

Para determinar su posible implementación en estas áreas geográficas, la presente investigación analizó desde el triple punto de vista de la sostenibilidad (social, económico y medioambiental), los tres sistemas de rating de proyectos de infraestructuras que existen actualmente en el mundo:

Envision de los Estados Unidos de América (ISI, 2012), el Civil Engineering Environmental Quality (CEEQUAL) assessment del Reino Unido (BRE Group, 2015) y el Infrastructure Sustainability (IS) rating tool de Australia (ISCA, 2012). El análisis consideró todas las fases de la vida del proyecto con el propósito de establecer su aplicabilidad en otros contextos o, en su caso, la necesidad de desarrollar un sistema ad-hoc de rating para los países subdesarrollados.

La mejora de las infraestructuras en los países subdesarrollados se ha convertido en una prioridad para las naciones más ricas, que actúan a través de diversas organizaciones internacionales de desarrollo para llevar a cabo sus proyectos en el mundo entero. Las infraestructuras son un elemento dinamizador esencial (UNCTAD, 2014) que permite el desarrollo del proceso necesario para poder equilibrar la importancia de los 3 pilares de la sostenibilidad en estos países. Dado que los actuales sistemas de rating no son apropiados para la consecución de este objetivo (Diaz-Sarachaga et al., 2016), se determinó la necesidad de crear un nuevo sistema ad-hoc de rating de la sostenibilidad de los proyectos de infraestructura para los países subdesarrollados que será denominado SIRSDEC (acrónimo en inglés de Sustainable Infrastructure Rating System for Developing Countries).

El nuevo sistema se estructuró a través de un árbol de decisión que incluía 3 niveles jerarquizados: requerimientos, criterios e indicadores, para evaluar los proyectos de infraestructura de acuerdo a los principios de la sostenibilidad. La metodología que desarrolla SIRSDEC combina la acción de dos métodos multicriterio de toma de decisión (MCDM) como son el Analytical Hierarchy Process (AHP) (Saaty, 1990) y el Modelo Integrado de Valor para Evaluaciones de Sostenibilidad (MIVES) (ETCG, 2015). Mientras AHP se utilizó para la obtención de los pesos de los diferentes elementos del árbol de decisión del sistema a partir de las opiniones recibidas de un grupo de expertos internacionales a quienes se les había distribuido un cuestionario en el que se realizaba la comparación por pares de dichos elementos, MIVES se empleó para determinar las funciones de valor de los indicadores del sistema (Jato-Espino et al., 2014).

La aplicación de la metodología para el desarrollo de SIRSDEC se inició con la distribución de un cuestionario on-line entre diversos expertos internacionales, previamente seleccionados dentro del campo del desarrollo sostenible, que pertenecen a diversos sectores como la academia, la consultoría, las organizaciones internacionales para el desarrollo y la empresa privada. El objetivo principal del cuestionario era comparar la importancia relativa entre los diferentes elementos del árbol de decisión de SIRSDEC, para posteriormente obtener mediante la metodología del AHP sus factores de ponderación. Tras realizar un análisis de la consistencia de las opiniones recibidas, se constató que era preciso aplicar un algoritmo no lineal basado en el denominado Generalized Reduced Gradient (GRG) (Abadie et al., 1968) para obligar a que todas las comparaciones fueran consistentes. Una vez calculados los factores de ponderación de los elementos del árbol de decisión, se definieron las funciones de valor de los indicadores de acuerdo a la metodología de MIVES.

Para la validación de SIRSDEC, se tomó como análisis de caso el proyecto de construcción de una balsa de lixiviados que forma parte de un proyecto minero situado en Perú, cuya problemática social obligó a la empresa minera a paralizar su inicio hasta conseguir una mayor aceptación por parte de los habitantes de la zona. Si bien el Ministerio peruano de Energía y Minas concedió la aprobación del Estudio de Impacto Ambiental (EIA) del proyecto, SIRSDEC identificó varios aspectos que no fueron suficientemente considerados inicialmente por la minera y que podían fomentar la participación y la aceptación de los miembros de la comunidad que se oponen frontalmente al proyecto.

1.1.2. Disposiciones regulativas que regulan la tesis

La presente tesis se rige según las disposiciones relativas a los estudios de Doctorado y la obtención del Título de Doctor en la Universidad de Cantabria, que se enumeran a continuación:

- La ley Orgánica 6/2001, de 21 de diciembre, de Universidades y sus normas de desarrollo.

- El Real Decreto 99/2011, de 28 de enero, por el que se regulan las enseñanzas oficiales de Doctorado.

- Los Estatutos de la Universidad de Cantabria, aprobados por Decreto 26/2012, de 10 de mayo (Boletín Oficial de Cantabria de 17 de mayo de 2012).

- Normativa de Gestión Académica de los Estudios de Doctorado aprobada en el Consejo de Gobierno de la Universidad de Cantabria con fecha de 9 de marzo de 2016.

- Normativa para la elaboración de tesis como compendio de artículos dentro del Programa de Doctorado en Ingeniería Civil (PDIC) de la Escuela de Doctorado de la Universidad de Cantabria (EDUC), aprobada por la Comisión Académica del Programa de Doctorado en Ingeniería Civil (CAPDIC) el 20 de mayo de 2016 y ratificada posteriormente por el Comité de Dirección de la Escuela de Doctorado el 14 de junio de 2016.

Este documento sigue las directrices de la redacción de tesis doctoral como compendio de artículos previamente publicados en revistas indexadas en el Journal Citation Reports (JCR) del “Institute for Scientific Information (ISI) - Web of Knowledge (WoK)” con mención de “Doctorado

Internacional". Los artículos publicados son los siguientes:

- Artículo 1: Evaluation of existing sustainable infrastructure rating systems for their application in developing countries.
- Artículo 2: Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC).
- Artículo 3: Application of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) to a case study.

1.2. Relación entre los artículos constitutivos de la tesis

Este documento anexa tres artículos relacionados con la línea de investigación que fundamentan la redacción de esta tesis doctoral: desde el análisis y la evaluación de los sistemas de rating existentes en la actualidad, cuya conclusión determina la necesidad de crear un nuevo sistema ad-hoc orientado a los países subdesarrollados, hasta el desarrollo y aplicación a un caso de estudio de la metodología necesaria para la creación de una nueva herramienta para la evaluación de la sostenibilidad de los proyectos de infraestructuras en estos países.

La primera publicación (DOI: 10.1016/j.ecolind.2016.07.033) recoge el análisis pormenorizado de los tres sistemas existentes para la evaluación de la sostenibilidad de los proyectos de infraestructuras: Envision de los Estados Unidos de América, Civil Engineering Environmental Quality (CEEQUAL) del Reino Unido e Infrastructure Sustainability (IS) Rating Tool de Australia. El artículo muestra que las características de los tres sistemas están esencialmente orientadas a los proyectos que se localizan en los países más desarrollados donde fueron creados. Asimismo, las cuestiones medioambientales son mayoritariamente evaluadas por estas herramientas, en detrimento de las de carácter social y económico, cuya relevancia es mucho mayor en los países más pobres. La principal conclusión de este artículo es la necesidad de desarrollar un nuevo sistema adaptado al singular contexto de los países subdesarrollados en el que se consideren de una manera equitativa los 3 pilares de la sostenibilidad: social, económico y medioambiental. La incorporación en el sistema de cuestiones relativas a la gestión y el buen gobierno de los proyectos es otra cuestión sugerida por el artículo.

En la segunda publicación (DOI: 10.1016/j.envsci.2016.12.010) se detalla pormenorizadamente la metodología establecida para el desarrollo de una nueva herramienta de evaluación de la sostenibilidad de los proyectos de infraestructuras en los países subdesarrollados. Inicialmente se determina el árbol de decisión del sistema, cuyos indicadores también contemplan los principios de la Declaración de Río sobre Medioambiente y Desarrollo, los Millennium Development Goals (MDGs) y los Sustainable Development Goals (SDGs). El método Analytic

Hierarchy Process (AHP) fue seleccionado como una de las metodologías existentes en el campo del análisis multi-criterio para la toma de decisiones (MCDM) para comparar por pares los requerimientos y criterios incluidos en SIRSDEC según los resultados de las respuestas recibidas del cuestionario on-line distribuido entre expertos internacionales, que permitirán el cálculo de los factores de ponderación. El Modelo Integrado de Valor para Evaluaciones de Sostenibilidad (MIVES) fue también considerado como complemento del método AHP para la caracterización de las funciones de valor de los indicadores utilizados por el nuevo sistema.

La aplicación de la metodología establecida para el desarrollo de SIRSDEC es tratada en la tercera publicación (DOI: 10.1016/j.envsci.2016.12.011). En este artículo se analiza la consistencia de los datos recibidos tomando como punto de partida las respuestas obtenidas del cuestionario on-line enviado a diversos expertos internacionales en el área de la sostenibilidad, donde se recogen los resultados de la comparación por pares de los requerimientos y criterios incluidos en el árbol de decisión de SIRSDEC. El tratamiento de las inconsistencias encontradas en las respuestas recibidas del cuestionario se realiza mediante la aplicación de un algoritmo no lineal basado en el llamado Generalized Reduced Gradient (GRG), que facilita la posterior agregación de los datos ya consistentes y la obtención de los factores de ponderación de los diferentes elementos que integran el sistema. La construcción de una balsa de lixiviados en una mina en el Perú fue considerada como el caso de estudio para la aplicación de SIRSDEC, con el objetivo de validar la metodología desarrollada en la investigación.

1.3. Estructura del documento

La tesis se compone de 4 capítulos que son: Introducción; Artículos publicados; Metodología, resultados y discusión; Conclusiones y futuras líneas de investigación, más un Extended abstract en lengua inglesa. Un listado de todas las referencias bibliográficas utilizadas en la investigación se anexa al final del documento, al igual que la bibliografía específica mencionada en la elaboración de cada artículo publicado.

En el primer capítulo se realiza una breve introducción del marco general en el que se desarrolla la investigación incluyendo los antecedentes de la misma, donde destaca la definición del concepto de sostenibilidad, así como de los tres pilares esenciales en los que se apoya. También se incluyen las disposiciones normativas en vigor que se han seguido para la elaboración de la investigación, una descripción de la estructura de la tesis y los objetivos e hipótesis considerados en el trabajo.

En el capítulo segundo se anexan los tres artículos publicados relacionados con la presente investigación, así como la información de las revistas indexadas en el Journal Citation Reports (JCR) del “Institute for Scientific Information (ISI) - Web of Knowledge (WoK)”.

En la primera sección del capítulo 3, se destaca el papel esencial que las infraestructuras juegan en el desarrollo sostenible de los países subdesarrollados, para luego reseñar las herramientas creadas para la evaluación de la sostenibilidad de los proyectos de infraestructura de transporte en las naciones más ricas. La descripción de los 3 sistemas de rating de infraestructuras existentes en la actualidad: Civil Engineering Environmental Quality (CEEQUAL), Infrastructure Sustainability (IS) Rating Tool y Envision permite realizar su evaluación para determinar su idoneidad para su utilización en los países subdesarrollados. El capítulo incluye también la descripción detallada de la metodología establecida para el desarrollo de SIRSDEC y su validación mediante su aplicación al proyecto de construcción de una balsa de lixiviados en una mina peruana.

Las conclusiones generales y particulares, así como las futuras líneas de investigación que se sugieren tras la conclusión de este trabajo están incluidas en el capítulo 4. Un Extended abstract resume la tesis completa en lengua inglesa.

1.4. Objetivos e hipótesis de partida

1.4.1. Objetivo general

Los diversos y múltiples viajes realizados por el Doctorando a través de diversos países subdesarrollados del mundo, algunos de ellos en América del Sur, África y Asia, sirvió para constatar la existencia de un buen número de proyectos internacionales de cooperación y desarrollo ya terminados cuya utilidad para los habitantes de las áreas dónde se localizaban era escasa o nula. Las charlas mantenidas con los pobladores de la zona sirvieron para ratificar que, en la mayoría de los casos, los proyectos habían sido realizados sin haber consultado a la población de los alrededores sobre su utilidad y/o necesidad. En otros casos, los proyectos ejecutados se correspondían a fases intermedias de proyectos más grandes, que al no ser completados en su totalidad impedía alcanzar los objetivos generales establecidos en el mismo. No en vano, la falta de mantenimiento de algunos proyectos construidos redujo notablemente su vida útil hasta hacerlos completamente inútiles.

En general, los proyectos antes mencionados se enmarcaban principalmente dentro del área de las comunicaciones terrestres, obras de abastecimiento de agua y saneamiento, suministro eléctrico, obras de acondicionamiento de cauces fluviales, etc. De ahí la razón por la que el Doctorando mostrase inquietud por comprobar si existía algún sistema que evaluara, previamente a la fase constructiva, la aportación de estos proyectos al desarrollo sostenible de las comunidades a las que iban dirigidos. La carencia de una herramienta eficiente que permitiera evaluar de una manera cuantitativa la sostenibilidad de los proyectos de infraestructuras en los países subdesarrollados hizo que se estableciera como objetivo general de esta investigación el desarrollo de un nuevo sistema de rating específico para estas áreas geográficas que contribuyese a su eficiente desarrollo sostenible y que sirviese de ayuda a las innumerables organizaciones y agencias internacionales de desarrollo que actúan en todo el mundo.

1.4.2. Objetivos específicos

Para alcanzar el objetivo principal antes descrito, se precisa el cumplimiento de varios objetivos específicos que forman parte de la metodología utilizada en la investigación:

- Análisis y evaluación de los sistemas existentes en la actualidad relativos al rating de la sostenibilidad de los proyectos de infraestructura, para determinar su idoneidad en su aplicación en los países subdesarrollados.

- Elaboración del árbol de decisión del nuevo sistema en el que se incluyeran aquellos criterios e indicadores necesarios que permitan la evaluación de la sostenibilidad de los proyectos desde la equitativa consideración de los tres aspectos de la sostenibilidad.

- Validación de SIRSDEC mediante su aplicación a un caso de estudio relativo a un proyecto minero situado en la región de Arequipa (Perú).

1.4.3. Hipótesis de partida

Las hipótesis de partida que se han establecido para el desarrollo de la presente tesis doctoral son las siguientes:

- El sistema propuesto (SIRSDEC) no precisa recalcular los factores de ponderación para cada país subdesarrollado en el que se pretenda aplicar, puesto que se trata de una herramienta genérica que puede ser implementada en todos estos países sin realizar modificación alguna.

- Debido a la creciente relevancia que tiene en la actualidad, se incluyó también la Gestión como un requerimiento más del sistema, que complementa a los tres pilares de la sostenibilidad: sociedad, medioambiente y economía.

- Como consecuencia de la falta de adecuada información de las existentes métricas de seguimiento, la caracterización de las funciones de valor de los indicadores del nuevo sistema se realizó mediante el uso de los datos proporcionados por las instituciones y organizaciones internacionales que más se les asemejan, con la finalidad de darle mayor consistencia al sistema.

2. ARTÍCULOS PUBLICADOS

2.1. Artículo 1: Evaluation of existing sustainable infrastructure rating systems for their application in developing countries

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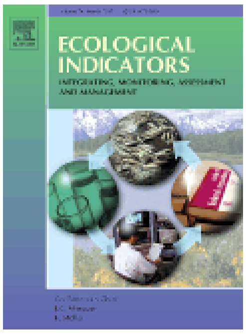
Año: 2016
Revista: Ecological Indicators
Volumen: 71
Páginas: 491-502
DOI: 10.1016/j.ecolind.2016.07.033



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Rank in Category: ECOLOGICAL INDICATORS

Journal Ranking

For **2015**, the journal **ECOLOGICAL INDICATORS** has an Impact Factor of **3.190**.

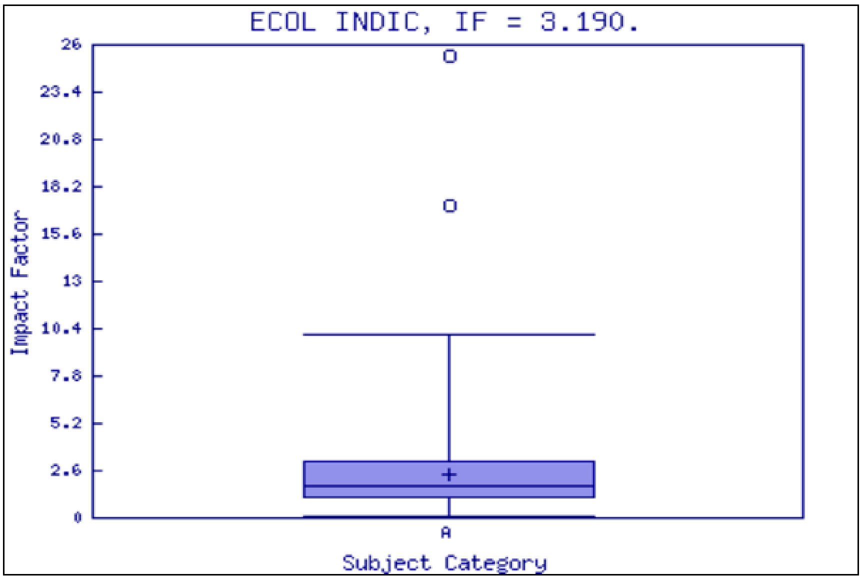
This table shows the ranking of this journal in its subject categories based on Impact Factor.

Category Name	Total Journals in Category	Journal Rank in Category	Quartile in Category
ENVIRONMENTAL SCIENCES	225	52	Q1

Category Box Plot

For **2015**, the journal **ECOLOGICAL INDICATORS** has an Impact Factor of **3.190**.

This is a box plot of the subject category or categories to which the journal has been assigned. It provides information about the distribution of journals based on Impact Factor values. It shows median, 25th and 75th percentiles, and the extreme values of the distribution.



Key

A - ENVIRONMENTAL SCIENCES

Diaz-Sarachaga et al. (2016) Ecological Indicators 71, 491-502

Evaluation of existing Sustainable Infrastructure Rating Systems for their application in developing countries

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Abstract

Several sustainable building rating systems were created worldwide during the last decades due to economic growth and the significance of environmental impact associated with the building industry. Similar infrastructure rating tools have started to be developed and implemented, being highly necessary to promote its development. Even though the existing sustainable infrastructure rating systems are focused on advanced economies, growing environmental concerns are increasing the need for new systems in the Developing World. This research analyses some of the mainstream infrastructure rating frameworks such as Envision (USA), Civil Engineering Environmental Quality (CEEQUAL) assessment (UK) and Infrastructure Sustainability (IS) Rating Tool (Australia) from the perspective of the Triple Bottom Line (economy, environment and society), in order to determine the effectiveness of their application in the context of the least developed countries. The analysis revealed that the three tools are biased towards the environmental dimension and are mainly oriented to developed countries. Consequently, the foundations on which these systems are based need to be further developed and enhanced to be of real relevance in poorer nations by balancing the weight of sustainable pillars, incorporating effective management guidelines and development goals set by United Nations declarations, and considering impacts beyond the single project framework.

Keywords

Triple Bottom Line; Infrastructure rating frameworks; Rating Systems; Sustainable Infrastructure; Developing countries.

1. Introduction

The Brundtland Commission Report defined Sustainable Development in 1987 as "development to meet the needs of the present without compromising the ability of future generations to meet their own needs" [1]. Sustainability is based on the balance of three key aspects named the Triple Bottom Line (TBL) [2]: Economics,

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Environment and Social responsibility. Economics seeks to fulfil the main goal of producing a long-term and positive economic impact, whilst Environment encourages organisations to benefit the planet as much as possible through sustainable practices, including the consideration of negative factors to the environment. Social responsibility aims to improve the lives of those with whom the projects interact. The well-being of users, workers, community members and other stakeholder interests should be considered as interdependent variables in Sustainability assessments [3]. As a consequence of the rising energy consumption and greenhouse gas emissions in the last century, which accounts for 30 and 40% of the total quantities for the building sector in developed countries [4], climate change has accelerated the development of international declarations and policies to preserve the environment and foster the use of assessment systems aimed at improving Sustainability.

Sustainability assessments have been defined as the processes of identifying, predicting and evaluating the potential impact of different initiatives and alternatives on the Triple Bottom Line (economy, environment and society) [5]. Furthermore, rating systems provide an effective framework for assessing environmental performance and integrating sustainable development into building and construction processes. They can be used as design tools by setting sustainable design priorities and goals, developing appropriate sustainable design strategies and determining performance measures to guide sustainable designs and decision making-processes [6, 7]. Amongst them, rating tools for buildings emerged more than two decades ago [8] in the UK and US before spreading worldwide. The most relevant are LEED (Leadership in Energy and Environmental Design) in the US [9], CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) in Japan [10] and BREEAM (Building Research Establishment Environmental Assessment Method) in the UK [11]. The building industry boosted the utilisation of these systems primarily for commercial buildings in the US due to the greater quantity of resources required in relation to the whole sector: 72% of electricity consumption, 39% of energy use, 38% of carbon dioxide (CO_2) emissions [12], 40% of raw materials use, 30% of waste output and 14% of potable water consumption.

On the other hand, the use of assessment tools focused on major infrastructures has not been very common so far. Several score ratings have been developed by various public and private institutions to assess highways and roads, but only three of them (Envision in the USA [13], CEEQUAL in the UK [14] and the Infrastructure Sustainability (IS) Rating scheme in Australia [15]) are able to evaluate all types and sizes of civil infrastructures, including ports, airports, highways, dams, bridges, wastewater treatment facilities, tunnels and railways.

This research aims to compare and assess existing sustainable infrastructure rating tools to determine whether any of them can be effectively implemented in developing countries. The effect of urban development is examined under the perspective of its impact in the social and economic transformation of countries. Although green community frameworks are widely used to monitor the sustainable development of cities, infrastructure systems can provide a complementary tool to promote the balanced consideration of all TBL principles. Since most megacities are located in the least developed world, the implementation of infrastructure rating systems in these countries is a key factor to improve their sustainable development over the next decades. The article continues with a description and comparison of the three main existing infrastructure rating systems in terms of their compliance with sustainability, in order to identify the differences between developed and developing countries that need to be considered for their application in poorer economies. As a result, some principles and goals emanating from several United Nations Declarations, which seek to mobilize efforts through sustainable development worldwide, are suggested for incorporation into sustainable infrastructure frameworks.

2. The effect of urban development on sustainability assessment systems

The world is predominantly urban. 10 % of the world's population inhabited urban areas at the beginning of the 20th century. By 2012, 50 % of the global population lived in urban areas, a percentage which is expected to rise to 70 per cent by 2050 [16]. Today, 3.6 billion urban dwellers are distributed unevenly among urban settlements of different sizes and more than 7 of every 10 urban residents in the world are found in developing countries. The level of urbanisation is expected to increase in all major areas of the developing world over the coming decades, with Africa and Asia urbanising more rapidly than the remaining continents [17]. The importance of urban areas is also confirmed by the diffusion of megacities of more than 20 million people, which are gaining ground mostly in the developing countries of Asia, Latin America and Africa [18]. Consequently, urbanisation will become a prominent trend over the next decades that should be meticulously considered in the assessment of sustainable development, in particular for poorer economies.

Urbanisation has the power to transform the social and economic fabric of countries. Cities are responsible for the biggest production and consumption of resources worldwide and are the main driver of economic growth and development, with about three-quarters of global economic activity coming from urban settlements. Urban population growth stimulates the urban share of global gross domestic product (GDP) and investment. The opportunity for development in countries can only be approached through sustainable urbanisation [19], which emphasises the economic and social importance of urban areas and also their poor environmental sustainability.

Urban projects promote the development of urban infrastructure through the encompassment of a very broad group of activities related to urban planning, urban design and architecture, transport studies, economics, ecology, geography, sociology, water management and engineering, waste management, energy engineering and economics, landscape planning and building architecture. Urban policy design is one of the most challenging problems for decision-makers because rapid urbanisation has increased the need for better governance of towns and cities. There are a number of different policy areas that need attention, including planning, housing and slum upgrading, land, energy and climate change, reconstruction and resilience, as well as infrastructure (transportation, water and sanitation), all of which should be added to the complexity of modern-day policy decision-making [20].

Sustainable urban development has become a powerful framework for developing solutions that improve the quality of life at a local level and can also be an important component to respond to the broader global environmental crises [21]. Urban planners have taken up the challenge of designing urban areas across the globe in ways that leave a smaller ecological footprint. Cultural values, education and citizen and community

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participation are all crucial aspects to consider when defining, measuring or implementing sustainable urban development policies and practices.

The difficulties in assessing sustainability in the urban environment are greater because of the lack of boundaries between the entities evaluated. Sustainability assessments at community and city scales are much more than the summation of individual green elements, because the scaling-up effect results in complex interactions that significantly alter the results obtained at building scale [22]. New frameworks for communities have been developed within the past years as an evolution of the sustainable building rating systems mentioned in the previous section in order to avoid the building scale factor. The most well-known systems are BREEAM Communities (Com) [23], CASBEE for Urban Development (UD) [24] and LEED for Neighbourhood Development (ND) [25].

BREEAM Com consists of forty individual assessment issues spanning five technical categories, plus a sixth category called "Innovation" for new and innovative technologies and practices. Each issue addresses a specific large-scale sustainability impact and is grouped within one of the five main technical categories: governance, land use and ecology, resources and energy, social and economic wellbeing and, transport and movement. Governance ensures the community involvement and leadership in the project, whilst land use and ecology improve biodiversity. The reduction of carbon emissions and use of natural resources is targeted by the resources and energy category, whereas healthy economy, socially cohesive community and the minimisation of impact on the health and wellbeing of inhabitants are goals sought by the social and economic wellbeing categories. Finally, the transport and movement category aims to create a safe and efficient transportation system for people and vehicles.

CASBEE UD considers two main kinds of criteria: performance and environmental loads. Performance criteria include factors such as the natural environment, quality of services and the contribution to the local community, whereas the environmental loads cover aspects related to impact on the local environment, social infrastructure and management of the local environment.

The LEED ND system rates neighbourhood development with at least two habitable buildings and an area no larger than 1,500 acres according to five categories: smart location and linkage (SLL), neighbourhood pattern and design (NPD), green infrastructure and buildings (GIB), innovation and design process (IDP) and regional priority credit (RPC). SLL encourages the development of existing communities and public transit infrastructure, fostering the improvement and redevelopment of existing urban spaces and limiting the expansion of the footprint. The conservation of land, the promotion of liveability, walkability and transportation efficiency and the reduction of public health risks by encouraging daily physical activities like walking and bicycling are assessed by NPF. GIB stimulates the design, construction and retrofit of buildings that use green building practices. IDP awards exemplary and innovative performance above and beyond the existing credits in the rating system, as well as the value of including an accredited professional in the design team, whilst RPC encourages projects to focus on earning credits related to the significance of the project to the local environment.

Another concept related to urban development that has taken hold in recent years is sustainable urban infrastructure [26]. This concept refers to infrastructure that facilitates the progress of a region towards the goal of sustainable living. Sustainable design can lead to the development of sustainable communities by ensuring that infrastructural knowledge provides improvements that do not deplete natural resources. Consequently, the transition toward and mass adoption of renewable resources feature heavily in sustainable infrastructure through public transport networks, the fostering of initiatives and programs for distributed generation and integrated energy demand management, high efficiency buildings, green buildings and sustainable habitats with energy-efficient landscaping, connected green spaces and wildlife corridors and low-impact development practices to protect water resources.

Community rating systems such as BREEAM Com, CASBEE UD and LEED ND align the principles of smart growth, new urban planning and green building into a set of standards for green design at the neighbourhood scale. These frameworks emphasize the key role of transportation efficiency in terms of infrastructure, which predominates over the utilities related to energy, IT and water and sanitation. The growing tendency in urban development, which currently focuses on environmental impact, is also starting to consider social and economic impact of expanding urban areas, setting aside liveability requirements in order to reinforce the role of the key sustainability principles. The least developed countries (LDCs) account for the greatest number of megacities in the world and will experience urbanization effects in the very short term over the next decades.

Envision, CEEQUAL and IS are complementary tools to community frameworks that provide effective stakeholder communication and engagement during the different life-cycle project stages, as well as the foundations for assessing sustainable community evolution. Furthermore, they encourage the implementation of project-based decision-making processes and management practices across the TBL to support the long-term interests of the community and provide a wider coverage of tools to stakeholders.

3. Overview of mainstream Sustainable Infrastructure scoring systems

The main features of the three mainstream Sustainable Infrastructure rating systems under analysis, namely CEEQUAL, Infrastructure Sustainability (IS) and Envision, are listed in Table 1. The next subsections detail the basis behind each of these scoring tools.

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Table 1. Summary of existing Sustainable Infrastructure rating tools

Characteristics	Civil Engineering Environment Quality (CEEQUAL) (Version 5)	Infrastructure Sustainability (IS) (Version 1.0)	Envision (Version 2.0 Stage 2)
Supporting Institution	CEEQUAL ltd	Infrastructure Sustainability Council of Australia (ISCA)	Institute for Sustainable Development (ISI)
Geographical Context	UK & Ireland / International	Australia & New Zealand	USA & Canada
Year of launching	2003	2012	2012
Manuals	CEEQUAL for Projects / CEEQUAL for Term Contracts	Infrastructure Sustainability (IS)	Envision
Categories	9	6	5
Sub-categories	48	15	60
Levels of Achievement	4 (Pass, Good, Very Good, Excellent)	3 (Commended, Excellent, Leading)	4 (Bronze, Silver, Gold, Platinum)
Awards	6 (CEEQUAL for Projects) and 2 (CEEQUAL for Term Contracts)	3 (Design, As Built, Operation)	1 (Planning and Design)
Verification Agents	Independent CEEQUAL-trained Verifiers	Independent ISCA-trained Verifiers	ISI independent third-party Verifiers

3.1. Civil Engineering Environmental Quality (CEEQUAL)

The Institution of Civil Engineers (ICE) led the development of CEEQUAL with financial support from the UK Government between 1999 and 2003. Relevant UK Government departments and agencies, civil engineering consultants, major contractors and professional and industry associations participated actively in the development of CEEQUAL. The tool was launched in September 2003 and became public in June 2004 after publishing Version 3 of the Assessment Manual for Projects. Since then, CEEQUAL has been updated until the latest Version 5.

CEEQUAL trained-assessors evaluate project/contract strategy and performance following a score scheme which includes a range of environmental and social issues arranged in nine sections and 48 sub-sections from the perspective of the three key stakeholders (Clients, Designers and Contractors) involved in the project (see Table 2). "Project Strategy" assesses the link between the project and sustainability, as well as its contribution to sustainable development. "Project Management" considers how sustainability issues are being incorporated into the overall project management. "People & Communities" includes the assessment related to people affected by projects, the potential effects on the local population and the important actions of consultation and engagement with project stakeholders. The "Land use & Landscape" category attempts to monitor the efficient use of land as a scarce resource. "The Historic Environment" comprises those buildings, structures and other features which have survived in the current landscape, townscape and seascape as evidence of environmental management over past centuries. "Ecology & Biodiversity" takes into account concerns about the damage to wildlife habitats and the species that occupy them. "Water environment" aims to protect fresh and marine water bodies. "Physical Resources - Use & Management" gives consideration to the responsible use of construction materials and how to deal with them at the end of their lifetime. Finally, "Transport" evaluates a wide range of effects such as land use changes, road accidents, air, noise and water pollution, as well as the consumption of resources. Four levels of achievement are considered in CEEQUAL: Pass (more than 25%), Good (more than 40%), Very Good (more than 60%) and Excellent (more than 75%).

CEEQUAL encompasses two different manuals: CEEQUAL for Projects and CEEQUAL for Term Contracts. CEEQUAL for Projects was specifically created for the assessment and rating of all types and scales of civil engineering, infrastructure, landscaping and public realm projects, including infrastructures associated with building developments. Depending on the location of the projects, the score is available in two editions: CEEQUAL for International Projects and CEEQUAL for UK & Ireland Projects. The re-assessment of CEEQUAL weights is always recommended to reflect the adequacy and relevance of the credits included in the system according to the priorities of other countries, wherein the environmental, social and economic concerns can differ significantly from those considered for the UK. In the case of developing countries, social and economic aspects take precedence over environmental concerns. Therefore, it is crucial to understand the level of human development in these countries, in order to appreciate their priorities and perceptions for infrastructure sustainability [27].

CEEQUAL for Projects has six types of Awards according to stakeholder involvement and the project stage considered in the application form. The Whole Project Award (WPA), jointly applied by or on behalf of the Client, Designer and Principal Contractor(s), is verified and awarded at the end of construction, whilst the Whole Project Award with an Interim Client & Design Award enables the project team to undertake an assessment during the design stage of WPA, which is superseded once the project and the WPA are completed. The Client & Design Award implies a joint application by the client and designer before the start of construction, whilst the Design Award is only for principal designer(s). Finally, the Design & Build Award exclusively involves the contractor and designer(s), whereas the Construction Award is only for principal contractor(s).

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Table 2. Score of Civil Engineering Environmental Quality (CEEQUAL) rating system (Version 5)

Credit		Concept	Score	%
1		**Project Strategy**	**625**	**12.46**
	1.1	Overall strategy for the project concept and design	500	9.97
	1.2	Overall strategy for construction	125	2.49
2		**Project Management**	**545**	**10.87**
	2.1	Basic Principles	100	1.99
	2.2	Sustainability management	160	3.19
	2.3	Contractual and procurement processes	116	2.31
	2.4	Delivering performance on environmental and social aspects	132	2.63
	2.5	Communicating sustainability performance	37	0.74
3		**People and Communities**	**530**	**10.57**
	3.1	Brief and design	66	1.32
	3.2	Consultation with stakeholders	27	0.54
	3.3	Effects on local population and planning of mitigation measures	44	0.88
	3.4	Implementation and monitoring during construction	148	2.95
	3.5	Continuing engagement with relevant local interest groups	74	1.48
	3.6	Effectiveness of the community engagement plan	69	1.38
	3.7	Human environment, aesthetics and employment	102	2.03
4		**Land use and landscape**	**1004**	**20.02**
	4.1	Basic principles on the use of land (above or below water)	233	4.65
	4.2	Contamination of land and beds of the sea, estuaries, rivers & lakes	242	4.82
	4.3	Flood risk	264	5.26
	4.4	Basic principles of landscapes issues	55	1.10
	4.5	Landscape-related legal requirements	85	1.69
	4.6	Implementation and management	83	1.65
	4.7	Completion and aftercare	42	0.84
5		**The historic environment**	**230**	**4.59**
	5.1	Baseline studies	23	0.46
	5.2	Legal requirements, planning guidance and consultation	17	0.34
	5.3	Conservation and enhancement	141	2.81
	5.4	Information Dissemination and Public Access	49	0.98
6		**Ecology and biodiversity**	**315**	**6.28**
	6.1	Basic Principles	61	1.22
	6.2	Legal requirements	76	1.52
	6.3	Conservation and enhancement of biodiversity	79	1.57
	6.4	Habitat creation measures	64	1.28
	6.5	Monitoring and maintenance	35	0.70
7		**The water environment**	**283**	**5.64**
	7.1	Basic principles	70	1.40
	7.2	Legal requirements	24	0.48
	7.3	Protection of the freshwater and marine environments	141	2.81
	7.4	Enhancement of the water environment	48	0.96
8		**Physical resources - use and management**	**1217**	**24.26**
	8.1	Basic principles	44	0.88
	8.2	Embodied impacts	112	2.23
	8.3	Design for resource efficiency	109	2.17
	8.4	Design for reduced energy consumption and carbon emissions in use	97	1.93
	8.5	Energy and carbon performance on site	109	2.17
	8.6	Water use	291	5.80
	8.7	Responsible sourcing, re-use and recycling of materials	106	2.11
	8.8	Minimising use and impacts of hazardous materials	47	0.94
	8.9	Site waste management planning & legal compliance	89	1.77
	8.10	Waste and management of arisings	213	4.25
9		**Transport**	**267**	**5.32**
	9.1.	Basic Principles	65	1.30
	9.2	Operational Transport	99	1.97
	9.3	Construction transport, including nuisance and disruption	79	1.57
	9.4	Minimising workforce travel	24	0.48
		Total	**5016**	**100**

CEEQUAL for Term Contracts was specifically developed for the assessment of civil engineering and public realm works that are undertaken through contracts over several years, also being suitable for projects which include the construction of new works based on many small-scale and repetitive operations. CEEQUAL for Term

Contracts is presented in two Assessment Manual editions, Maintenance and Construction of small or repetitive new works considering only two Awards: The Whole Team Award & Assessment and the Delivery Award & Assessment, when evaluations are respectively undertaken by the main contractor(s) and designers without client involvement. In the latter case, assessments are performed in the first and penultimate years of the contract after annual visits of the CEEQUAL Verifier before contract completion.

3.2. Infrastructure Sustainability (IS) Rating Tool

As a consequence of the presentation given in February 2007 to Engineers Australia by David Hood and Glenn Hedges, entitled "Does Australia Need an Environmental Rating Scheme for Non-Building Projects", a Steering Committee was formed in March 2007 with the main goal of investigating other existing international rating systems to initiate the creation of a local scheme. The Australian Green Infrastructure Council (AGIC) was created and registered in February 2008 to develop the rating tool, which was concluded in 2011 after undertaking different trials and weighting surveys. The Infrastructure Sustainability (IS) Rating Tool Version 1.0 was released nationally in 2012, a year in which AGIC was renamed the Infrastructure Sustainability Council of Australia (ISCA).

Table 3 shows the IS rating scheme Version 1.0, which consists of 15 Categories organised in 6 topics. The rating tool is based on three performance levels: Design, Build and Operation ratings. A Design rating can be awarded after the inclusion of sustainable elements and construction requirements in the project's design. Once the planning and design phases are completed, requirements for sustainability and performance during construction are assessed. The Build rating is awarded after the end of project construction and replaces the Design rating. In order to be awarded an Operation rating, the asset must have completed at least a period of twenty-four months of operation. Achieving Design or Build ratings is not a requirement for Operation rating. Three levels of achievement are considered by the IS rating tool: Commended (25 to 50 points), Excellent (50 to 75 points) and Leading (75 to 105).

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Table 3. Score of Infrastructure Sustainability (IS) Rating Tool (Version 1.0)

Credit		Concept	Score	%
1		**Management and Governance**	**20.5**	**19.52**
	1.1	Management Systems	10.50	10.00
	1.2	Procurement and Purchasing	5.00	4.76
	1.3	Climate Change Adaptation	5.00	4.76
2		**Using Resources**	**24.5**	**23.33**
	2.1	Energy and Carbon	10.50	10.00
	2.2	Water	7.00	6.67
	2.3	Materials	7.00	6.67
3		**Emissions, Pollution and Waste**	**24.5**	**23.33**
	3.1	Discharge to air, land and water	10.50	10.00
	3.2	Land	7.00	6.67
	3.3	Waste	7.00	6.67
4		**Ecology**	**10.50**	**10.00**
	4.1	Ecology	10.50	10.00
5		**People and Place**	**20.00**	**19.05**
	5.1	Community Health, Well-being and Safety	5.00	4.76
	5.2	Heritage	5.00	4.76
	5.3	Stakeholder Participation	5.00	4.76
	5.4	Urban and Landscape Design	5.00	4.76
6		**Innovation**	**5.00**	**4.76**
	6.1	Innovation	5.00	4.76
		Total	**105.00**	**100.00**

3.3. Envision Sustainable Infrastructure rating system

Envision was created by a strategic alliance of the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure (ISI). ISI launched the Envision Version 2.0 in 2012. Similar to its building counterpart (LEED), this planning and design guidance tool provides industry-wide sustainability metrics for all infrastructure types.

Envision Version 2.0 Stage 2 has 60 sustainability credits consisting of a series of yes/no questions arranged in five categories that address major impact areas in terms of the Triple Bottom Line pillars (see Table 4). Envision provides innovation points for projects with advanced sustainable infrastructure practices or exceptional performance beyond expectations. Five levels of achievement are defined by Envision to assess performance and foster project improvement: Improved (performance is above conventional); Enhanced (sustainable performance adheres to Envision principles); Superior (sustainable performance is noteworthy); Conserving (performance results in zero impact); and Restorative (performance restores natural or social systems). There are 4 Envision award levels according to the percentage of credits obtained: Bronze (20 to 30%), Silver Award (30 to 40%), Gold Award (40 to 50%) and Platinum Award (over 50%).

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Table 4. Score of Envision Sustainable Infrastructure rating system (Version 2.0 Stage 2)

Credit	Concept	Improved	%	Enhanced	%	Superior	%	Conserving	%	Restorative	%
1	**Quality of Life**	**13**	**16.46**	**27**	**15.17**	**62**	**17.46**	**150**	**21.43**	**151**	**29.38**
1.1	Purpose	4	5.06	9	5.06	20	5.63	45	6.43	56	10.89
1.2	Community	6	7.59	12	6.74	23	6.48	70	10.00	52	10.12
1.3	Wellbeing	3	3.80	6	3.37	19	5.35	35	5.00	43	8.37
2	**Leadership**	**10**	**12.66**	**31**	**17.42**	**56**	**15.77**	**115**	**16.43**	**31**	**6.03**
2.1	Collaboration	5	6.33	17	9.55	33	9.30	60	8.57	0	0.00
2.2	Management	2	2.53	6	3.37	13	3.66	25	3.57	31	6.03
2.3	Planning	3	3.80	8	4.49	10	2.82	30	4.29	0	0.00
3	**Resource Allocation**	**29**	**36.71**	**66**	**37.08**	**112**	**31.55**	**170**	**24.29**	**62**	**12.06**
3.1	Materials	15	18.99	34	19.10	59	16.62	80	11.43	0	0.00
3.2	Energy	7	8.86	16	8.99	25	7.04	45	6.43	20	3.89
3.3	Water	7	8.86	16	8.99	28	7.89	45	6.43	42	8.17
4	**Natural Word**	**15**	**18.99**	**33**	**18.54**	**86**	**24.23**	**165**	**23.57**	**169**	**32.88**
4.1	Siting	8	10.13	17	9.55	49	13.80	80	11.43	74	14.40
4.2	Land &Water	2	2.53	10	5.62	23	6.48	40	5.71	39	7.59
4.3	Biodiversity	5	6.33	6	3.37	14	3.94	45	6.43	56	10.89
5	**Climate**	**12**	**15.19**	**21**	**11.80**	**39**	**10.99**	**100**	**14.29**	**101**	**19.65**
5.1	Emission	6	7.59	13	7.30	13	3.66	30	4.29	40	7.78
5.2	Resilience	6	7.59	8	4.49	26	7.32	70	10.00	61	11.87
	Total	**79**	**100.00**	**178**	**100.00**	**355**	**100.00**	**700**	**100.00**	**514**	**100.00**

Even though ISI does not consider economic assessments, some of its Chartered members have created some tools for that purposes, such as Business Case Evaluator, PRISM, Sustainable Return on Investment (SROI) and the Zofnass Economic Process Tool. Business Case Evaluator provides a value-based and risk-adjusted analysis of storm-water infrastructure projects and maps. PRISM is an evaluation tool used for evaluating Triple Bottom Line factors using risk-based dollar equivalents. SROI is a framework to measure the Triple Bottom Line impacts of a project that determines the full value of a project and develops tangible metrics to assess the total investment value. Finally, the Zofnass Economic Process Tool offers a way to quantify sustainability impacts in infrastructure projects based on Envision.

4. Discussion

In the previous section, the three main existing sustainable infrastructure rating tools have been briefly described, including their backgrounds, score schemes of current versions and levels of achievement and awards. In this context, the aim of this section is to evaluate the suitability of these frameworks in developing countries. To this end, the main aspects to consider for the application of infrastructure rating tools in these countries is discussed and the existing sustainable infrastructure systems are compared and reviewed in terms of the TBL, in order to evaluate their applicability in developing countries according to the United Nations Declaration.

4.1. Developing countries in the context of Sustainable Infrastructure Rating Tools

There are different considerations in developed and developing countries in terms of the needs to be covered by sustainable infrastructure rating tools, mainly due to different national priorities and strategies. This section enumerates special features of poorer economies in comparison with advanced ones which must be considered in the assessment of existing frameworks for their application in developing countries.

The Human Development Index (HDI) is a composite statistic of life expectancy, education and income per capita used by the United Nations to rank countries, such that those countries with a HDI below 0.8 are considered developing countries [28]. Nations with low human development indices are likely to emphasise paternalistic socio-economic development instead of environmental aspects when formulating their sustainability agenda in the short to medium term [27]. Social priorities are associated with the stimulation of micro-economic activities and the capacity of building through the generation of employment and other interventionist socio-economic policies.

Developing countries require a major increase in infrastructure investment to reduce growth constraints, contribute to urbanisation needs and meet their development, inclusion and environmental goals. Global trade plays an important role in the development of countries and consequently in infrastructure. This includes traditional transport infrastructure such as roads, railways, ports and information technology infrastructure. The investment budget is predicted to rise from the current level of $1 trillion per year to approximately $1.8-2.3 trillion per year by 2020, assuming 4% of annual growth rate of the Gross Domestic Product (GDP), which means about 3-8% of total GDP. An additional $200-300 billion is also destined to measures aimed at ensuring lower emissions and more resilience to climate change [29].

The concentration of world population in cities and the rapid growth of the number of megacities in the world, which are phenomena mainly located in developing countries, emphasise the key role of infrastructure in urban development in order to achieve the goal of sustainable living. Urban settlements as the main driver of economic growth and development require particular attention to be paid to social and economic aspects without neglecting environmental issues. The development of sustainability in urban areas requires a balance among urban development, environmental protection and the specific demands of citizens (incomes, employment, shelter, basic services, social infrastructure and transportation) [30].

Stakeholders in less developed economies often allocate different weights to different sustainability areas depending on the prevailing problems in society. Some indicators such as health and safety are vulnerable to shifts in the definition and prioritisation of the core elements of sustainability by society. However, this approach raises some issues related to intergenerational priorities in sustainability and the subsequent associated risks, which makes the design of sustainability risk management strategies necessary.

Developing countries prefer indicators that are measured based on their compliance with statutory and regulatory provisions. Consequently, the existing approach to enforce sustainability practices is predominantly accomplished through command and control structures in the form of ordinances and statutory guidelines. A better and more efficient approach might consist of the establishment of responsible sustainability practices driven by economic forces.

The temporal space-time dimension of sustainability necessitates the development of generic but flexible decision support tools that facilitate the selection of indicators based on country and location-specific needs through the study of the local priorities in relation to the sustainability agenda and the incorporation of international indicators. Developing countries subscribed to internationally accepted sustainability metrics need to address their local situation as a part of overall international development strategies. Sustainable infrastructure rating systems are suggested as useful frameworks to implement and monitor sustainable performance indicators and green infrastructure practices in these countries.

4.2. Comparison of mainstream Sustainable Infrastructure Rating Systems

There are many commonalities among Envision, CEEQUAL and IS to ensure and assess sustainability in infrastructure projects. Although they all include the main aspects of sustainability emphasising particular criteria, the boundaries that delimit whether a project is sustainable or not are not clearly defined. Process and outcome assessments are often mixed in these approaches, which also have differences in the way in which they address the different sustainability needs that appear at different stages of project life-cycle. Furthermore, the importance given to management by these systems in the sustainability assessment is very unequal [31].

Table 5 summarises the main criteria of the examined sustainable infrastructure rating systems. The environmental dimension is mostly considered through very common aspects such as GHG emissions, habitats and biodiversity preservation, pollution (air, lighting, noise and water), energy consumption (renewable resources and efficiency), flooding risk, land use and more efficient resource management. These frameworks deal with the social dimension through general community issues such as stakeholders' engagement, communication, health, well-being and historical and cultural heritage. Management covers further aspects such as procurement, project and risk management, decision-making processes and regulations and policies. Finally, the economic pillar focuses on workforce conditions, sustainable growth and development, improvement of the community's quality of life and connectivity.

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Table 5. Main criteria considered by the rating systems under assessment

Economy	Environment	Society	Management
Minimising workforce travel	Principles on the use of land	Stakeholders & Community engagement	Project Management (design, construction, contract)
Increase of community's connectivity	Flood risk management	Assessment of impacts in neighbours	Sustainable procurement management
Employment growth	Maintenance, enhancement or restoration of biodiversity and habitats	Promotion of local employment	Decision-making processes
Resource efficiency	Maintenance or enhancement of landscapes	Historical, cultural and archaeological heritage	Risk and Opportunity management
Business development	Efficient water use	Increase in public information	Conflicting regulations and policies
Procurement practices	Maintenance or enhancement of water quality	Promotion of community health, well-being and safety	
Workforce development	Reduction of GHG emissions	Workforce safety	
Stimulation of sustainable growth and development	Noise management	Focus on accessibility	
Improvement of community Quality of Life	Reduction of Air pollutants	Enhancement of public space	
	Lighting pollution management	Preservation of views and local character	
	Reduction of energy use		
	Promotion of renewable energy		
	Efficient resource management		
	Hazardous materials management		

All points awarded by the tools can be grouped into the three sustainable pillar categories as shown in Table 6. Only the superior level of achievement has been considered for Envision, because its sustainable performance is similar to CEEQUAL and IS systems. The share of points awarded by CEEQUAL, IS and Envision included in Table 6 reveals that all systems are fundamentally dominated by an environmentally-based approach. The average trend in the three systems reflects that Environment is the most relevant category with around two thirds of the total score, whilst Society and Economy represent around 20% and 10% of points, respectively. This unbalanced integration of the sustainability dimensions may lead to the promotion of weak sustainability [32].

Table 6. Share of Triple Bottom Line pillars score

Rating System	Economy		Environment		Society		Total	
	Points	%	Points	%	Points	%	Points	%
CEEQUAL	515.66	10.28	3140.16	62.6	1360.16	27.12	5016	100
Infrastructure Sustainability (IS)	13	12.38	74	70.48	18	17.14	105	100
Envision Superior	29.64	8.35	253.64	71.46	71.64	20.18	355	100

The score thresholds leading to the different levels of achievement established by the three systems show that limits are approximately equally set in CEEQUAL and the IS rating system, whilst Envision Superior displays an important difference. Despite CEEQUAL and IS require higher score to reach the top level of achievement with around 75% of all points, Envision, which only needs 50% of those points, puts a strong focus on some criteria (e.g. restorative actions) that can make it even more demanding in some ways.

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4.3. Assessment of Sustainable Infrastructure Rating Systems for their application in developing countries according to the United Nations Declarations

The United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 [33] reaffirmed the Declaration of the United Nations Conference on the Human Environment, adopted in Stockholm on 16 June 1972, which established a new and equitable global partnership through the creation of new levels of cooperation among states, key sectors of societies and people, in order to subscribe international agreements that respect the interests of all and protect their integrity worldwide. Amongst the 27 principles proclaimed in that Declaration, principles 11 and 22 directly affect sustainable infrastructure rating systems. Principle 11 declares that states shall enact effective environmental legislation, so that environmental standards, management objectives and priorities should reflect the environmental and development context to which they apply. Standards applied by some countries may be inappropriate and of unwarranted economic and social cost to developing countries. CEEQUAL is capable of scoring projects worldwide by undertaking an analysis that ensures the system reflects the needs of the country in question and modifies the UK baseline scheme through the re-assessment of weights. In contrast, Envision and IS are exclusively oriented to their geographical context: North America (US and Canada) and Australia and New Zealand, respectively. In order to be in line with the terms of principle 11, the three systems should include all the sustainable priorities and needs for the countries where they will be applied. Similarly, principle 22 states that indigenous people and other local communities have a vital role in environmental management and development because of their knowledge and traditional practices. States should recognise and support their identity, culture and interests and enable their participation in the achievement of sustainable development [33].

As shown in Table 5, CEEQUAL, IS and Envision rating systems omit significant aspects in the social dimension such as equal opportunities, organisational capacities and education, poverty or indigenous communities. The UN Millennium Declaration [34] sets out a framework of 8 goals, 18 targets and 48 indicators to measure progress towards the Millennium Development Goals (MDGs) with a deadline of 2015 (see Table 7). At the end of this period, this document was superseded by the 2030 Agenda for Sustainable Development [35], which sets forth an action plan with 17 Sustainable Development Goals (SDGs) and 169 targets, in order to enhance the scope of MDGs. The MDGs approach was adopted by experts from the United Nations, the International Monetary Fund, the Organisation for Economic Co-operation and Development (OECD) and the World Bank. Even though MDGs involve problems common to all countries worldwide, the pronounced disparities between developed and the least developed nations lead to paying much more attention to their achievement in the latter. Amongst all Millennium Development Goals, some targets of Goals 1, 3, 7 and 8 should also be covered by the rating systems for infrastructure projects in developing countries. The remaining MDG goals are oriented to education and health issues.

Goal 1 ("Eradicate Extreme Poverty & Hunger") targets halving the proportion of people whose income is less than $1 per day and the proportion of people who suffer from hunger. Rating systems can contribute to

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monitoring the economic effect of projects in the reduction of poverty through the extensive use of local manpower and supplies to promote local sustainable growth. Goal 3 ("Promote Gender Equality and Empower Women") seeks the elimination of gender disparity in primary and secondary education, preferable by 2005, and at all levels of education before 2015. The increasing and gradual incorporation of women into the labour market should be accompanied by policies of equal gender education and wages, reinforcing the role of women in society.

Goal 7 ("Ensure Environmental Sustainability") aims to integrate the principles of sustainable development into countries' policies and programs and reverse the loss of environmental resources. In addition, it intends to halve the proportion of people without sustainable access to safe drinking water and basic sanitation. Effective management frameworks are highly necessary to address sustainable development, where basic sanitation and drinking water are the main priorities. Goal 8 ("Develop a Global Partnership for Development") targets developing a financial system to improve governance and address special needs of poorer economies such as debt problems, youth employment, poverty reduction and access to benefits of new technologies.

From the economic perspective, there are three relevant subjects that should also be deeply considered and incorporated into the three analysed sustainable infrastructure rating systems: the evidence that projects support sustainable growth and economic development, the financial viability of projects and their contribution to the reduction of poverty as stated in Millennium Development Goal 1. Whilst sustainable growth and economic development issues are taken into account in some Envision credits such as QL 1.1, QL 1.2 and QL 1.3, CEEQUAL and IS systems omit the meaningful economic subjects above mentioned.

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Table 7. Millennium Development Goals (MDGs)

G#	Goal	T#	Target	I#	Indicator
1	Eradicate extreme Hunger and Poverty	1	Halve the proportion of people whose income is less than $1 a day	1	Proportion of population below $1 per day
				2	Poverty gap ratio (incidence x depth of poverty)
				3	Share of poorest quintile in national consumption
		2	Halve the proportion of people who suffer from hunger	4	Prevalence of underweight children under five years of age
				5	Proportion of population below minimum level of dietary energy consumption
2	Achieve Universal Primary Education	3	Ensure that children everywhere, boys and girls alike, will be able to complete a full course of primary schooling	6	Net enrolment ratio in primary education
				7	Proportion of pupils starting grade 1 who reach grade 5
				8	Literacy rate of 15-24 year-olds
3	Promote Gender Equality and Empower Women	4	Eliminate gender disparity in primary and secondary education by 2005, and in all levels of education before 2015	9	Ratio of girls to boys in primary, secondary and tertiary education
				10	Ratio of literate women to men, 15-24 years old
				11	Share of women in waged employment in the non-agricultural sector
				12	Proportion of seats held by women in national parliament
4	Reduce Child Mortality	5	Reduce by two-thirds the under-five mortality rate	13	Under-five mortality rate
				14	Infant mortality rate
				15	Proportion of 1 year-old children immunized against measles
5	Improve Maternal Health	6	Reduce by three-quarters the maternal mortality ratio	16	Maternal mortality ratio
				17	Proportion of births attended by skilled health personnel
6	Combat HIV/AIDS, Malaria and other diseases	7	Have halted and begun to reverse the spread of HIV/AIDS by 2015	18	HIV prevalence among pregnant women aged 15-24 years
				19	Condom use rate of the contraceptive prevalence rate
				19a	Condom use at last high-risk sex
				19b	Percentage of population aged 15-24 with comprehensive correct knowledge of HIV/AIDS
				19c	Contraceptive prevalence rate
				20	Ratio of school attendance of orphans to school attendance of non-orphans aged 10-14
		8	Have halted and begun to reverse the incidence of malaria and other major diseases	21	Prevalence and death rates associated with malaria
				22	Proportion of population in malaria-risk areas using prevention and treatment measures
				23	Prevalence and death rates associated with tuberculosis
				24	Proportion of tuberculosis cases detected and cured
7	Ensure Environmental Sustainability	9	Integrate the principles of sustainable development into countries' policies and programs and reverse the loss of environmental resources	25	Proportion of land area covered by forest
				26	Ratio of area protected to maintain biological diversity to surface area
				27	Energy use (kg oil equivalent) per $1 Gross Domestic Product (GDP)
				28	Carbon dioxide emissions per capita and consumption of ozone-depleting CFCs
				29	Proportion of population using solid fuels
		10	Halve the proportion of people without sustainable access to safe drinking water and basic sanitation	30	Proportion of population with access to an improved water source, urban and rural
				31	Proportion of population with access to improved sanitation, urban and rural
		11	Have achieved by 2020 a significant improvement in the lives of at least 100 million slum dwellers	32	Proportion of households with access to secure tenure
8	Develop a Global Partnership for Development	12	Develop further an open, rule-based, predictable, non-discriminatory trading and financial system (includes a commitment to good governance, development, and poverty reduction, both nationally and internationally)	33	Net Official Development Assistance (ODA), total and to LDCs, as percentage of OECD/Development Assistance Committee (DAC) donors' gross national income (GNI)
				34	Proportion of total bilateral, sector-allocable ODA of OECD/DAC donors to basic social services (basic education, primary health care, nutrition, safe water and sanitation)
		13	Address the special needs of the Least Developed Countries (includes tariff- and quota-free access for Least Developed Countries, exports, enhanced program of debt relief for heavily indebted poor countries and cancellation of official bilateral debt, and more generous official development assistance for countries committed to poverty reduction)	35	Proportion of bilateral ODA of OECD/DAC donors that is untied
				36	ODA received in landlocked developing countries (LDCs) as a proportion of their GNIs
				37	ODA received in small developing island States as a proportion of their GNIs
				38	Proportion of total developed country imports (by value and excluding arms) from developing countries and from LDCs, admitted free of duty.
		14	Address the special needs of landlocked developing countries and small developing island states	39	Average tariffs imposed by developed countries on agricultural products and textiles and clothing from developing countries
				40	
		15	Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term	41	Agricultural support estimate for OECD countries as percentage of their GDP
				42	Proportion of ODA provided to help build trade capacity
		16	In cooperation with developing countries, develop and implement strategies for decent and productive work for youth	43	Total number of countries that have reached their Heavily Indebted Poor Countries Initiative (HIPC) decision pints and number that have reached their HIPC completion points
				44	Debt relief committed under HIPC initiative
		17	In cooperation with pharmaceutical companies, provide access to affordable essential drugs in developing countries	45	Debt service as a percentage of exports of goods and services
				46	Unemployment rate of young people aged 15-24 years, each sex and total
		18	In cooperation with the private sector, make available the benefits of new technologies, especially information and communications technology	47	Proportion of population with access to affordable essential drugs on a sustainable basis
				48	Telephone lines and cellular subscribers per 100 population
					Personal computers in use per 100 population and Internet users per 100 population

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The lack of definitive management guidelines to establish key elements that constitute a sustainable project often confuses project owners, consultants and other stakeholders. Some of them apply their own notions about sustainable development based on their particular interests through some newly created systems. However, most of them do not provide an effective connection between the overall goals of sustainable development and the projects that move society towards these goals. The implementation of sustainability management and reporting systems is crucial in order to meet project goals for sustainable development and measure progress towards the goals, while describing performance through a series of sustainability factors such as economic, environmental, social and corporate governance performances [36].

The addition of these relevant subjects to infrastructure frameworks contributes to balancing the relevance of the three sustainable pillars in the achievement of sustainable development goals, in particular in developing countries where these factors play a much more crucial role than in developed economies. Sustainable procurement describes the consideration of environmental, social and economic parameters in addition to the conventional ones of cost, time and quality for selecting suppliers and service providers. These considerations require that suppliers report the sustainability impact of the materials and products they offer, such as the consumption of waste, carbon and water, the contribution to the local economy through the use of local labour and the incorporation of sustainability criteria in the local community engagement process.

Designers and contractors also collaborate with suppliers to deliver the final product according to required sustainability standards. Pre-qualification of consultants, designers or contractors is highly recommended to minimize risks during the procurement process. Even though the CEEQUAL, Envision and IS rating tools include best sustainable procurement practices, they should promote their extensive use through an effective combination with project management practices to enhance the contribution to social and economic dimensions.

5. Conclusions

This article analyses the suitability of current sustainable infrastructure rating systems, namely CEEQUAL, Envision and IS, by taking into account some factors that can affect sustainability assessment in the least developed countries, such as the effect of urban development, the particular context of developing countries and the United Nations Declarations related to international development. The main conclusions drawn from this study are summarized as follows:

- The three available infrastructure tools analysed are biased towards environmental concerns in detriment of the economic and social dimensions, which are a top priority for developing countries, where the promotion of economic growth and sustainable living is a prevailing goal. Furthermore, existing frameworks are mainly oriented to advanced economies where they were originally launched. Therefore, an exercise in understanding and incorporating priorities and needs of poorer economies into current systems is highly necessary to validate their successful implementation in these geographical areas.

- Management is arisen as the fourth pillar to support the Triple Bottom Line. The lack of definitive management frameworks requests the implementation of a wide range of guidelines related to project & risk management and sustainable procurement that can enhance the contribution of project stakeholders. These directives should be accompanied by effective reporting systems and suitable metrics and indicators based on the needs of poorer countries that are able to monitor and measure progress towards sustainable goals.
- Although some green building rating tools such as BREEAM Communities, CASBEE for Urban Development and LEED for Neighbourhood Development are widely employed to assess the degree of sustainable development of communities and cities, sustainable infrastructure frameworks can also complement them through the balanced consideration of the Triple Bottom Line.
- The principles proclaimed in the Declaration of the United Nations Conference on the Human Environment and the Millennium and Sustainable Development Goals should also be included in sustainable infrastructure tools. Even though all principles and development goals are applicable worldwide, some of them should be specifically incorporated to frameworks focused on developing countries because of their distinctive context.
- The development of infrastructures may also trigger some interrelationships between social, economic and environmental risks, which were not included in the assessment because they overcome considerations of single projects. The long lifespan, broad spatial effects and inherent uncertainty of infrastructure projects mean that they often cause impacts that may be difficult to manage. Infrastructure projects are particularly susceptible to climate change and natural disaster risks that can be specially accentuated in the least developed countries. This component also serves to reaffirm the intimate linkage of all sustainable pillars (economy, environment, and society) to understand the meaning of Sustainability. The predominant role of one of these aspects in detriment of the rest can seriously affect the achievement of goals derived from the implementation of infrastructures in developing countries, where their own idiosyncrasies make them more vulnerable.

In summary, the increasing relevance of infrastructure in the least developing countries heightens the need for further analysis of their particular context, not only in order to redress the omission of the main site-specific issues in the conception of rating systems, but also the inclusion of sustainable impact assessments beyond the single project framework and the appropriate consideration of the development goals set by United Nations declarations.

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2.2. Artículo 2: Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC)

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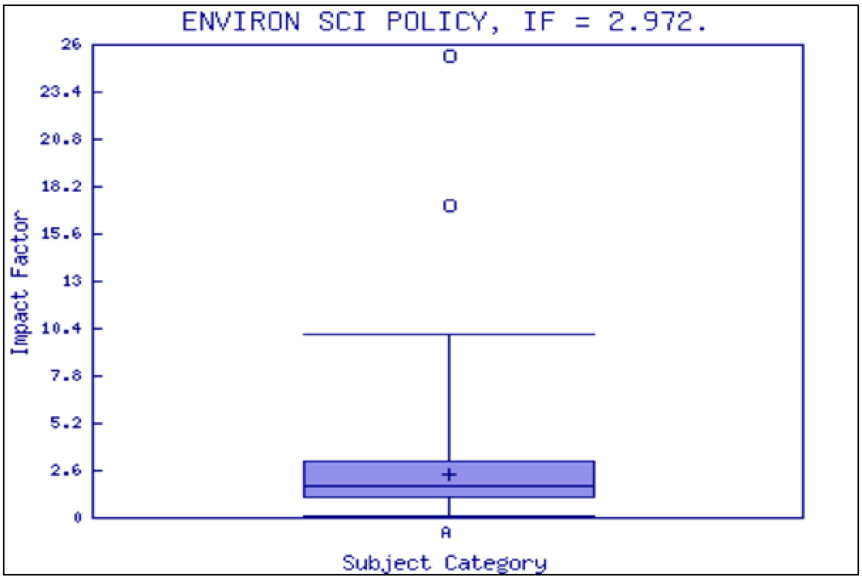

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Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC)

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Abstract

The improvement of infrastructures in developing countries has become a priority for the most advanced economies, which have founded a broad range of international development organizations to undertake infrastructure projects worldwide. Infrastructure is the key driver that can accelerate the balance among the economic, social and environmental aspects forming the Triple Bottom Line (TBL) in these countries. Given the lack of appropriate tools to ensure the achievement of this goal, this paper describes the methodology conceived for the development of a Sustainable Infrastructure Rating System (SIRSDEC) aimed at promoting the design, construction and operation of sustainable infrastructure projects in these geographical areas. SIRSDEC is structured into a hierarchical decision-making tree consisting of three levels of elements (requirements, criteria and indicators) selected to assess infrastructure systems according to sustainability principles. The methodology on which SIRSDEC is based combines the action of two multi-criteria decision-making methods (MCDM) such as the Analytical Hierarchy Process (AHP) and the Integrated Value Model for Sustainable Assessment (MIVES). AHP is proposed to weight the elements forming the decision-making tree after processing the opinions provided by a group of international experts regarding the importance of requirements, criteria and indicators, whilst MIVES is suggested to value infrastructure projects according to their contribution to the TBL. The article emphasizes the added value provided by the combination of AHP and MIVES in the design of an ad-hoc rating system aimed at fostering the implementation of sustainable infrastructure projects in developing countries.

Keywords

AHP; MCDM; MIVES; Rating System; Sustainable Infrastructure.

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1. Introduction

The third of the 27 principles proclaimed in the final Declaration of Rio+20 United Nations Conference on Sustainable Development held in June 2012 stated that the right to development must be fulfilled to meet developmental and environmental needs of present and future generations. This principle reaffirmed the key role of sustainability in contemporary society and promoted the urgent need for developing effective frameworks to balance long-term economic, environmental and social aspects in construction processes (UN, 1992).

A sustainability rating system can be defined as a set of best practices that evaluates sustainability through the scoring of a series of indicators (Hart, 2006). Furthermore, this framework enables diverse indicators measured in different units (e.g. pollutants/carbon emitted to atmosphere, renewable energy used, recycled materials, energy consumption/conservation, ecosystem/biodiversity preservation, culture heritage maintenance, etc.) to be integrated into a single analysis aimed at rating infrastructure projects in terms of their contribution to sustainability.

Property industry was the pioneer in the development of sustainability rating systems for buildings in advanced economies, such as Leadership in Energy and Environmental Design (LEED) in the U.S. (USGBC, 2009), Building Research Establish Environmental Assessment Method (BREEAM) in the U.K. (BRE, 2014) and Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan (IBEC, 2011). A few years later, the transportation community designed its own specific systems too. At present, there are a significant number of national and international rating systems oriented to evaluate green buildings and only a few focused on analysing infrastructures from the point of view of sustainable development. These systems vary in terms of scope and complexity but are generally designed to provide guidance, scoring and potential rewards for using sustainable best practices. Rating systems usually focus on practices that are compatible with current regulations but are beyond existing minimum regulatory requirements. The main purpose of most sustainability rating systems is not to set a scientifically defensible taxonomy of sustainability, but rather a tool to encourage the implementation of sustainability practices beyond regulatory minimum targets and communicate sustainability concepts in a comprehensible manner to all stakeholders, from construction professionals to citizens.

Rating systems are often criticized because they tend to minimize the appraisal of economic and social aspects in detriment of environmental issues (Gibberd, 2005). In addition, international development agencies and organizations have not broadly incorporated rating systems into the assessment of their project processes (UNOPS, 2012), whilst the evaluation of the economic benefits derived from their implementation is very complicated (FIDIC, 2012). In relation to the context of this research, rating systems are also deficient due to their focus on developed economies and omission of specific features of third world countries (EAP & ARUP, 2011).

There are three main rating systems that assess infrastructure projects following the principles of sustainability: ENVISION (USA) (ISI, 2012), Civil Engineering Environmental Quality (CEEQUAL) (BRE Group, 2015) and

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Infrastructure Sustainability (IS) Rating Tool (Australia) (ISCA, 2012). A review of these rating systems revealed that they are imbalanced in relation to the importance given to the three pillars of sustainability, also known as the Triple Bottom Line (TBL), since the number of environmental credits considered are more numerous than those assigned to economic and social aspects (Diaz-Sarachaga et al., 2016). Commercial reasons are the main goal of infrastructures rating systems in richer nations, in order to advertise the quality of projects and the interest of clients, designers and/or builders in sustainability, whereas the context of developing countries requires a different approach for evaluating the whole sustainability contribution of projects to the development of these nations. The lack of data related to the indicators included in existing frameworks and the disregard for management practices are another setbacks which hinder the accurate implementation of these tools in developing countries.

Moreover, these systems were found to be mainly oriented to their countries of origin and omit most of both the Millennium Development Goals (MDGs) established in the United Nations (UN) Millennium Declaration (UN, 2000) and the Sustainable Development Goals (SDGs) adopted by the UN General Assembly on 25 September 2015 (UN, 2015). MDG 1 (Eradicate Extreme Poverty & Hunger), MDG 3 (Promote Gender Equality and Empower Women) and MDG 7 (Ensure Environmental Sustainability) should be included in rating systems for infrastructure projects in developing countries. SDGs 4, 5, 11 and 16 address social issues such as the search for education equality in terms of gender and quality, the transformation of cities and human settlements in safe, inclusive and resilient places. The promotion of sustainable economic growth and employment and resilient infrastructure and industrialization are targeted by SDGs 8 and 9. The governance area, which corresponds to SDGs 12 and 17, involves the use of sustainable consumption and production patterns and the strengthening of the global partnership for sustainable development.

The scarcity of definitive management guidelines to establish key elements for assessing the degree of sustainability of a project confuses owners, consultants and other stakeholders. The implementation of sustainability management practices and reporting systems is also crucial to meet project goals for sustainable development and measure progress towards the achievement of these aims (FIDIC, 2012).

As a contribution to enhance the field of sustainable rating systems, this paper proposes a methodology and a set of TBL indicators to create a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) through the combination of two multi-criteria decision-making methods: Analytic Hierarchical Process (AHP) and Integrated Value Model for Sustainable Assessment (MIVES). The combination of AHP and MIVES has been used successfully in the past to appraise the contribution to sustainability provided by different construction alternatives (San-Jose Lombera et al., 2010; Pons and Aguado, 2012), to the extent of being included in the Spanish Structural Concrete Standard (EHE-08) (Aguado et al., 2012). AHP is used to weight the elements into which the system is structured according to the opinions returned by a group of international experts regarding their relative importance, whilst MIVES provides value functions to transform indicators measured in different units into a value index (Jato-Espino et al., 2014). SIRSDEC arises as an effective response to the weaknesses detected in current infrastructure rating systems and seeks to create, develop and

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implement a tool capable of guiding and promoting sustainable development in poorer countries through the implementation of infrastructure projects.

2. Sustainable Infrastructure in Developing Countries

The United Nations (UN) created the Human Development Index (HDI), based on the consideration of a series of criteria such as life expectancy, per capita income and literacy rate, to classify countries into categories according to their economic development. Countries with an HDI below 0.8 are generally considered as Developing Countries. UN has 193 member states, of which 53 and 140 are classified as developed and developing countries, respectively. Developing countries include Albania, Bosnia and Herzegovina, Serbia and Macedonia in Europe, Africa, Asia (except Japan, South Korea, Hong Kong, Singapore, Qatar, Brunei and Bahrein) and South America (excluding Chile and Argentine) (UN-Habitat, 2015).

Developing countries require a major increase in infrastructure investment to reduce growth constraints, contribute to urbanization needs and meet their development, inclusion and environmental goals. Global trade plays an outstanding role in countries development and consequently in infrastructure. This includes traditional transport infrastructure such as roads, railways and ports, and information technology infrastructure. World population is expected to increase from 6.1 to 8.1 billion between 2010 and 2030 (UN-Habitat, 2011). Most of this rise corresponds to urban settlements located in developing countries, which accelerates more the need of sustainable urban infrastructure (UN-DESA, 2014).

Infrastructure role is also essential to ensure the sustainability of economies through the limitation of environmental impacts of infrastructure assets, mitigation of Climate Change and fostering of sustainable practices (Ebobisse, 2015). The rise of investment budget has been estimated from $1 trillion per year nowadays to approximately $1.8-2.3 trillion per year by 2020, assuming 4% of Gross Domestic Product (GDP) annual growth rate, which means about 3-8% of total GDP (Fardoust et al., 2010). In addition, $200-300 billion are destined for measures aimed at ensuring lower emissions and more resilience to climate change. Figure 1 depicts pie charts indicating the investment required in 2020 according to regions and sectors. East Asia Pacific (EAP) is expected to require most of this investment, followed by South Asia (SA) and Latin America and The Caribbean (LAC). Regarding the distribution by sectors, basic infrastructure such as Electricity, Water and Transportation monopolize most of the budget. An estimate of 1.4 billion people still has no access to electricity, whilst 0.9 billion do not have access to drinkable water and 2.6 billion lack basic sanitation, which justify the importance of focusing on the first two sectors (Bhattacharya et al., 2012).

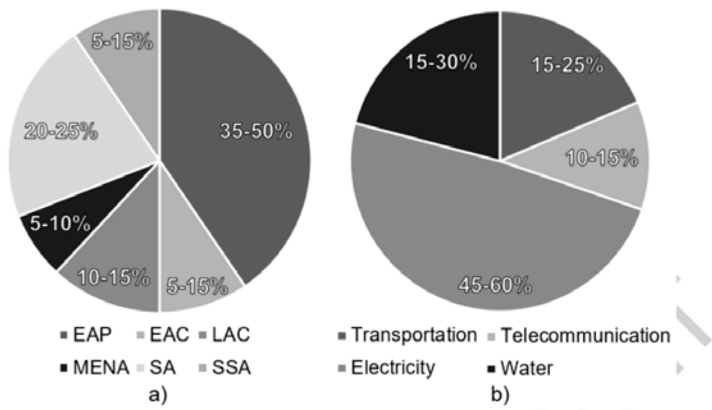

Figure 1. Estimated annual infrastructure investment in 2020 split by a) Region b) Sector ($ trillion)

Infrastructure projects have a prominent impact on determining environmental sustainability. Between 10 and 15% of the required infrastructure investment can be assigned to make such investment sustainable by ensuring lower emissions, higher efficiency and resilience to Climate Change (UNCTAD, 2014). Despite this additional cost, the net effect of these investments is very positive from social, economic and environmental perspectives (UN-DESA, 2015). The rise of economic growth and the change from primary to secondary and tertiary economic industries are evident consequences of infrastructure development, which also reduce levels of inequality and give added social returns to the community (UNOPS, 2012).

An increasing number of international development organizations are managing a wide range of projects in developing countries over the last decades to foster social, economic and environmental development. Amongst them, the role of Multilateral Development Banks (MDBs) is highly remarkable. MDBs delivered a joint statement Commitment to Sustainable Transport during the Rio+20 Conference, with the aim of strengthening the role of transportation infrastructure in sustainable development by providing $175 billion of loans and grants to develop projects in developing countries from 2012 to 2022. At present, more than 200 projects have been approved, including 115 for roads, 39 for urban transport, 24 for rail, 13 for airports and 5 for inland waterway and maritime projects (MDBs, 2015). Furthermore, the MDB Infrastructure Action Plan (MDBs, 2011) reflects extensive analysis and collaboration among the MDBs through a background report on infrastructure issues in third world countries provided to the Group of 20 (G20) in June 2011. This plan describes an ambitious set of initiatives aimed at unlocking the infrastructure project pipeline, in order to enable both increasing the participation and financing in the private sector and improving the efficiency of infrastructure spending.

Despite the huge budget destined for the development of infrastructures in developing countries, no global Sustainability Infrastructure Rating System has been created to manage and monitor them. The Sustainable Transport Appraisal Rating (STAR) framework (Veron-Okamoto et al., 2014), created by the Asian Development Bank and used by the MDBs, includes criteria to assess the social, economic and environmental sustainability of transportation projects. Engineers against Poverty and Arup worked on a Sustainability Poverty and

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Infrastructure Routine for Evaluation (ASPIRE) (EAP & ARUP, 2011) that appraises projects qualitatively according to the TBL, but does not rate them. The International Federation of Consulting Engineers (FIDIC) elaborated Project Sustainability Management Guidelines in 2004 to provide some guidelines about what a sustainable project consists of (FIDIC, 2004).

3. Methodology

A literature review was conducted to collect information related to existing Sustainable Infrastructure Rating Systems, multi-criteria decision-making methods, sustainable development goals established by international organizations and needs of developing countries in terms of the TBL. Once the objectives to be achieved by SIRSDEC were established, the decision-making problem was defined according to a hierarchical three-level scheme, usually called decision-making tree, consisting of a series of requirements, criteria and indicators. A questionnaire form was distributed to international experts to collect their opinion regarding the relative importance among the elements in the decision-making tree. The Analytic Hierarchy Process (AHP) was selected to transform the linguistic pairwise comparisons provided by the experts into the weights of requirements, criteria and indicators. The Integrated Value Model for Sustainable Assessments (MIVES) (ETCG, 2015) was proposed to convert the ratings of the indicators across the indicators into value indices reflecting the satisfaction degree they produced. The definition of different feasible alternatives to the decision-making problem allows their appraisal from the perspective of multiple criteria and objectives (Janssen, 1992) and the subsequent determination of their contribution to sustainability. Figure 2 illustrates the research methodology used to conceive SIRSDEC.

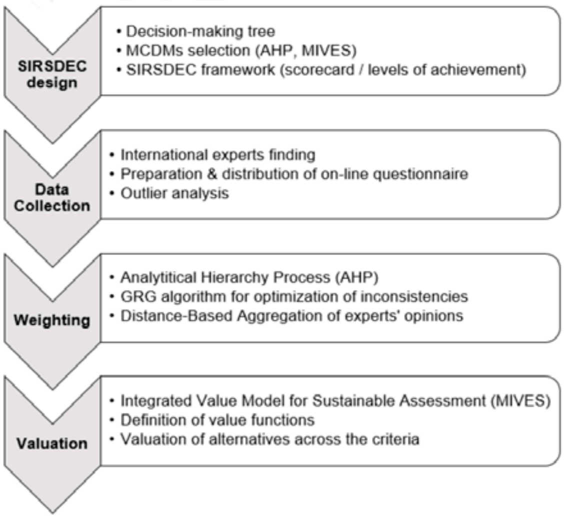

Figure 2. Research methodology developed for this paper

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3.1. SIRSDEC design

Sustainability assessments consist of the identification, prediction and evaluation of the potential impact of different solutions or alternatives across the TBL (Devuyst, 2000). Developing countries emphasise socio-economic development over environmental aspects when formulating their sustainability agenda (Ugwu and Haupt, 2005). Therefore, the achievement of sustainable development goals in these areas requires a balance among environmental awareness and the specific socio-economic demands of citizens (incomes, employment, shelter, basic services, social infrastructure and transportation) (Hiremath et al., 2013). Consequently, the assessment of sustainability in poorer nations requires the design of decision support tools to facilitate the selection of indicators based on country and location-specific needs through the study of the local priorities in relation to the sustainability agenda and the incorporation of international indicators (Diaz-Sarachaga et al., 2016).

Under these premises, SIRSDEC was designed to include indicators mainly referred to Agenda 21 issues (UN, 1992), in order to achieve a balance between the three pillars of sustainable development. Therefore, these indicators focused on the particular context of developing countries and considered all the stages of a long-term project life-cycle such as design, construction, operation, renovation and demolition/reuse. The management dimension was also considered to overcome the existing shortage of guidelines to interconnect the overall goals of sustainable development in poorer countries (Hiremath, 2013). Furthermore, additional overarching features were also taken into account in the selection process of the set of criteria and indicators to characterize SIRSDEC. Amongst them, the relevance of the principles of sustainability reflects the whole performance of the rating system and its orientation to policy issues, which enables identifying the changes required to promote progress towards sustainability goals (Hart, 2006). The breakdown of the SIRSDEC decision-making tree is shown in Table 1, including 4 requirements, 23 criteria and 29 indicators.

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Table 1. SIRSDEC decision-making tree

R#	Requirement	C #	Criteria	I #	Indicator
R1	Management	C1.1	International Standards	I1.1.1	ISO 9001 or equivalent
				I1.1.2	ISO 14001 or equivalent
		C1.2	Project Sustainability Management (PSM) plan	I1.2.1	Project Sustainability Management plan
		C1.3	Sustainability Risk Management (SRM) plan	I1.3.1	Sustainability Risk Management plan
		C1.4	Sustainable Procurement plan	I1.4.1	Sustainable Procurement plan
		C1.5	Inspection & Auditing (I&A) plan	I1.5.1	I&A plan
		C1.6	Reporting & Lessons Learned (R&LL)	I1.6.1	Periodic reports distribution
				I1.6.2	Lessons Learned Log
R2	Society	C2.1	Community & Stakeholders involvement	I2.1.1	Stakeholders involvement ratio
		C2.2	Role of indigenous people	I2.2.1	Indigenous involvement ratio
		C2.3	Equitable development	I2.3.1	Gender average wage ratio (f/m)
		C2.4	Social impacts & benefits	I2.4.1	Population impacted by project
				I2.4.2	Settlements area disturbed
		C2.5	Cultural Heritage	I2.5.1	Local cultural assessment
R3	Environment	C3.1	Natural Ecosystem conservation	I3.1.1	Impacted ecosystem area ratio
		C3.2	Biodiversity Ecosystem	I3.2.1	Endangered species ratio
		C3.3	Greenhouse gases emissions	I3.3.1	GHG emissions reduction rate
		C3.4	Energy consumption	I3.4.1	Energy savings rate
				I3.4.2	Renewable energy use rate
		C3.5	Water management	I3.5.1	Fresh water consumption
				I3.5.2	Runoff water stored
		C3.6	Flooding risk	I3.6.1	Floodplains area
		C3.7	Air Quality	I3.7.1	Air pollutants reduction
		C3.8	Waste management	I3.8.1	Waste production decrease
				I3.8.2	Recycled/reused waste
R4	Economy	C4.1	Combating poverty	I4.1.1	Local economic assessment
		C4.2	Agriculture impacts	I4.2.1	Farmland area impacted
		C4.3	Local materials consumption	I4.3.1	Local materials use rate
		C4.4	Local employment	I4.4.1	Local employment rate

Each of the 23 criteria that forms SIRSDEC corresponds to an objective that infrastructure projects must achieve to be considered "sustainable" in developing countries. As a prerequisite, SIRSDEC has 13 mandatory criteria to ensure all projects face key issues related to sustainability in less developed countries. In the domain of management, there are 4 compulsory criteria: International Standards (C1.1), Project Sustainability Management (PSM) plan (C1.2), Sustainable Procurement plan (C1.4), and Inspection & Auditing (I&A) plan (C1.5). The social aspect encompasses 3 additional mandatory criteria, such as Community & Stakeholders involvement (C2.1), Equitable development (C2.3) and Culture Heritage (C2.5). The environmental requirement includes 4 indispensable criteria: Natural Ecosystem conservation (C3.1), Greenhouse gases emissions (C3.3.), Water management (C3.5), and Flooding risk (C3.6). Combating poverty (C4.1) and Local employment (C4.4) in the economic requirement complete the set of 13 essential criteria demanded for all projects.

SIRSDEC includes a set of 29 measurable indicators that represent key issues in infrastructure project delivery, in order to monitor the performance, sustainability understanding and appropriate linkage between stakeholders. The management requirement consists of 8 indicators. I1.1.1 evaluates the implementation and maintenance of ISO 9001 (or equivalent) to align project team members with international quality management standards, whilst I1.1.2 plays the same role with ISO 14001 (or equivalent) to fulfil a set of environmental management practices. I1.2.1 rewards the ability to design and implement projects integrating social, environmental and economic aspects. The use of the Sustainability Risk Management (SRM) plan monitored through I1.3.1 targets the identification, assessment, prioritization and implementation of an action plan for sustainability risks. The consideration of the Sustainable Procurement plan scored by I1.4.1 aims to manage

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procurement and supply chains through the balance of social, economic and environmental aspects. The implementation of the I&A plan to ensure the compliance of sustainable practices, the distribution of progress reports to stakeholders and the recording & outreach of lessons learned are the goals sought by I1.5.1, I1.6.1 and I1.6.2, respectively.

Six indicators are considered in the social requirement. I2.1.1 and I2.2.1 assess the degree of involvement of stakeholders and indigenous community in the project with respect to the total affected stakeholders and population. Gender wage equality is evaluated using I2.3.1 as the ratio of average female wages to male salaries. I2.4.1 shows the proportion of population negatively impacted by the infrastructure under analysis over its life-cycle in social, environmental and economic terms. The ratio of housing temporary and/or permanently affected by the project is monitored by I2.4.2. I2.5.1 awards the identification, assessment, management and maintenance of cultural heritage as defined in the United Nations Educational, Scientific and Cultural Organization (UNESCO) (UNESCO, 1972).

The environmental dimension contains 11 indicators affecting the whole life-cycle of the project. I3.1.1 and I3.1.2 reflect the proportion of ecosystem area and endangered species impacted negatively during the development and operation of projects, respectively. I3.3.1 and I3.4.1 appraise the reduction of GHG emissions and used energy with respect to standard estimates. The ratio of consumed fresh water in comparison with available water resources is assessed by I3.5.1, whilst the capability to store runoff is rewarded by I3.5.2. The rate of land area in the project sensitive to suffer damage by flooding is assessed through I3.6.1. I3.7.1 and I3.8.2 award actions taken to decrease air pollutant emissions and waste production in comparison with standard values (NEC, 2001).

The economic requirement is characterized in SIRSDEC through 4 indicators. I4.1.1 rewards the assessment of the economic benefits added by the project that can contribute to reducing levels of poverty and promoting economic growth in the region. The impact of the project on land where permanent crops are located is measured by I4.2.1. Finally, the fostering of local materials and manpower use is appraised by I4.3.1 and I4.4.1, respectively.

SIRSDEC is a system designed to help users to evaluate the sustainability of any infrastructure project developed in developing countries at any stage in their life cycles. The total score of the system amounts 29 points, each of them related to the fulfilment of the objectives measured through the set of indicators, so that each indicator scores in a range between 0 and 1. There are 13 compulsory criteria that represent 15 points which must be necessarily achieved to pass evaluation. The accomplishment of the remaining indicators can lead to reach the two other levels of achievement considered in SIRSDEC: Pass (15 points), Silver (16 to 22 points) and Gold (22+ points).

Despite SIRSDEC tries to fill the existing gap of sustainability frameworks to rate infrastructure projects in developing countries, some aspects limit its standardized application. SIRSDEC aims to appraise sustainability in all different stages of a project, including operation. Hence, this system requires a permanent source of

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relevant and reliable information which might be difficult to acquire at the present time. Furthermore, no systematic management practices are implemented in these countries, which hinders the use of SIRSDEC as the cornerstone of a general sustainability framework. Finally, although SIRSDEC was originally designed as an easy-to-use tool to be widely deployed worldwide, the specifics of some geographical areas might require the customization and reweighting of indicators in very particular cases.

3.2. Data collection

An on-line questionnaire was prepared using Google Forms to collect and summarize the opinions from international leading experts belonging to several countries worldwide in an easy and automatic manner. This approach facilitated the distribution of the survey among a larger number of participants located in different continents and the quick integration of the data received using the same tool. The questionnaire is expected to be sent to more than a hundred of professionals related to the assessment of sustainability, so that a response rate of about 25% could be considered enough to validate its representativeness. The profiles sought to form the panel of respondents should include international leading experts in the domain of sustainability and environmental assessment systems such as professionals from academia, industry, public development institutions and research organizations.

The survey was divided into three parts. The first part defined the purpose of each element in the decision-making tree represented in Table 1, guided the respondents about how to fill in the questionnaire and requested some information related to their profile for making statistics. The second section invited the experts to answer several general questions related to sustainability and its assessment, whilst the last part focused on the pairwise comparisons between indicators, criteria and requirements according to questions like "How important is element *i* with respect to element *j*?".

3.3. Weighting of the elements in the decision-making tree

Weighting is a key factor in sustainability assessments, since it has a great influence on the overall score reachable by a project (Lee et al., 2002). SIRSDEC has been designed as a generic framework valid for all developing countries, which implies that weighting re-assessment is not necessary for evaluating a project to be implemented in any country included in this category. The comparisons provided by the experts in the last step of the questionnaire were processed to obtain weights of the elements in the decision-making tree using the Analytic Hierarchy Process (AHP) (Saaty, 1980). This method was selected for weighting because of its simplicity and flexibility to be combined with other multi-criteria methods (Vaidya et al., 2006). Table 2 shows the numerical scale considered in the AHP method to quantify a list of pairwise comparisons as that collected from the questionnaires returned by the experts.

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Table 2. AHP pairwise comparison scale

Qualitative evaluation		**Rating**
Absolutely more important	(AMI)	9
Much more important	(MMI)	7
More important	(MI)	5
Slightly more important	(SMI)	3
Equally important	(EI)	1
Slightly less important	(SLI)	1/3
Less important	(LI)	1/5
Much less important	(MLI)	1/7
Absolutely less important	(ALI)	1/9

The application of the comparison scale shown in Table 2 enables the construction of a $n\,x\,n$ reciprocal matrix of pairwise comparisons (Skibniewski et al., 1992). Its consistency is evaluated throughout the maximum matrix eigenvalue ($\lambda_{\max}$), so that the matrix is completely consistent when $\lambda_{\max} = n$ and becomes increasingly inconsistent as the eigenvalue grows, according to the consistency ratio (C.R.) defined in Eq. (1).

$$\mathrm{C.R.} = \frac{\mathrm{C.I.}}{\mathrm{R.I}} < 0.1 \qquad (1)$$

where C.I. is the consistency index and R.I. is the random consistency index. A matrix is considered consistent when the ratio between C.I. and R.I. is less than 0.1, with C.I. being expressed as in Eq. (2). The values of R.I. listed in Table 3 represent the average C.I. for 500 randomly generated matrices of the same order.

$$\mathrm{C.I.} = \frac{\lambda - n}{n} \qquad (2)$$

Table 3. Random consistency index

Matrix size (*n*)	2	3	4	5	6	7	8	9	10
R.I	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The method proposed by Jato-Espino et al. (2016), which is based on the Generalized Reduced Gradient (GRG) algorithm (Abadie et al., 1968) and an aggregation system according to the proximity between the judgments of each pair of respondents, was used to adjust possible inconsistencies in the questionnaires and synthetize they all into a consensual set of weights.

Therefore, if $[\mathrm{A}]$ is the inconsistent comparison matrix related to a set of criteria $\mathrm{C_j} = \langle \mathrm{C_1}, \mathrm{C_2}, \ldots, \mathrm{C_n} \rangle$ and $[\mathrm{A}]'$ is the objective consistent matrix being sought, the algorithm minimizes the differences between the upper right triangles of both matrices to fulfil Eq. (1), with the limitation of remaining within the corresponding lower and upper threshold values of the AHP comparison scale. The differences between both matrices are measured using the Root Mean Square Error (RMSE) (Chai et al., 2014). A logarithmic scale is applied to equalize the differences between lower and higher thresholds, so that the minimization problem is expressed as shown in Eq. (3).

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$$\text{Minimize} \sqrt{\frac{1}{n}\sum_{i,j=1}^{n}\left(\ln a_{ij} - \ln a'_{ij}\right)^2} \quad (3)$$

$$\text{subject to:} \quad C.R. \leq 0.1$$
$$\ln a_{ij}^{LT} < \ln a'_{ij} < \ln a_{ij}^{UT}$$

The Euclidean distance, a common metric to assess similarities between datasets (Xing et al., 2003), is proposed to evaluate the affinity between the judgments provided by the respondents, so that a symmetric $n \times n$ matrix $[N]$ is obtained from the Euclidean distances between each pair of experts, with n being the number of respondents. Therefore, the weight for each expert is determined as the inverse of the sum of the distances from each respondent to the remaining ones.

These weights were aggregated using the geometric mean, which has been proven to be the proper method to integrate a set of n individual opinions into a unique agreed judgment ($a_{ij,c}$) as the n^{th} root of their product (Aczél et al., 1983), (Aczél et al., 1987). Finally, the weights w_i of the elements in the decision-making tree can be calculated through Eq. (5), whose application must be preceded by the normalization ($a_{ij,cn}$) of the values in the consensual comparison matrix formed of n values of $a_{ij,c}$ as shown in Eq. (4):

$$a_{ij,cn} = \frac{a_{ij,c}}{\sqrt{\sum_{i=1}^{n} a_{i,c}{}^2}} \quad (4)$$

$$w_i = \frac{\sum_{i=1}^{n} \frac{1}{\sqrt{\sum_{i=1}^{n} a_{ij,c}}}}{\sum\sum_{i=1}^{n} \frac{1}{\sqrt{\sum_{i=1}^{n} a_{ij,c}}}} \quad (5)$$

3.4. Data collection

MIVES is a multi-criteria decision-making (MCDM) method that emerged as the result of initial researches conducted by three Spanish institutions: Universidad del País Vasco (UPV), Universitat Politècnica de Catalunya (UPC) and LABEIN-Tecnalia. MIVES was developed through two projects approved in public competitions organized under the Spanish National Research Plan, using value analysis as a platform for decision-making for evaluating alternatives and evaluating sustainability quantitatively (San-Jose et al., 2010). Value functions are the key elements of MIVES, since they enable the transformation of the ratings of alternatives across the indicators, which are commonly measured in different units, into non-dimensional values in the range between 0 and 1 that represent the degree of satisfaction they provide.

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Value functions are defined by five parameters (K_i, C_i, X_{min}, X_{max} and P_i) which determine four different shapes to model these transformations: linear, concave, convex and S-shape. Figure 3 illustrates the parameters to be taken by these functions, as well as the shapes in which they result. S-shape functions include the most relevant increase in satisfaction in the central zone of the curve. On the contrary, convex and concave curves reveal increases in satisfaction in areas close to X_{min} and X_{max}, depending on whether the function is increasing or decreasing. Linear functions consist of a steady increasing or decreasing of satisfaction regardless of the value of the abscissa.

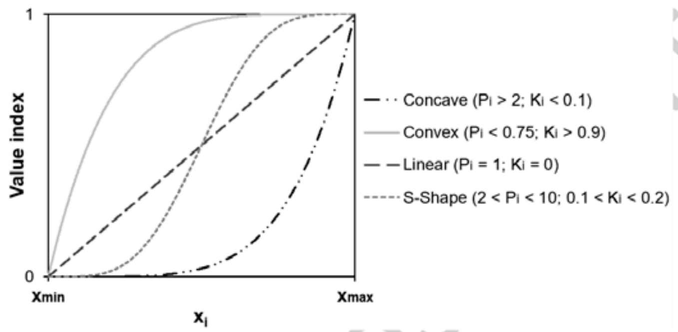

Figure 3. Different shapes and parameters of MIVES value functions

Value functions for increasing indicators are calculated according to Eqs. (6) and (7). If the value of the indicator decreases as its rating increases, X_{min} is replaced by X_{max} in both formulations.

$$V_{ind} = B * \left[1 - e^{-K_i * \left(\frac{|X - X_{min}|}{C_i}\right)^{P_i}}\right] \quad (6)$$

where X_{min} is the abscissa for the minimum value reachable by the indicator, X is the actual rating of the alternative with respect to the indicator, P_i is the form factor and C_i and K_i are the abscissa and ordinate in the inflection point of the curve, respectively. B is an adjusting to ensure that value indices remain in the range $[0,1]$ and is determined by Eq. (7):

$$B = \left[1 - e^{-K_i * \left(\frac{|X_{max} - X_{min}|}{C_i}\right)^{P_i}}\right]^{-1} \quad (7)$$

where X_{max} is the abscissa for the maximum value the indicator might achieve. The overall sustainability index V_i of an alternative is calculated through the aggregation of the value indices from the lower (indicators) to the upper (requirements) levels of the decision-making tree:

$$V_i = \sum_{j=1}^{m} V_{ij} * W_j \quad (8)$$

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where V_{ij} and W_j are the sustainability index and weight for an alternative in relation to the i level in the decision-making tree and m is the number of elements in each level forming the decision-making tree.

Binary stepped value functions (0 or 1) were assigned to those indicators that does not consider intermediate values and are simply evaluated according to whether their purpose is met or not (I1.1.1, I1.12, I1.2.1, I1.3.1, I1.4.1, I1.5.1, I1.6.1, I1.6.2, I2.5.1 and I4.1.1). The parameters to characterize the remaining indicators using the value functions depicted in Figure 3 were defined from data found in international development organizations such as the World Bank, the International Labour Office (ILO), the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), the United Nations Human Settlements programme (UN-HABITAT) and the United Nations Educational Scientific and Cultural Organization (UNESCO). Since these data were collected by international agencies to monitor specific metrics which can differ from the goals sought by some of the indicators included in SIRSDEC, additional information corresponding to developed countries in relation to similar parameters could be considered instead. Furthermore, data included in existing sustainable rating systems were another reference to be used in the definition of value functions if international data did not positively correlate to the set of indicators considered in SIRSDEC.

4. Conclusions

This article presents the methodology to develop a rating tool to appraise infrastructure projects in developing countries (SIRSDEC) according to their contribution to the Triple Bottom Line through the combination of two multi-criteria analysis methods such as AHP and MIVES. In contrast to existing rating systems, which weight criteria and indicators related to sustainability by direct allocation, SIRSDEC uses the judgments received from international experts to determine these weights through an on-line questionnaire based on the AHP pairwise comparison scale. The contribution of infrastructure projects in developing countries to sustainable development across the weighted indicators and criteria is assessed using the value functions provided by MIVES, which facilitate the standardization of indicators and their subsequent unrestricted integration into an overall sustainable value index.

SIRSDEC emphasizes the role of social and economic aspects, including the management dimension as the linkage between the three pillars of sustainable development. In contrast to existing overarching frameworks, which are substantially oriented to environmental issues, the particular context of poorest economies requires balancing the importance of the criteria and indicators belonging to these four aspects, in order to conduct a feasible sustainability assessment. In this line, the proposed tool has established specific criteria and indicators to enhance social and economic impacts of projects on communities. Hence, in the absence of scoring guidelines for developing countries, SIRSDEC provides an effective decision-making tool to be used by public and private not-for-profit organizations, in order to promote the sustainable development of poorer nations through the assessment of infrastructure projects.

Indicators derived from Agenda 21 and the Millennium and Sustainable Development Goals, which are the flagship of sustainable development assessment, have been found to not evaluate properly the sustainable performance in less developed countries. Information collected from public development institutions, United Nations agencies and development banks are mainly focused on health and education, whilst only a minority of indicators refers to relevant factors concerning the Triple Bottom Line. This circumstance hinders the definition of the value functions required to characterize the set of indicators forming SIRSDEC. Consequently, new additional indicators related to social, economic and environmental domains should also be considered in the short time by public institutions to monitor the achievement of sustainable development goals in developing countries accurately.

SIRSDEC can be considered as the starting point of future researches. UN agencies and multilateral banks require effective rating systems to tangibly assess how the large number of infrastructure projects in which they invest every year in poorer countries contribute to sustainable development. The international standardisation of sustainable development indicators involving a balanced consideration between social, economic and environmental aspects, as well as the inclusion of the management dimension as the linkage between them, are the key factors to consider in the analysis of sustainable development. The growing relevance of urbanization trend in developing countries brings a new opportunity to promote the application of frameworks like SIRSDEC for measuring sustainable urban development.

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2.3. Artículo 3: Application of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) to a case study

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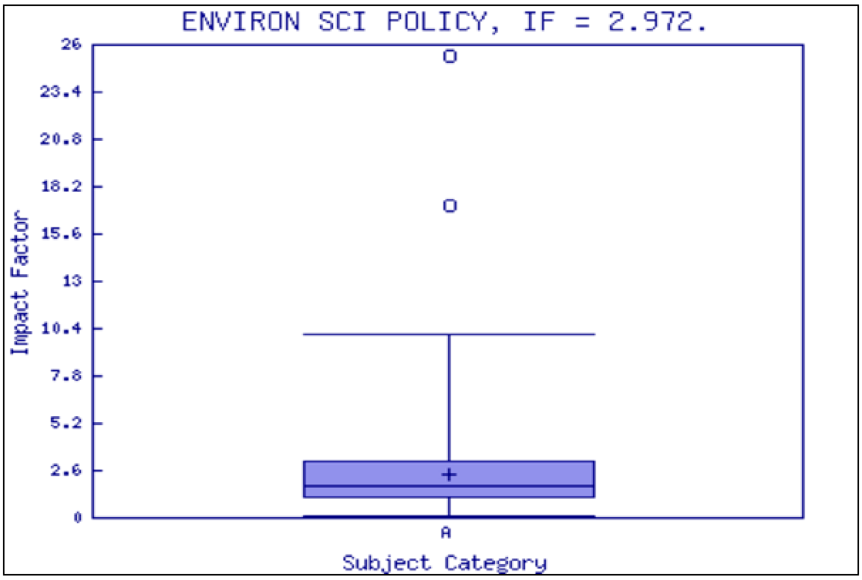

Key

A - ENVIRONMENTAL SCIENCES

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Application of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) to a case study

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Abstract

A large amount of international public and private not-for-profit organizations strives to enhance the conditions of less developed economies under the flagship of sustainability throughout a wide range of infrastructure projects. However, the results are uncertain. Sustainable development in poorer countries requires effective frameworks to ensure the balanced consideration of social, economic and environmental dimensions. This paper discusses the application of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) to a mining infrastructure project located in Peru, in order to validate the methodology developed for this framework. The opinions returned from a questionnaire addressed to international experts according to the pairwise comparison scale of the Analytic Hierarchy Process (AHP) method were processed to obtain the weights of the elements forming the decision-making tree of SIRSDEC. The Integrated Value Model for Sustainable Assessment (MIVES) was introduced to assess infrastructure projects through the definition of value functions for each sustainability indicator, which enables the integration of variables measured in different units into a standardized value index. The weights obtained for SIRSDEC reflected the balance of the three pillars of sustainability, with a slight predominance of the social dimension. The case study highlighted the contribution of the new system to identify key sustainability issues which were omitted in the original project and posed several actions to improve community's perception and facilitate the development of the project.

Keywords

Sustainability; Developing countries; Rating System; SIRSDEC; AHP; MIVES.

1. Introduction

This article complements the structured methodology for creating the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) (Diaz-Sarachaga et al., 2016a) as a decisive response to the urgent need to implement effective frameworks to support the principles of sustainable development worldwide. Existing rating tools for infrastructure do not involve a balanced consideration of social, economic and environmental aspects in the application of sustainability principles in these nations. SIRSDEC emphasizes the role of social and economic issues as a priority for the achievement of sustainable development goals (Gibberd, 2005), because less developed economies cannot be focused on environmental concerns (Libovich, 2005). Furthermore, management has been included as an additional dimension in this framework, in order to ensure that international standards and best practices are also taken into account as key guidelines to foster sustainability (Hiremath et al., 2013).

According to Belton and Steward (Belton et al., 2002), Multi-Criteria Decision Method (MCDM) is an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups to explore decisions that matter. The application of MCDMs provide decision-makers with effective frameworks to confidently select the most suitable options and rank alternatives from best to worst (Greco et al., 2005). The Analytic Hierarchy Process (AHP) (Saaty, 1980) is used in this article due to its simplicity and flexibility to be combined with other MCDMs such as the Integrated Value Model for Sustainable Assessment (MIVES) (ETCG, 2015), which enables standardizing different attributed indicators to easily compare a series of alternatives through a value index.

2. SIRSDEC development framework

2.1. SIRSDEC decision-making tree

SIRSDEC is an overarching framework that appraises the contribution to sustainability of infrastructure projects throughout their design, construction, operation, renovation and demolition/reuse stages. In accordance with the MIVES method, a decision-making tree was designed to structure SIRSDEC according to three hierarchical levels including 4 requirements, 23 criteria and 29 indicators (see Table 1). The requirements were related to the three pillars of sustainability (society, environment and economy) and management concerns, whilst the set of criteria and indicators derived from them were mostly selected after considering the objectives of Agenda 21 (UN, 1992), the Millennium Development Goals (MDGs) established in the United Nations (UN) Millennium Declaration (UN, 2000) and the Sustainable Development Goals (SDGs) adopted by the UN General Assembly on 25 September 2015 (UN, 2015), which are the main guidelines for sustainable development worldwide. The set of 29 indicators included in SIRSDEC are graded in a range from 0 to 1 point each, according to the value functions assigned to them. If all 29 indicators are rewarded with 1 point, the maximum possible SIRSDEC score is 121. Hence, SIRSDEC differentiates three levels of performance: Pass (63), Silver (from 63 to 90) and Gold (>90).

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Table 1. SIRSDEC decision-making tree

R#	Requirement	C #.#	Criteria	I #.#.#	Indicator
R1	Management	C 1.1	International Standards	I 1.1.1	ISO 9001 or equivalent
				I 1.1.2	ISO 14001 or equivalent
		C 1.2	Project Sustainability Management (PSM) plan	I 1.2.1	Project Sustainability Management plan
		C 1.3	Sustainability Risk Management (SRM) plan	I 1.3.1	Sustainability Risk Management plan
		C 1.4	Sustainable Procurement plan	I 1.4.1	Sustainable Procurement plan
		C 1.5	Inspection & Auditing (I&A) plan	I 1.5.1	I&A plan
		C 1.6	Reporting & Lessons Learned (R&LL)	I 1.6.1	Periodic reports distribution
				I 1.6.2	Lessons Learned Log
R2	Society	C 2.1	Community & Stakeholders involvement	I 2.1.1	Stakeholders involvement ratio
		C 2.2	Role of indigenous people and communities	I 2.2.1	Indigenous involvement ratio
		C 2.3	Equitable development	I 2.3.1	Gender average wage ratio (female/male)
		C 2.4	Social impacts & benefits	I 2.4.1	Population impacted by project
				I 2.4.2	Settlements area disturbed
		C 2.5	Cultural Heritage	I 2.5.1	Local cultural assessment
R3	Environment	C 3.1	Natural Ecosystems conservation	I 3.1.1	Impacted ecosystem area ratio
		C 3.2	Biodiversity Ecosystem	I 3.2.1	Endangered species ratio
		C 3.3	Greenhouse gases emissions	I 3.3.1	GHG emissions reduction rate
		C 3.4	Energy consumption	I 3.4.1	Energy savings rate
				I 3.4.2	Renewable energy use rate
		C 3.5	Water management	I 3.5.1	Fresh water consumption reduction
				I 3.5.2	Runoff water stored
		C 3.6	Flooding risk	I 3.6.1	Floodplains area
		C 3.7	Air Quality	I 3.7.1	Air pollutants reduction
		C 3.8	Waste management	I 3.8.1	Waste production decrease
				I 3.8.2	Recycled/reused waste
R4	Economy	C 4.1	Combating poverty	I 4.1.1	Local economic assessment
		C 4.2	Agriculture impacts	I 4.2.1	Farmland area impacted
		C 4.3	Local materials consumption	I 4.3.1	Local materials use rate
		C 4.4	Local employment	I 4.4.1	Local employment rate

2.2. Analysis of questionnaires

An on-line questionnaire using Google Forms was addressed to 118 experts in the field of environmental and sustainable development, including professionals from public and private sectors such as development institutions, academia and industry. Expert participation is a key element for developing a weighting system to be incorporated into a sustainable assessment method (Chandratilake et al., 2013). The survey was conducted over the entire month of January 2016. 24 questionnaires were returned from experts belonging to 12 different countries as shown in Figure 1, which involves a response rate of 20.3%. There were no invalid answers because the questionnaire format forced experts to reply all questions linked to the pairwise comparisons among the requirements, criteria and indicators of SIRSDEC according to the AHP scale (see Table 2). All these respondents had been involved in sustainability-driven projects and are aware of sustainable frameworks. 23 of them had worked with sustainable rating tools, whilst only one had no experience in this matter. 11 respondents (45.8%) were academics, consultant and public sectors were represented by 5 participants (20.8%) each and 3 experts (12.6%) belonged to the contractor industry. The set of entities to which these experts were related are listed below:

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BHP Billiton, Boluda Shipping Corporation and CWG Metro Riyad Joint Venture (Contractor industry); Waterloo University, Malaysia University Technology, Hamad Bin Khalifa University, University of Wisconsin-Madison, Coventry University, Colorado State University and Cardiff University (Academy); Qatar Green Council, AMEC Foster Wheeler, Tecnalia and Atkins (Consultancy); United Nations Office for Project Services (UNOPS), Agencia Española para Cooperación y Desarrollo (AECID), Qatar Foundation, International Organization of Supreme Audit Institutions Working Group on Environmental Auditing (INTOSAI WGEA) (Public development institutions).

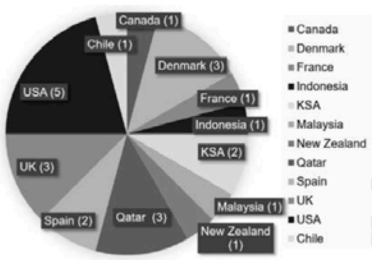

Figure 1. Countries of origin of the experts who responded to the questionnaire

Table 2. AHP pairwise comparison scale

Qualitative evaluation		Rating
Absolutely more important	(AMI)	9
Much more important	(MMI)	7
More important	(MI)	5
Slightly more important	(SMI)	3
Equally important	(EI)	1
Slightly less important	(SLI)	1/3
Less important	(LI)	1/5
Much less important	(MLI)	1/7
Absolutely less important	(ALI)	1/9

The survey also included three general questions to compare SIRSDEC with existing rating tools for infrastructures. 22 respondents (91.7%) considered a sustainable infrastructure rating system focused on developing countries an effective framework for guiding development projects. 15 respondents (62.5%) thought that the three sustainable principles should be equally weighted in the design process of a rating system for developing countries. The addition of management aspects to the sustainable Triple Bottom Line (TBL) was supported by 19 respondents (79.2%). Besides, the participants were invited to propose the removal and/or addition of some criteria and/or indicators to SIRSDEC. Disaster risk reduction for resilience, noise pollution plans and the consideration of the relationships with authorities were the three additional criteria suggested by the experts. Two new indicators were also proposed to be incorporated into the system: amount of land cleared and embodied energy in built infrastructure. Finally, some respondents showed their preference to discard C1.3, I1.1.1 and I1.3.1. Since these parameters belong to the management requirement, which is deemed to be the fourth pillar of sustainability, they remained in the SIRSDEC decision-making tree to emphasize the role of this dimension. Table 3 shows the linguistic comparisons (see Table 2) provided by the experts with respect to each pair of elements in the decision-making tree.

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Table 3. Experts' judgments according to the elements in the decision-making tree

Pairwise Comparison	Expert Number																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
R1 vs R2	SLI	LI	MLI	EI	EI	SMI	MLI	EI	SLI	EI	MI	EI	SLI	SLI	LI	SLI	LI	EI	SLI	EI	SLI	SLI	MLI	SMI
R1 vs R3	SLI	LI	ALI	EI	EI	LI	MLI	AMI	SLI	EI	EI	EI	EI	SLI	EI	SLI	SLI	EI	SLI	EI	MLI	MI	MLI	SMI
R1 vs R4	SLI	LI	ALI	EI	EI	LI	ALI	ALI	SLI	SLI	EI	SLI	EI	SLI	EI	SLI	EI	EI	SLI	SLI	MLI	SMI	MLI	SMI
R2 vs R3	EI	EI	EI	EI	EI	SLI	MI	EI	EI	SLI	EI	SMI	EI	EI	MMI	SLI	EI	EI	EI	SMI	EI	MI	EI	EI
R2 vs R4	EI	MI	MI	EI	EI	LI	SLI	EI	EI	EI	EI	SMI	SMI	SMI	SMI	SLI	SMI	EI	EI	SMI	SMI	MMI	EI	EI
R3 vs R4	EI	MI	MI	SMI	EI	MI	LI	LI	EI	EI	EI	SLI	MI	SMI	LI	SLI	SMI	EI	EI	EI	MI	MI	EI	EI
C1.1 vs C1.2	SLI	SLI	EI	SMI	MLI	EI	MI	LI	LI	LI	SMI	LI	EI	LI	SLI	EI	LI	LI	LI	EI	ALI	EI	MI	MMI
C1.1 vs C1.3	SLI	MLI	SLI	SMI	MLI	EI	MI	AMI	LI	SLI	LI	SMI	LI	LI	MI	EI	MI	SMI	LI	LI	ALI	MMI	SMI	MMI
C1.1 vs C1.4	SLI	MLI	SMI	SMI	MLI	MI	MI	MMI	LI	ALI	EI	SLI	LI	LI	EI	EI	MI	SLI	LI	SMI	ALI	MI	MI	SMI
C1.1 vs C1.5	SLI	MLI	MLI	SMI	ALI	EI	SLI	MI	EI	SLI	MI	SLI	EI	LI	SMI	EI	LI	EI	SLI	SLI	ALI	EI	SMI	MI
C1.1 vs C1.6	SLI	MLI	LI	SMI	MLI	MI	MI	LI	LI	LI	MI	SMI	LI	SLI	EI	SMI	LI	MI	EI	SLI	ALI	MMI	EI	SMI
C1.2 vs C1.3	EI	EI	MI	EI	EI	SMI	MI	SLI	SMI	EI	MI	SLI	EI	SLI	SMI	SMI	SMI	MI	EI	SMI	EI	MMI	SLI	MMI
C1.2 vs C1.4	EI	EI	MMI	EI	EI	SMI	MI	SLI	SMI	EI	EI	SLI	MMI	SLI	EI	EI	MI	SMI	EI	SMI	EI	MMI	SLI	SMI
C1.2 vs C1.5	EI	EI	EI	MI	LI	EI	LI	SLI	EI	EI	MI	SMI	MMI	SLI	EI	EI	EI	EI	EI	SMI	EI	LI	SMI	MI
C1.2 vs C1.6	EI	EI	SMI	EI	LI	EI	MI	EI	SMI	EI	MI	EI	SMI	EI	MI	EI	EI	MI	EI	SMI	MI	EI	SLI	SMI
C1.3 vs C1.4	EI	EI	MI	SLI	SLI	EI	SMI	EI	SMI	EI	EI	SLI	MMI	SMI	EI	EI	SMI	SLI	SLI	SMI	EI	SLI	MI	SMI
C1.3 vs C1.5	EI	EI	EI	SMI	LI	EI	LI	MI	SLI	SLI	EI	EI	MI	SLI	EI	EI	SLI	LI	SMI	SLI	SMI	MLI	SMI	MI
C1.3 vs C1.6	EI	SMI	SLI	SLI	LI	EI	EI	EI	SLI	EI	MI	SMI	EI	SLI	LI	EI	SLI	SLI	EI	SLI	SMI	LI	SLI	SMI
C1.4 vs C1.5	EI	MI	SLI	SMI	LI	EI	SLI	SLI	LI	SMI	MI	SMI	EI	SLI	EI	EI	LI	EI	EI	SLI	SMI	LI	EI	SMI
C1.4 vs C1.6	EI	EI	SLI	EI	LI	EI	MI	SLI	LI	EI	EI	SLI	LI	SLI	LI	EI	LI	SMI	EI	SLI	EI	SLI	SLI	SLI
C1.5 vs C1.6	EI	EI	EI	SLI	EI	EI	MI	EI	EI	SLI	MI	SMI	LI	SMI	EI	EI	EI	EI	SLI	EI	EI	MLI	EI	SMI
C2.1 vs C2.2	EI	SLI	SLI	SLI	EI	EI	MMI	SLI	SMI	LI	MI	SLI	EI	EI	MI	SLI	EI	EI	SLI	LI	EI	EI	EI	MI
C2.1 vs C2.3	SMI	SMI	EI	EI	MI	SMI	SMI	SLI	SLI	LI	MMI	EI	EI	EI	EI	SLI	EI	EI	SLI	SLI	EI	EI	EI	MI
C2.1 vs C2.4	SLI	LI	SLI	EI	EI	SMI	SMI	SLI	EI	EI	MMI	SLI	LI	LI	LI	EI	SMI	EI	SLI	SLI	EI	EI	EI	MI
C2.1 vs C2.5	LI	SMI	SLI	SMI	EI	SLI	LI	SLI	EI	SLI	MMI	SLI	SLI	SLI	EI	EI	MI	EI	SLI	MLI	EI	EI	EI	MI
C2.2 vs C2.3	EI	MI	MI	SMI	MI	EI	SLI	AMI	SLI	EI	EI	SMI	EI	SLI	SMI	SMI	EI	EI	EI	MI	EI	SLI	SLI	EI
C2.2 vs C2.4	EI	EI	MI	EI	MI	SMI	LI	AMI	LI	EI	SMI	SMI	EI	LI	EI	SMI	EI	EI	EI	SMI	EI	LI	EI	EI
C2.2 vs C2.5	EI	MI	EI	SMI	EI	EI	MLI	AMI	SLI	EI	MI	SLI	SLI	SLI	EI	SMI	LI	SMI	SMI	EI	EI	EI	EI	EI
C2.3 vs C2.4	EI	SLI	EI	EI	EI	SMI	SMI	MMI	EI	SMI	MMI	SMI	SMI	SLI	LI	EI	EI	EI	EI	SMI	LI	SMI	MI	SMI
C2.3 vs C2.5	EI	SMI	EI	SMI	EI	SLI	SLI	AMI	SMI	MI	MI	SMI	SMI	SLI	EI	EI	MI	MI	SMI	EI	LI	EI	EI	EI
C2.4 vs C2.5	SMI	MI	MI	EI	EI	EI	SMI	EI	MI	SMI	MMI	SLI	SMI	SMI	EI	EI	MI	MI	SMI	SLI	EI	EI	EI	SMI
C3.1 vs C3.2	EI	EI	EI	EI	EI	SMI	MI	MMI	MI	EI	EI	SMI	MI	EI	EI	EI	EI	EI	EI	EI	EI	EI	EI	EI
C3.1 vs C3.3	EI	SMI	EI	EI	MI	LI	MI	LI	EI	EI	EI	SLI	EI	SMI	EI	EI	EI	EI	SMI	SMI	EI	EI	SLI	EI
C3.1 vs C3.4	EI	SMI	MI	EI	MI	LI	MMI	MI	EI	EI	EI	SMI	SMI	SMI	MI	MMI	EI	MI	EI	SMI	EI	MMI	EI	MI
C3.1 vs C3.5	EI	EI	SMI	EI	EI	LI	MMI	AMI	EI	EI	EI	SMI	SMI	SMI	LI	SMI	EI	MI	EI	SLI	EI	EI	SLI	SMI
C3.1 vs C3.6	EI	SMI	MMI	EI	EI	LI	MI	AMI	EI	EI	EI	MI	MI	SMI	SLI	SMI	SMI	EI	SLI	SLI	EI	LI	SMI	SMI
C3.1 vs C3.7	EI	SMI	EI	SLI	MI	LI	MI	LI	EI	EI	MI	SMI	SMI	SMI	EI	SMI	SLI	EI	EI	SMI	EI	SLI	SLI	SMI
C3.1 vs C3.8	EI	SMI	SLI	SLI	SMI	LI	MI	LI	EI	EI	MI	MI	SMI	SMI	LI	SMI	SMI	MI	EI	SMI	EI	SLI	EI	MI
C3.2 vs C3.3	EI	EI	EI	SLI	MI	LI	MI	AMI	SLI	SLI	MI	MI	SMI	SMI	MI	SMI	EI	EI	SLI	LI	EI	LI	LI	EI
C3.2 vs C3.4	EI	EI	EI	EI	MI	LI	MI	AMI	SLI	EI	MI	MI	MI	SMI	MI	SMI	SMI	MI	SLI	SLI	MI	LI	EI	MI
C3.2 vs C3.5	EI	EI	EI	EI	EI	LI	SMI	AMI	SLI	EI	MI	LI	MI	SMI	EI	SMI	EI	SMI	AMI	SMI	EI	EI	SLI	SMI
C3.2 vs C3.6	EI	EI	SMI	EI	EI	LI	MI	AMI	SLI	EI	MI	SMI	MMI	SMI	LI	SMI	EI	MI	SMI	SMI	MI	SLI	EI	SMI
C3.2 vs C3.7	EI	EI	EI	EI	MI	LI	MI	ALI	SLI	EI	MI	SMI	MI	SMI	LI	SMI	EI	SMI	EI	SMI	SMI	SLI	EI	EI
C3.2 vs C3.8	EI	EI	SMI	EI	SMI	LI	SMI	AMI	SLI	EI	MI	MI	SMI	SMI	LI	SMI	SMI	MI	EI	SMI	EI	EI	SMI	SMI
C3.3 vs C3.4	EI	EI	MI	EI	EI	MI	LI	EI	EI	EI	EI	MMI	LI	SMI	MLI	SLI	EI	SMI	LI	EI	EI	EI	MI	MI
C3.3 vs C3.5	EI	SLI	SMI	EI	LI	SMI	LI	AMI	EI	EI	EI	MI	EI	SMI	MLI	SLI	SLI	EI	SLI	EI	EI	EI	SMI	EI
C3.3 vs C3.6	EI	EI	MI	SLI	LI	MMI	SLI	AMI	EI	EI	EI	MI	MI	SMI	ALI	EI	SLI	EI	SLI	SMI	MI	MI	SMI	EI
C3.3 vs C3.7	EI	EI	EI	EI	EI	AMI	SLI	EI	EI	EI	MMI	EI	EI	EI	LI	EI	SLI	EI	SLI	SMI	MI	MI	EI	EI
C3.3 vs C3.8	EI	EI	SMI	EI	LI	MI	LI	EI	EI	EI	MI	EI	EI	EI	MLI	EI	MI	MI	SLI	SMI	EI	MI	MI	SMI
C3.4 vs C3.5	EI	EI	SLI	SMI	LI	AMI	SLI	MLI	EI	EI	MI	EI	EI	EI	LI	EI	EI	SLI	EI	EI	LI	EI	LI	EI
C3.4 vs C3.6	EI	SLI	SLI	EI	LI	EI	MI	AMI	EI	EI	MI	SLI	MI	SMI	LI	EI	SMI	SLI	SMI	SLI	EI	SMI	SLI	SMI
C3.4 vs C3.7	EI	EI	LI	EI	EI	MI	MI	EI	EI	EI	SLI	SMI	EI	EI	SMI	SMI	SLI	SLI	SMI	SMI	SMI	EI	SLI	SLI
C3.4 vs C3.8	EI	EI	SLI	SMI	EI	SMI	SLI	EI	EI	EI	MMI	SMI	EI	EI	SLI	EI	MI	EI	SMI	EI	LI	SLI	SLI	SMI
C3.5 vs C3.6	MI	EI	EI	EI	EI	MI	MI	AMI	EI	EI	MMI	SMI	MI	SMI	MMI	EI	SLI	EI	EI	EI	MI	MMI	SMI	EI
C3.5 vs C3.7	EI	EI	EI	EI	MI	LI	SMI	AMI	EI	EI	MMI	EI	EI	EI	MMI	SMI	SLI	EI	SMI	SMI	MI	EI	SLI	SLI
C3.5 vs C3.8	EI	SMI	SMI	SMI	EI	EI	SLI	EI	EI	EI	EI	EI	EI	EI	SMI	SMI	SMI	MI	SMI	EI	EI	SLI	SMI	MI
C3.6 vs C3.7	EI	EI	SLI	EI	MI	LI	LI	AMI	EI	EI	EI	EI	LI	SLI	MMI	EI	EI	EI	EI	SMI	EI	LI	SLI	SLI
C3.6 vs C3.8	EI	SMI	MI	EI	EI	LI	LI	EI	EI	EI	SMI	SLI	LI	SLI	SLI	SLI	SMI	MI	SMI	SMI	LI	LI	SLI	SMI
C3.7 vs C3.8	EI	EI	MI	EI	EI	LI	SLI	ALI	EI	EI	EI	EI	EI	EI	SLI	EI	SMI	MI	EI	SLI	LI	SLI	SMI	SMI
C4.1 vs C4.2	EI	EI	MMI	EI	EI	MI	SLI	EI	SMI	MI	EI	EI	SLI	SMI	EI	SMI	MI	MI	EI	MI	EI	AMI	EI	SLI
C4.1 vs C4.3	EI	SMI	MMI	SMI	EI	MI	SLI	AMI	SMI	SMI	EI	SMI	EI	MI	MMI	SMI	MI	MI	EI	MI	MI	EI	MMI	EI
C4.1 vs C4.4	EI	SMI	MI	SMI	EI	MI	LI	AMI	SMI	SMI	MI	MI	EI	SLI	MMI	SMI	EI	EI	EI	SMI	EI	SMI	EI	SMI
C4.2 vs C4.3	EI	MI	MI	SMI	EI	SMI	MLI	EI	EI	SLI	MI	SMI	SMI	MI	AMI	EI	EI	EI	EI	EI	MI	LI	SMI	MI
C4.2 vs C4.4	EI	MI	MI	EI	EI	SMI	MLI	EI	SLI	EI	MI	SMI	MI	MI	AMI	EI	EI	SLI	EI	SLI	EI	MLI	EI	MI
C4.3 vs C4.4	EI	LI	EI	EI	LI	SMI	SLI	EI	EI	EI	MI	SLI	EI	LI	MMI	EI	EI	EI	EI	SLI	MLI	EI	LI	SLI
I1.1.1 vs I1.1.2	EI	LI	LI	EI	EI	EI	SLI	SLI	EI	SLI	SMI	MLI	EI	EI	LI	EI	EI	EI	EI	EI	ALI	MI	EI	SLI
I1.6.1 vs I1.6.2	EI	MI	MI	SLI	MLI	MI	SLI	EI	SLI	MLI	SMI	MLI	SMI	EI	EI	EI	EI	MI	SLI	SLI	ALI	SMI	MI	SLI
I2.4.1 vs I2.4.2	EI	SMI	MMI	SMI	LI	MMI	MMI	MMI	MI	EI	MI	EI	MMI	SMI	EI	SMI	SLI	SMI	MI	SLI	EI	MMI	MI	MI
I3.4.1 vs I3.4.2	SLI	EI	MLI	SLI	LI	AMI	MI	EI	LI	EI	SMI	LI	MLI	LI	MLI	LI	MI	LI	SMI	SMI	EI	LI	LI	MI
I3.5.1 vs I3.5.2	SLI	MI	AMI	SLI	EI	MI	LI	MI	MI	EI	MI	EI	LI	MLI	SLI	EI	MI	EI	SLI	SLI	EI	MLI	MMI	MI
I3.8.1 vs I3.8.2	SLI	MMI	MLI	SLI	MLI	MI	MMI	EI	MI	MI	EI	SMI	MLI	EI	MI	MLI	MI	MLI	LI	SMI	LI	SLI	EI	MI

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2.3. Weighting of the elements in the decision-making tree

The weighting of the elements in the hierarchy into which SIRSDEC is structured is essential to support its realistic application. The AHP method (Saaty, 1990) was used to assess the pairwise comparisons of expert judgments. Table 4 includes the values of C.R. obtained after evaluating the consistency of the comparisons received from each expert in relation to requirements and criteria. The results showed that the number of inconsistent comparisons exceeded 50% for each group (C.R. > 0.1). The comparisons associated with the economic and environmental criteria included 13 inconsistencies each, whilst those related to social criteria and the four requirements involved 14 and 12 inconsistencies, respectively. The highest number of inconsistencies (16) corresponded to the management criteria.

Table 4. Summary of the consistency analysis of the comparisons provided by the respondents

Respondent #	Requirement	Economic criteria	Social criteria	Management criteria	Environmental criteria
	C.R.	C.R.	C.R.	C.R.	C.R.
1	0.000	0.000	0.237	0.000	0.028
2	0.139	0.150	0.076	0.087	0.047
3	0.166	0.178	0.255	0.193	0.208
4	0.058	0.058	0.080	0.068	0.090
5	0.000	0.131	0.123	0.092	0.041
6	0.292	0.124	0.165	0.090	0.308
7	0.171	0.210	0.404	0.235	0.182
8	0.644	0.257	0.376	0.734	1.391
9	0.000	0.059	0.076	0.218	0.003
10	0.184	0.043	0.139	0.088	0.012
11	0.131	0.132	0.250	0.373	0.278
12	0.181	0.105	0.274	0.442	0.332
13	0.098	0.012	0.262	0.231	0.124
14	0.059	0.551	0.046	0.153	0.041
15	0.086	0.226	0.281	0.204	0.315
16	0.120	0.000	0.034	0.045	0.093
17	0.012	0.127	0.420	0.130	0.122
18	0.000	0.103	0.070	0.135	0.051
19	0.000	0.000	0.035	0.126	0.252
20	0.184	0.016	0.086	0.193	0.213
21	0.197	0.005	0.105	0.079	0.082
22	0.201	0.057	0.126	0.373	0.371
23	0.000	0.005	0.073	0.254	0.171
24	0.000	0.169	0.098	0.355	0.088
Consistent comparisons	12	11	10	8	11
Inconsistent comparisons	12	13	14	16	13

The Grubbs' test (Grubbs, 1950) was undertaken to detect outliers in the values of C.R. (see Figure 2). Respondent #8 provided extreme comparisons in relation to requirements, management criteria and environmental criteria, whilst respondent #14 was too inconsistent with respect to the economic criteria.

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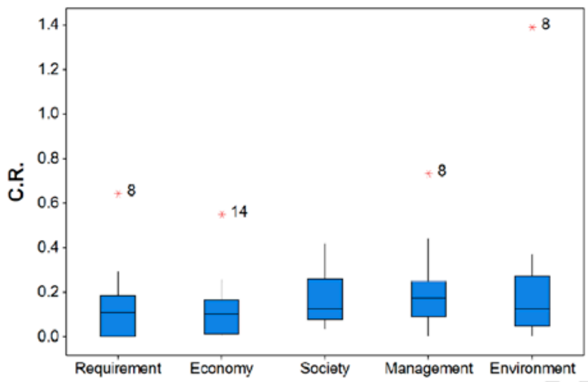

Figure 2. Boxplots of the values of C.R. associated with the pairwise comparisons provided by the experts

The methodology proposed by Jato-Espino et al. (2016), consisting on the Generalized Reduced Gradient (GRG) algorithm (Abadie et al., 1968) and an aggregation system based on the proximity between the judgments of each pair of respondents, was used to adjust the inconsistent judgments found in the returned questionnaires and integrate them into a consensual set of weights. The application of the GRG algorithm made consistent every comparison with a value of C.R. > 0.1, except those provided by the respondent #8, who proved to be too inconsistent with respect to several comparisons and was therefore discarded for further analyses. Since the remaining experts were found to be too inconsistent only for one isolated comparison each at most, their remaining judgments were considered henceforth.

Table 5 shows the consensual weights obtained for each element of the decision-making tree after aggregating the consistent judgments of the experts according to their similarity of thought, in order to give more importance to those who proved to have closer points of view. The social dimension reached the highest weight (0.324), followed by Environment (0.289), Economy (0.247) and Management (0.140). These values ensured the achievement of a balance among the weights of the pillars of sustainable development. Combating poverty (C4.1) was found to be the most important factor in economic terms, whilst Natural Ecosystems conservation (C3.1) and Biodiversity Ecosystem (C3.2) were the criteria with the highest weights in the environmental domain. As for the social requirement, three criteria highlighted over the rest: Role of indigenous people & communities (C2.2), Equitable Development (C2.3) and Social impacts & Benefits (C2.4). Finally, the results demonstrated that Project Sustainability Management plan (C1.2) was the most relevant criterion in the management category.

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Table 5. Weights for the elements in the SIRSDEC decision-making tree

Requirement R#	Weight $W_{R\#}$	Criteria C#.#	Weight $W_{C\#.\#}$	Indicator I#.#.#	Weight $W_{I\#.\#.\#}$
R1	0.140	C1.1	0.112	I1.1.1	1.000
				I1.1.2	1.000
		C1.2	0.230	I1.2.1	1.000
		C1.3	0.148	I1.3.1	1.000
		C1.4	0.135	I1.4.1	1.000
		C1.5	0.171	I1.5.1	1.000
		C1.6	0.204	I1.6.1	1.000
				I1.6.2	1.000
R2	0.324	C2.1	0.179	I2.1.1	1.000
		C2.2	0.214	I2.2.1	1.000
		C2.3	0.211	I2.3.1	1.000
		C2.4	0.222	I2.4.1	1.000
				I2.4.2	1.000
		C2.5	0.174	I2.5.1	1.000
R3	0.289	C3.1	0.169	I3.1.1	1.000
		C3.2	0.155	I3.2.1	1.000
		C3.3	0.130	I3.3.1	1.000
		C3.4	0.102	I3.4.1	1.000
				I3.4.2	1.000
		C3.5	0.143	I3.5.1	1.000
				I3.5.2	1.000
		C3.6	0.094	I3.6.1	1.000
		C3.7	0.109	I3.7.1	1.000
		C3.8	0.098	I3.8.1	1.000
				I3.8.2	1.000
R4	0.247	C4.1	0.398	I4.1.1	1.000
		C4.2	0.256	I4.2.1	1.000
		C4.3	0.145	I4.3.1	1.000
		C4.4	0.201	I4.4.1	1.000

2.4. Characterization of indicators using value functions

The eight indicators included in the management requirement promote the use of effective project governance frameworks, sustainable best practices and standards focused on enhancing management in infrastructure projects. Binary stepped value functions were assigned to all indicators in this category. Hence, 0 or 1 points are allocated to them depending on whether the goals they seek are met or not. The same principle was also applied to indicators I2.5.1 and I4.1.1. Regarding the social requirement, indicators I2.1.1 and I2.2.1 are also rated using binary stepped functions according to standards of the International Association for Public Participation (IAP2, 2016). Projects in which stakeholders, population and/or indigenous community are at least involved are rewarded with 1 point, otherwise they are rated with 0 points.

Increasing linear functions were set for indicators I3.3.1, I3.4.1, I3.4.2, I3.5.1, I3.5.2, I3.8.1 and I3.8.2 to reward the performance of indicators proportionally. Due to the scarcity of metrics for developing countries, the lower and upper values for these value functions were based on thresholds established by existing sustainable infrastructure rating systems (Envision (ISI, 2012), Civil Engineering Environmental Quality (CEEQUAL, 2015) and Infrastructure Sustainability (IS) Rating Tool (ISCA, 2012)) for equivalent indicators. The minimum and maximum values for indicators I2.4.2, I3.1.1, I3.2.1 and I4.2.1 were extracted from the same data source. These indicators were characterized through concave value functions, in order to reward projects that have low values

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with respect to them. Indicators I2.3.1 and I4.1.1 were represented by increasing convex value functions, with their bounds delimited according to reports from the International Labor Organization (ILO) (ILO, 2015).

S-shape was found to be the most appropriate value function for indicators I2.4.1, I3.6.1, I3.7.1 and I4.3.1. These indicators were defined again from thresholds found in existing infrastructure rating systems, with the exception of I3.7.1, whose range of values was taken from the NEC directive 2001/81/EC (EU, 2016). Table 6 summarizes the parameters that characterize the value functions defined for each indicator included in SIRSDEC.

Table 6. Parameters established for the value functions to characterize each indicator in SIRSDEC

Indicator	Xmin	Xmax	Pi	Ci	Ki	Function
I 1.1.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.1.2	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.2.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.3.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.4.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.5.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.6.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.6.2	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 2.1.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 2.2.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 2.3.1	51.00	99.00	0.75	51.00	4.000	Convex
I 2.4.1	25.00	0.00	3.00	5.00	0.020	S-Shape
I 2.4.2	20.00	0.00	5.00	3.00	0.002	Concave
I 2.5.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 3.1.1	30.00	0.00	2.50	15.00	0.050	Concave
I 3.2.1	30.00	0.00	2.50	15.00	0.050	Concave
I 3.3.1	10.00	40.00	1.00	40.00	1.000	Linear
I 3.4.1	10.00	30.00	1.00	30.00	1.000	Linear
I 3.4.2	10.00	25.00	1.00	25.00	1.000	Linear
I 3.5.1	5.00	20.00	1.00	20.00	1.000	Linear
I 3.5.2	0.00	30.00	1.00	30.00	1.000	Linear
I 3.6.1	15.00	0.00	5.00	8.00	0.250	S-Shape
I 3.7.1	0.00	52.00	5.50	11.00	0.015	S-Shape
I 3.8.1	0.00	20.00	1.00	20.00	1.000	Linear
I 3.8.2	20.00	50.00	1.00	50.00	1.000	Linear
I 4.1.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 4.2.1	30.00	0.00	2.50	15.00	0.050	Concave
I 4.3.1	0.00	30.00	3.00	5.00	0.025	S-Shape
I 4.4.1	10.00	30.00	0.70	30.00	2.000	Convex

3. A case study in the Arequipa Region, Peru: The Tia Maria project

Southern Copper, a multinational leading copper mining company, is developing the Tia Maria project at the province of Islay in the Peruvian Arequipa Region. The project, which is scheduled to start operations by 2017 and foresees an initial estimated production of 120,000 tons of copper for the first year, involves the construction of a raft leaching with a capacity of 131,250 m³ across a surface of 37,500 m². The Environmental Impact Assessment (EIA) of the Tia Maria project was approved by the Peruvian Ministry of Energy and Mines in August 2014. However, the outright rejection of the project by the community of Islay has forced Southern Copper to temporarily paralyze the project in order to clarify a series of issues with the inhabitants of the area.

The aim of the case study is the application of SIRSDEC to the raft leaching project in Peru, taking into account information of the approved EIA to appraise its sustainability. According to the United Nations specifications (UN-Habitat, 2015), countries with a Human Development Index (HDI) below 0.8 are considered as Developing Countries. The 2015 HDI of Peru is 0.734, which justifies the use of SIRSDEC to assess this project from the perspective of the TBL.

As a result of the application of mandatory Southern Copper policies and standards, every project developed by the firm must be aligned with ISO 9001 and 14001 specifications (C1.1) and include Project Sustainability Management and Sustainability Risk Management plans (C1.2 and C1.3). In addition, Sustainable procurement and Inspection & Auditing plans (C1.4 and C1.5) are also implemented in all projects carried out by this company. Lessons learned from the past are logged and distributed among the organization staff to decrease the repetition of the same mistakes in the future (C1.6). Consequently, all management indicators for the Tia Maria project were rewarded with 1 point each.

The involvement of community, stakeholders and indigenous people during the project development was null. Furthermore, 35% of local population might be impacted by the project. Consequently, the value of I2.1.1, I2.2.1 and I2.4.1 was 0. The fact that there was no disturbance to settlements, farmland area and floodplains granted 1 point to I2.4.2, I4.2.1 and I3.6.1. Company standards also demanded the assessment of local cultural heritage and economy and the equality of wages for both sexes, which rewarded I2.4.2, I2.5.1, I4.1.1 and I2.3.1 with 1 point.

The project did not envisage energy savings, use of renewables and runoff water storage, which allocated 0 points to I3.4.1, I3.4.2 and I3.5.2. The impact of the project was estimated to affect 37% of endangered species and 10% of local employment, which rewarded I3.2.1 and I4.4.1 with 0 points. 8% of impacted ecosystem area and fresh water consumption reduction granted 0.5 and 0.26 points to I3.1.1 and I3.5.1, respectively. Waste production and waste recycled/reused experienced a decrease in 15% and 47%, so that indicators I3.8.1 and I3.8.2 received 0.83 and 0.95 points each. Local materials consumption was calculated to be 12%, which means a value of 0.29 for I.4.3.1. GHG emissions and Air pollutants reduction were 18% and 23%, which resulted in values of 0.34 and 0.58 for indicators I3.3.1 and I3.7.1. Table 7 summarizes the ratings and values reached by the SIRSDEC indicators for the Tia Maria project.

Table 7. Assessment of SIRSDEC Indicators for the Tia Maria project

	Indicator	Tia Maria project Indicator rating	Tia Maria project indicator value
(*)	I 1.1.1	1.00	1.00
(*)	I 1.1.2	1.00	1.00
(*)	I 1.2.1	1.00	1.00
	I 1.3.1	1.00	1.00
(*)	I 1.4.1	1.00	1.00
(*)	I 1.5.1	1.00	1.00
	I 1.6.1	1.00	1.00
	I 1.6.2	1.00	1.00
(*)	I 2.1.1	Not involved	0.00
	I 2.2.1	Not involved	0.00
(*)	I 2.3.1	100%	1.00
	I 2.4.1	35%	0.00
	I 2.4.2	0.00	1.00
(*)	I 2.5.1	1.00	1.00
(*)	I 3.1.1	8%	0.50
	I 3.2.1	37%	0.00
(*)	I 3.3.1	18%	0.34
	I 3.4.1	0%	0.00
	I 3.4.2	0%	0.00
(*)	I 3.5.1	8%	0.26
(*)	I 3.5.2	0%	0.00
(*)	I 3.6.1	0%	1.00
	I 3.7.1	23%	0.58
	I 3.8.1	15%	0.83
	I 3.8.2	47%	0.95
(*)	I 4.1.1	1.00	1.00
	I 4.2.1	0%	1.00
	I 4.3.1	12%	0.29
(*)	I 4.4.1	10%	0.00
SIRSDEC score			69.66

(*) Mandatory indicators

Even though the SIRSDEC score obtained was 69.66 (Silver), which is over 63.00 (Pass), the project did not fulfil some mandatory indicators such as I2.1.1, I3.1.1, I3.3.1, I3.5.2 and I4.4.1. Consequently, the Tia Maria project did not reach the minimum score required to pass the SIRSDEC evaluation. Moreover, the values for indicators I2.4.1, I3.2.1, I3.4.1, I3.4.2 and I4.2.1 were out of the system thresholds.

Some actions were suggested to be implemented in the project to fulfill the principles being sought by SIRSDEC and reach the Pass level of achievement, including the reduction of current social rejection. These actions intended to enhance the involvement of social stakeholders and indigenous community, in order to increase the knowledge about the project among population throughout a broad information campaign and periodic meetings with the community. The main concern of inhabitants is the negative impact of mining project on farmlands, because agriculture is their primary source of income. In this sense, the majority of manpower might be appointed among local inhabitants during the construction stage and remain during the operation of the mine. Hence, the rise of the local employment ratio up to 25% of population could contribute to mitigate economic concerns.

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The raft leaching project would also incorporate additional design improvements to prevent from the break and overflow of the infrastructure, which might have very negative impacts on both ecosystem and biodiversity. These changes also would reduce GHG and air pollutants emissions. The construction of a runoff water tank would enable the reduction of fresh water consumption. Furthermore, the installation of new photovoltaic panels would contribute to saving energy and increasing the use of renewables. Table 8 includes the proposed actions and their impact in the re-assessment of the affected indicators. The implementation of these new measures would result in a SIRSDEC score for the Tia Maria project of 95.10 (Gold), including the fulfillment of all mandatory indicators and keeping within the ranges established by the framework.

Table 8. Re-assessment of affected SIRSDEC indicators

Indicator	Action	Initial indicator rating	Final indicator rating	Initial indicator value	Final indicator value
(*) I2.1.1	Information Campaign and meetings	Not involved	Involved	0.00	1.00
I2.2.1	Information Campaign and meetings	Not involved	Involved	0.00	1.00
I2.4.1	Design improvements & increase of local employment rate	35%	23%	0.00	0.01
(*) I3.1.1	Design improvements	8%	0%	0.50	1.00
I3.2.1	Design improvements	37%	23%	0.00	0.03
(*) I3.3.1	Design improvements	18%	40%	0.34	1.00
I3.4.1	Design improvements	0%	11%	0.00	0.07
I3.4.2	Photovoltaic panels	0%	14%	0.00	0.33
(*) I3.5.1	Runoff water tank construction	8%	15%	0.26	0.75
(*) I3.5.2	Runoff water tank construction	0%	20%	0.00	0.77
I3.7.1	Design improvements	23%	29%	0.58	0.96
I4.4.1	local employment priority	10%	25%	0.00	0.91

Although Table 5 shows a set of consensual weights which is considered valid for all developing countries because it comes from the responses provided by worldwide specialists in sustainability, sensitivity analysis was conducted to determine the response of SIRSDEC when some of these weights are altered. In particular, a new scenario was designed to replicate the average distribution of weights considered in existing sustainable infrastructure rating systems in developed countries: CEEQUAL, Infrastructure Sustainability (IS) and Envision Superior. According to Diaz-Sarachaga et al. (2016b), the economic, environmental and social requirements in these systems reached average weights of 0.103, 0.682 and 0.215, respectively. The re-assessment of the Tia Maria project using SIRSDEC after modifying the weights in Table 5 according to these values resulted in a score of 54.16, which is under 63.00 (Pass) and, by extension, under the score obtained for the weighting scenario determined from the opinions provided by the experts: 69.66 (Silver). This fact highlighted the need to increase the importance of social and economic aspects in the assessment of infrastructure projects in developing countries to obtain a realistic valuation of their contribution to sustainability, as pointed out in Diaz-Sarachaga et al. (2016a, 2016b).

4. Conclusions

Massive international investments on sustainable development in poorer countries demand effective guidelines and frameworks to ensure the achievement of sustainable goals. Assessment tools require the development of customized indicators from international development agencies that emphasize the role of infrastructure as a key driver for sustainable development. This article presents the step-by-step application of the methodology created for the design of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) through an infrastructure project located in the Arequipa Region (Peru).

The analysis of the responses in the questionnaires sent to intentional experts revealed that they valued positively the creation of a sustainable infrastructure rating system focused on developing countries. The distribution of weights for the requirements resulted in an almost complete balance between the three pillars of sustainable development, with a slight predominance of the social dimension (32.4%) over the environmental (28.9%) and economic (24.7%) aspects. This was one of the aims of SIRSDEC in comparison with existing infrastructure rating systems, which are biased towards environmental concerns. The experts also welcomed the initiative of including management as the fourth requirement to strengthen the linkage between the three cornerstones forming the Triple Bottom Line.

The AHP method was used to transform the linguistic opinions provided by the experts into numerical pairwise comparisons. The inconsistences found in the returned questionnaires were adjusted using the Generalized Reduced Gradient algorithm, whilst the subsequent set of consistent pairwise comparisons was aggregated into a consensual vector of weights according to the similarity of thought among the experts. The application of the Integrated Value Model for Sustainable Assessment (MIVES) enabled the characterization of indicators and their standardization into a dimensionless value index using value functions. Some data from existing sustainable infrastructure rating tools were considered to establish the ranges that delimit these functions, due to the lack of statistics focused on developing countries.

The results of the case study showed the relevance of social and economic issues over environmental concerns in developing countries. SIRSDEC identified key indicators, which were initially neglected by the construction company, to promote a new approach for the community and unblock the Tia Maria project. Despite it did not initially achieve the minimum SIRSDEC requirements to be considered sustainable, its re-assessment through the proposal of several actions mainly focused on social and economic aspects enabled the achievement of sustainable objectives. Furthermore, the re-assessment of the project using the average weights used in current sustainable infrastructure rating systems resulted in an undervaluation of its contribution to sustainability, in comparison with the initial scenario based on the weights obtained from the experts. Therefore, environmental issues contributed less to the score than social and economic matters, which indicates that the influence of the latter on sustainability increases in developing countries.

This research ratifies SIRSDEC as an effective sustainable infrastructure rating system oriented to developing countries under the balanced consideration of the three principles of sustainability. However, although this paper is a promising starting point to demonstrate the usefulness of SIRSDEC to assess the contribution of infrastructure projects to sustainable development, further research should consider the inclusion of new sustainability indicators from international agencies and multilateral banks, in order to better represent the economic and social priorities of poorer countries and facilitate the collection of information throughout the lifecycle of this kind of projects. Moreover, the specifics of some particular locations might require a customization of the weights assigned to the elements forming SIRSDEC, in case there are any special reasons why some indicators must be more important than usual.

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3. METODOLOGÍA, RESULTADOS Y DISCUSIÓN

Este capítulo consta de tres secciones, cada una de ellas asociada a la metodología, resultados y discusión correspondientes a los tres artículos anexados en la tesis. En la primera sección, se destacó el papel esencial que las infraestructuras juegan en el desarrollo sostenible de los países subdesarrollados, para luego reseñar las herramientas creadas para la evaluación de la sostenibilidad de los proyectos de infraestructura de transporte en las naciones más ricas. Estas herramientas pueden tomarse como el punto de referencia para el desarrollo posterior de los 3 sistemas de rating de infraestructuras existentes en la actualidad: Civil Engineering Environmental Quality (CEEQUAL), Infrastructure Sustainability (IS) Rating Tool y Envision. La descripción de cada uno de ellos permitió finalmente realizar una evaluación para determinar su idoneidad para su utilización en los países subdesarrollados. Las dos secciones posteriores incluyen la descripción detallada de la metodología establecida para el desarrollo de SIRSDEC y la validación del nuevo sistema tras su aplicación al proyecto de construcción de una balsa de lixiviados en una mina peruana.

3.1. Evaluación de los sistemas de rating de infraestructuras existentes para su aplicación en países subdesarrollados

3.1.1. Infraestructuras sostenibles en los países subdesarrollados

El índice de desarrollo humano (HDI) fue creado por las Naciones Unidas (UN) para clasificar a los países según su nivel de desarrollo (UN-Habitat, 2015). Este índice incluye diferentes parámetros como la esperanza de vida, los ingresos per cápita o el porcentaje de analfabetismo. Aquellos países con un HDI inferior a 0,8 son considerados como países subdesarrollados. De los 193 estados adscritos a las Naciones Unidas, 53 son clasificados como desarrollados, mientras los restantes 140 pertenecen a la categoría de subdesarrollados. En Europa, Albania, Bosnia-Herzegovina, Serbia y Macedonia son considerados países subdesarrollados. Los países de África, Asia (excepto Japón, Corea del Sur, Hong Kong, Singapur, Qatar, Brunei y Bahrein) y Sudamérica (salvo Chile y Argentina) completan esta categoría.

Los países subdesarrollados requieren un significativo aumento de las inversiones destinadas a los proyectos de infraestructuras para facilitar su crecimiento económico, satisfacer sus necesidades de urbanización y cumplir con sus objetivos en materia social y medioambiental. El efecto de la globalización también juega un papel destacado en el desarrollo de los países y por lo tanto de sus infraestructuras, tanto aquellas más convencionales como las carreteras, los ferrocarriles o los puertos, como las nuevas infraestructuras relacionadas con las telecomunicaciones. Se estima un incremento de 2.000 millones de habitantes en la población mundial entre 2010 y 2030 (UN-Habitat, 2011), de los cuales la mayor parte se concentrará en asentamientos urbanos de los países menos desarrollados, lo que aumentará la necesidad de construir más infraestructuras urbanas sostenibles (UN-DESA, 2014).

El papel de las infraestructuras es esencial para consolidar la sostenibilidad de las economías de estos países, reducir los impactos medioambientales originados por los proyectos de construcción, mitigar los efectos del cambio climático y promover el uso de prácticas sostenibles (Ebobisse, 2015). La creciente antigüedad de las infraestructuras requiere que su diseño satisfaga las necesidades que derivan de los actuales desafíos medioambientales. En la actualidad, se estima que se debería destinar un billón de dólares al año a la inversión en infraestructuras en los países menos desarrollados. Esta cifra podría alcanzar la cantidad de 1,8 a 2,3 billones en el 2020, lo que significaría un incremento anual del 4% del PIB, o lo que es lo mismo, representaría un total del 3 al 8% del PIB total de estos países (Fardoust et al., 2010). En la Figura 1 se refleja la inversión que se necesitaría en 2020 para cada región geográfica mundial y para cada tipo de infraestructura.

La zona del Este de Asia - Pacífico (EAP) es la que requiere más inversión, con el 35-50% del total del presupuesto, seguida del Sur de Asia (SA) con un 20-25%. Entre un 10 y un 15% del monto se dirigiría a Latino América y Caribe (LAC), África Sub-sahariana (SSA) y el Este de África (EAC). Medio Oriente y Norte de África (MENA) con el 5-10% sería la región que menos recursos precisaría. Según la tipología de infraestructura requerida, el área de Electricidad precisaría el 45-60% del presupuesto, por delante de los proyectos relacionados con el Agua, que representarían entre el 15 y el 30%. Transportes con el 15-25% y Telecomunicaciones con el 10-15% necesitarían la menor inversión. Por otro lado, se prevé que entre el 10 y el 15% de la inversión requerida en infraestructuras se debería destinar a que éstas fueran sostenibles, asegurando la baja emisión de gases a la atmósfera, aumentando la resistencia al cambio climático, etc.

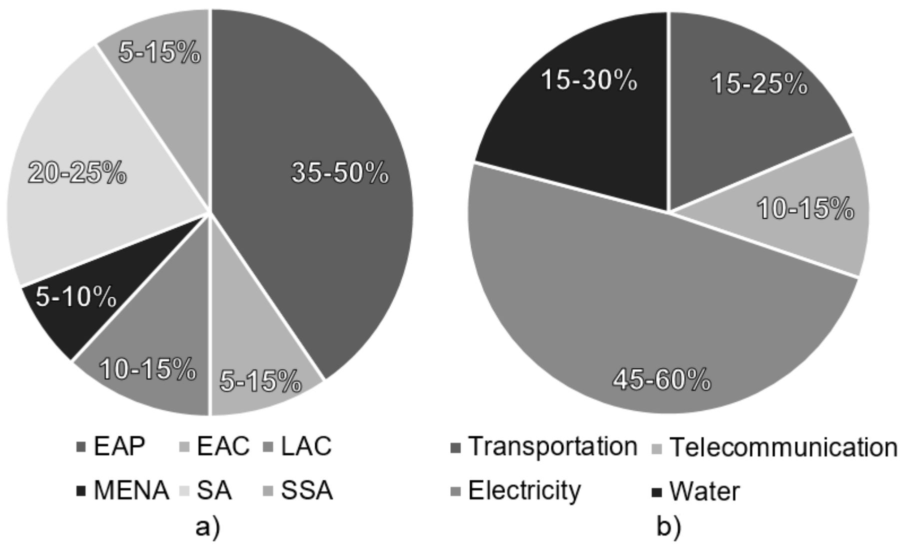

Figura 1. Inversión estimada en infraestructuras en 2020 por a) Región geográfica y b) Tipo de infraestructura

A pesar de la ingente inversión destinada a los proyectos de infraestructuras en los países subdesarrollados, no existe ningún sistema de rating de la sostenibilidad diseñado para ser utilizado en el contexto específico de estos países. El sistema STAR (Veron-Okamoto et al., 2014), elaborado por el Banco Asiático de Desarrollo y utilizado por los MDBs (acrónimo en inglés de Bancos Multilaterales de Desarrollo), permite la evaluación de proyectos de transportes e incluye las directrices necesarias para el análisis de los proyectos de transporte desde el punto de vista social, económico y medioambiental. Ingenieros contra la Pobreza y Arup han trabajado en una herramienta denominada ASPIRE (EAP & ARUP, 2011) que también evalúa los proyectos desde la perspectiva del triple pilar de la sostenibilidad, aunque no permite calificar los proyectos. La Federación Internacional de Ingenieros Consultores (FIDIC) elaboró una guía para la gestión de la sostenibilidad de los proyectos en 2004 en la que se describen las características de un proyecto sostenible (FIDIC, 2004), pero no alcanza a ser un sistema de evaluación cuantitativa.

3.1.2. Herramientas para la evaluación de la sostenibilidad en proyectos de infraestructuras de transporte

La industria del transporte ha desarrollado varias metodologías y herramientas de evaluación, especialmente en los Estados Unidos de América, para analizar el desempeño y la sostenibilidad de este sector a través de varias guías de actuación dirigidas al transporte sostenible, como reglamentos, ordenanzas y herramientas de auto-evaluación o de rating gestionadas por asesores independientes.

Greenroads Rating System fue concebido inicialmente en 2007 como el resultado de una investigación llevada a cabo por la Universidad de Washington y CH2M HILL (Söderlund et al., 2008). Se trata de un sistema orientado al diseño y construcción de carreteras que fue utilizado por primera vez en 2009. Considera dos tipos de actividades: requerimientos del proyecto y actividades voluntarias. Los requerimientos comprenden 11 actividades obligatorias, mientras las actividades voluntarias son 37 y se agrupan en 5 categorías que se denominan Créditos Voluntarios (VC): Medioambiente y Agua (EW), Acceso y Permisos (AE), Actividades de Construcción (CA), Materiales y Recursos (MR) y Tecnologías de Pavimentos (PT). Cada crédito voluntario se valora en un rango de 1 a 5 puntos, llegando a alcanzar 108 puntos la suma de todos ellos. Asimismo, el sistema considera una categoría adicional denominada “Custom Credits” que recompensa nuevas o innovadoras propuestas hasta con un total de 10 puntos, con lo que incluyendo estas dos categorías se llegaría a los 118 puntos. Hay 4 niveles Greenroads que pueden alcanzarse si se cumplen todos los requerimientos de proyecto y se obtiene un mínimo de puntos entre los denominados optativos: Bronce (entre 32 y 42 puntos), Plata (43 a 53), Oro (54 a 63) y Evergreen (superior a 63 puntos).

Con el objetivo de minimizar los impactos medioambientales, el Departamento de Transporte del Estado de Nueva York (NYSDOT) creó el GreenLITES en 2008 como un programa de evaluación para premiar el diseño, operación y mantenimiento de los proyectos de transporte que incorporen medidas en sostenibilidad medioambiental (NYSDOT). Todos los proyectos de NYSDOT son clasificados según un nivel de certificación que se asigna de acuerdo a los créditos que reciban. GreenLITES identifica más de 175 créditos sostenibles en cinco categorías: Lugares Sostenibles, Calidad del Agua, Materiales y Recursos, Energía y Atmósfera e Innovación. Existen 4 niveles de certificación: GreenLITES Certified (15 a 29 puntos), GreenLITES Silver (30 a 44), GreenLITES (45 a 59) y GreenLITES Evergreen (más de 60).

El Building Environmentally and Economically Sustainable Transportation-Infrastructure-Highways (BE^{2}ST-in-Highways) es un sistema de auto-evaluación de la sostenibilidad creado en 2010 en los Estados Unidos de América por la Universidad de Wisconsin para dotar a los proyectistas y urbanistas de una guía para la construcción de autopistas sostenibles (BE^{2}ST-in-Highways). Después de elaborar la propuesta inicial que será utilizada como referencia del proyecto de una autopista, la herramienta identifica las diferencias cuantitativas entre la línea base y la alternativa. Para ello, previamente, se lleva a cabo un análisis para evaluar los requerimientos y pre-requisitos obligatorios, en los cuales se utilizan un indicador social y otro especifico del proyecto para verificar que el proyecto cumple con las normas, ordenanzas y reglamentos locales, así como con los requerimientos específicos del proyecto. BE^{2}ST-in-Highways es un programa que utiliza Excel, pero que está asociado con otras hojas de cálculo como PaLATE (análisis de ciclo de vida), RealCost (análisis del coste del ciclo de vida) y TNM-LookUp (análisis del ruido producido por el tráfico) (Lee et al., 2014). Los 100 créditos del sistema se distribuyen proporcionalmente en 9 categorías: consumo de energía, potencial de calentamiento global, proporción de reciclaje in situ, total de material reciclado, consumo de agua, análisis del coste del ciclo de vida, coste social de las emisiones de carbono, ruido del tráfico y residuos peligrosos. El sistema distingue tres niveles de certificación: Bronce (más del 50% de los créditos), Plata (más del 75% de los créditos) y Oro (más del 90%) (BE^{2}ST-in-Highways).

INVEST (Infrastructure Voluntary Evaluation Sustainability Tool) (FHA) es una website gratuita desarrollada por la FHWA (Federal Highway Administration) para su utilización en USA que contiene una herramienta de auto-evaluación compuesta por un conjunto de buenas prácticas del ámbito de la sostenibilidad que abarcan el ciclo de vida completo de los servicios de transportes, incluyendo el marco general de su planificación, diseño, construcción, operación y mantenimiento. La herramienta INVEST incluye tres apartados: sistema de planificación para los estados (SP), desarrollo de proyectos (PD) y operaciones y mantenimiento (OM). Los módulos de SP y OM tienen la finalidad de evaluar los programas de las agencias y el de PD es utilizado para la evaluación de proyectos, desde la planificación preliminar hasta la construcción. La herramienta no contempla ni la asignación de puntos ni la certificación de los proyectos.

I-LAST (Illinois Liveable and Sustainable Transportation) Rating System es un sistema de medición del desempeño en materia de sostenibilidad desarrollado por un grupo de trabajo formado por el Departamento de Transportes de Illinois (IDOT), el Consejo Americano de Ingenierías (ACEC) y la Asociación de Constructores Transportistas de Illinois (IRTBA) (Illinois

Department of Transportation, 2010). El principal objetivo establecido era el de agregar todos los inputs facilitados por los usuarios del sector en este sistema de rating; sin embargo, no se realizó ninguna actualización del sistema desde el lanzamiento de la versión 2 en enero de 2012. El I-LAST contiene 153 buenas prácticas de sostenibilidad (créditos) que se agrupan en 8 categorías: Planificación, Diseño, Medioambiente, Calidad del Agua, Transporte, Iluminación, Materiales e Innovación. Se asigna un punto a cada crédito según el grado de cumplimiento de los criterios establecidos por el sistema. I-LAST no contempla ningún nivel de certificación, ni tampoco está incluido como un sistema o procedimiento de obligada utilización por el IDOT.

H.W Lochner Inc., una empresa de consultoría en el campo del transporte con sede en Chicago, creó en 2008 una herramienta voluntaria de auto-evaluación denominada STEED (Sustainable Transportation Engineering & Environmental Design) para que los proyectos se redactasen siguiendo las directrices del triple pilar de la sostenibilidad e incorporando alternativas sostenibles en las diferentes fases del proyecto: planificación, evaluación medioambiental, diseño y construcción. STEED divide cada uno de esos tres pilares en siete categorías que totalizan 153 puntos. La categoría económica, con 45 puntos, incluye la consideración del ciclo de vida (5 puntos), duración de la construcción (7), movilidad (8), innovación (9), conectividad modal (6) e impacto económico en los usuarios (4). El medioambiente, con un total de 62 puntos, comprende varias sub-categorías como calidad del aire (8), biodiversidad (8), energía (8), limpieza medioambiental (8), luz y ruido (11), materiales y recursos (10) y recursos hídricos (9). Finalmente, la responsabilidad social representa 46 puntos distribuidos entre estética y condiciones de vida (10), cultura e historia (5), capital social (6), tierra y geología (7), uso de la tierra / transporte (5), participación de la población (6) y seguridad y salud (7). STEED no establece ningún nivel de certificación para los proyectos (Abdul, 2012).

Del 2009 al 2015, el consejo norteamericano de transporte sostenible (STC) desarrolló y dirigió el Sustainable Transportation Analysis & Rating System (STARS), que es un marco integrado de planificación para los proyectos de transporte que pretende ayudar a los planificadores urbanistas y a los expertos en transportes en la identificación de estrategias innovadoras que faciliten su toma de decisión. STARS se organiza en 12 créditos que se agrupan en 4 categorías: proceso integrado, acceso, clima y energía y análisis de costes. Para que un proyecto pueda ser certificado por STARS, el primer crédito de cada categoría debe de ser obligatoriamente obtenido. Asimismo, se deben conseguir los cuatro créditos obligatorios del sistema, así como otros cinco créditos que podrán ser elegidos por el usuario. De los cinco créditos opcionales, al menos dos deben de pertenecer a la categoría de acceso y otros dos a los de clima y energía. El STC verifica la documentación y decide si los créditos son calificados como "Pass" o como "Improve". Los proyectos que obtengan la calificación de "Pass" para los 4 créditos obligatorios y al menos 5 para los voluntarios serán denominados "STARS 1.2 Certified Pilot Project" (STC, 2013).

3.1.3. Sistemas existentes de rating de la sostenibilidad de los proyectos de infraestructura

En la Tabla 1 se resumen las principales características de los tres sistemas de rating de la sostenibilidad de los proyectos de infraestructuras que serán descritos en detalle posteriormente: CEEQUAL, Infrastructure Sustainability (IS) y Envision.

Tabla 1. Resumen de los sistemas de rating de la sostenibilidad para proyectos de infraestructura

Característica	Civil Engineering Environment Quality (CEEQUAL)	Infrastructure Sustainability (IS)	Envision
Institución soporte	CEEQUAL Ltd	Infrastructure Sustainability Council of Australia (ISCA)	Institute for Sustainable Development (ISI)
Área de influencia	UK & Ireland / Internacional	Australia & New Zeeland	USA & Canada
Año de lanzamiento	2003	2012	2012
Manuales	CEEQUAL para Projects / CEEQUAL para Term Contracts	Infrastructure Sustainability (IS)	ENVISION
Categorías	9	6	5
Sub-categorías	48	15	60
Niveles de cumplimiento	4 (Pass, Good, Very Good, Excellent)	3 (Commended, Excellent, Leading)	5 (Improved, Enhanced, Superior, Conserving, Restorative)
Reconocimientos	6 CEEQUAL for Projects 2 CEEQUAL for Term Contracts	3 (Design, As Built, Operation)	4 (Bronze, Silver, Gold, Platinum)
Agentes certificadores	Certificadores independientes capacitados por CEEQUAL	Certificadores independientes capacitados por ISCA	Certificadores independientes capacitados por Envision

3.1.3.1. Civil Engineering Environmental Quality (CEEQUAL)

Entre 1999 y 2003, la Institución de Ingenieros Civiles (ICE) desarrolló CEEQUAL con el apoyo financiero del Gobierno británico y del fondo de investigación y desarrollo del ICE, a quienes se unió más tarde el consultor Crane Environmental Ltd. La herramienta fue presentada en público en septiembre de 2003, pero su lanzamiento comercial no llegó hasta junio de 2004 tras la publicación de la versión 3 del manual de evaluación de proyectos. Desde entonces, CEEQUAL ha sido actualizado varias veces hasta llegar a la versión 5 actualmente en vigor. A comienzos de 2015 se habían contabilizado más de 260 acreditaciones finales, mientras que otras 250 se encontraban en proceso de certificación. El presupuesto total de los proyectos evaluados era de 25.000 millones de libras esterlinas.

CEEQUAL incluye diversas cuestiones sociales y medioambientales organizadas en 9 secciones según se recoge en la Tabla 2, con más de 48 categorías en las que se involucran los principales agentes del proyecto: clientes, proyectistas y contratistas.

Tabla 2. Esquema del sistema de rating Civil Engineering Environmental Quality (CEEQUAL)

Crédito	Concepto	Puntuación	%
1	**Estrategia del Proyecto**	**625**	**12.46**
1.1	Estrategia global para el Proyecto conceptual y el diseño	500	9.97
1.2	Estrategia global para la construcción	125	2.49
2	**Gestión del proyecto**	**545**	**10.87**
2.1	Principios básicos	100	1.99
2.2	Gestión de la sostenibilidad	160	3.19
2.3	Procesos de procura y contratos	116	2.31
2.4	Desempeño en aspectos sociales y medioambientales	132	2.63
2.5	Comunicando el desempeño de la sostenibilidad	37	0.74
3	**Población y Comunidad**	**530**	**10.57**
3.1	Resumen y diseño	66	1.32
3.2	Consultas con principales intervinientes del Proyecto	27	0.54
3.3	Efectos en la población y plan de mitigación	44	0.88
3.4	Implementación y monitoreo durante la construcción	148	2.95
3.5	Compromiso continuo con grupos relevantes de la comunidad	74	1.48
3.6	Efectividad del compromiso de la comunidad	69	1.38
3.7	Medio humano, estética y empleo	102	2.03
4	**Uso de la Tierra y Paisaje**	**1004**	**20.02**
4.1	Principios básicos del uso de la tierra (sobre y bajo el agua)	233	4.65
4.2	Contaminación de la tierra y del lecho marino, estuarios.	242	4.82
4.3	Riesgo de inundación	264	5.26
4.4	Principios básicos sobre el paisajismo	55	1.10
4.5	Requerimientos legales relacionados con el paisajismo	85	1.69
4.6	Implementación y gestión	83	1.65
4.7	Terminación y mantenimiento	42	0.84
5	**Medio histórico**	**230**	**4.59**
5.1	Informes principales	23	0.46
5.2	Requerimientos legales, guía para la planificación y consulta	17	0.34
5.3	Conservación y mejora	141	2.81
5.4	Acceso del público e información	49	0.98
6	**Ecología y Biodiversidad**	**315**	**6.28**
6.1	Principios básicos	61	1.22
6.2	Requerimientos legales	76	1.52
6.3	Conservación y mejora de la biodiversidad	79	1.57
6.4	Medidas para la creación de hábitats	64	1.28
6.5	Seguimiento y mantenimiento	35	0.70
7	**Medio acuático**	**283**	**5.64**
7.1	Principios básicos	70	1.40
7.2	Requerimientos legales	24	0.48
7.3	Protección del agua potable y del medio marino	141	2.81
7.4	Mejora del medio acuático	48	0.96
8	**Recursos materiales - uso y gestión**	**1217**	**24.26**
8.1	Principios básicos	44	0.88
8.2	Impactos inherentes a los materiales	112	2.23
8.3	Diseño para el ahorro energético y emisión de carbono durante diseño	109	2.17
8.4	Diseño para el ahorro energético y emisión de carbono durante construcción	97	1.93
8.5	Diseño para el ahorro energético y emisión de carbono durante operación	109	2.17
8.6	Uso del agua	291	5.80
8.7	Uso responsable, reutilización y reciclaje de materiales	106	2.11
8.8	Uso mínimo y minimización impactos materiales peligrosos	47	0.94
8.9	Gestión de residuos, planificación y cumplimiento normativa	89	1.77
8.10	Residuos y gestión problemas que generen	213	4.25
9	**Transporte**	**267**	**5.32**
9.1	Principios básicos	65	1.30
9.2	Transporte operacional	99	1.97
9.3	Transporte durante la construcción, incluyendo ruido y atascos	79	1.57
9.4	Minimización de los desplazamientos del personal	24	0.48
	Total	**5016**	**100**

Los certificadores de los proyectos, siguiendo las directrices del manual de CEEQUAL, recopilan los documentos que acreditan la puntuación de cada crédito, algunos de obligado cumplimiento. Una vez que la evaluación ha sido completada, se valida por un certificador externo para que el resultado final sea aceptado definitivamente por el equipo de proyecto; posteriormente, se otorga un nivel de certificación al proyecto acorde a la puntuación obtenida. Hay 4 diferentes niveles de certificación en CEEQUAL: Pass (< 25%), Good (< 40%), Very Good (< 60%) y Excellent (< 75%).

CEEQUAL dispone de dos modalidades: CEEQUAL para proyectos y CEEQUAL para contratos. El primero fue específicamente desarrollado para la evaluación de cualquier tipo de proyecto de ingeniería civil, infraestructura, paisajismo y proyectos con impacto social, sin importar su tamaño e incluyendo también aquellas infraestructuras relacionadas con los desarrollos urbanos. Existen dos versiones diferentes para este manual: CEEQUAL para proyectos internacionales y CEEQUAL para los proyectos situados únicamente en UK e Irlanda. Se establecen las diferencias entre ambos según la ubicación de los proyectos. Sin embargo, los factores de ponderación deben ser ajustados de acuerdo al área geográfica donde se localicen los proyectos. CEEQUAL para proyectos dispone de 6 tipos diferentes de certificación:

- La certificación Total para el Proyecto (WPA), que es solicitada conjuntamente por el cliente, proyectista y contratista principal, siendo sólo otorgada a la finalización de la construcción.

- La certificación Total para el Proyecto, con una certificación provisional para el cliente y el proyectista que permite al equipo evaluar el proyecto durante la fase de diseño.

- La certificación de Diseño y Cliente, que corresponde a la solicitud conjunta del cliente y del proyectista antes del inicio de la construcción.

- La certificación de Diseño, que sólo puede ser requerida por el proyectista principal, quien puede adquirir conocimientos y experiencia con CEEQUAL sin la participación de los restantes intervinientes del proyecto.

- La certificación de Diseño y Construcción, que corresponde a la solicitud conjunta del contratista principal y del proyectista para ser premiados por su contribución al proyecto, en el que el cliente no participa.

- La certificación de Construcción, que sólo puede ser otorgada al contratista principal.

La modalidad de CEEQUAL para contratos fue desarrollada específicamente para la evaluación de proyectos de ingeniería civil que se realicen a través de contratos de varios años de duración en un área geográfica determinada. Existen dos tipos de certificaciones para esta modalidad:

- La certificación Total para el Equipo y Evaluación, cuando el cliente exige contractualmente el uso de CEEQUAL.

- La certificación de Entrega y Evaluación, que permite que el contratista principal y el proyectista evalúen el desempeño del contrato sin la participación del cliente.

3.1.3.2. Infrastructure Sustainability (IS) Rating Tool

Tras el interés suscitado en febrero de 2007 por la conferencia impartida en la sede de Ingenieros de Australia por David Hood y Glenn Hedges denominada "¿Necesita Australia un Sistema de rating medioambiental para proyectos que no sean de edificación?", se constituyó un comité en marzo de 2007 con el objetivo de definir los límites y el alcance de una futura investigación sobre los sistemas de rating de infraestructuras internacionales existentes para iniciar el posterior desarrollo de un sistema aplicable en todo el país. En febrero de 2008 se creó y registró el Consejo de Infraestructuras Sostenibles de Australia (AGIC). El desarrollo del sistema comenzó en noviembre de 2008 para concluir en 2011 después de realizarse diferentes pruebas y encuestas para la obtención de los factores de ponderación. La versión 1.0 del Infrastructure Sustainability (IS) Rating Tool fue divulgada a nivel nacional en 2012. Ese mismo año, el AGIC fue rebautizado como el Consejo de la Sostenibilidad para las Infraestructuras de Australia (ISCA). Hasta la fecha, han sido certificados o registrados siguiendo las directrices del sistema IS proyectos por valor superior a los 40.000 millones de dólares australianos en el campo de las infraestructuras o de los proyectos de ingeniería civil en Australia y Nueva Zelanda.

ISCA verifica toda la documentación facilitada por el equipo de gestión del proyecto y, con el apoyo de consultores independientes, propone una determinada certificación para el proyecto. Posteriormente, certifica el proyecto según el nivel alcanzado correspondiente a la puntuación obtenida sobre un total de 105 puntos, existiendo 3 niveles de cumplimiento: Commended (de 25 a 50 puntos), Excellent (de 50 a 75) y Leading (de 75 a 105).

La Tabla 3 muestra el esquema del sistema IS con 6 temas que incluyen 15 categorías diferentes. La herramienta está basada en tres niveles de desempeño: calificación del diseño, de la construcción y de la operación. La certificación del diseño puede ser obtenida después de considerar los elementos y requerimientos en materia de sostenibilidad del proyecto constructivo. La certificación de construcción sólo será otorgada cuando la construcción esté totalmente finalizada, reemplazando a la certificación del diseño. Para obtener la certificación de la operación, debe de haber transcurrido un período superior a 24 meses desde el inicio de la explotación del proyecto, siendo esta certificación independiente de las de diseño o de construcción.

Tabla 3. Esquema del sistema de rating Infrastructure Sustainability (IS) Rating Tool

Crédito	Concepto	Puntuación	%
1	**Gestión y Gobierno**	**20.50**	**19.52**
1.1	Sistemas de gestión	10.50	10.00
1.2	Procura	5.00	4.76
1.3	Adaptación al cambio climático	5.00	4.76
2	**Utilización de recursos**	**24.50**	**23.33**
2.1	Energía y emisiones de carbón	7.00	6.67
2.2	Agua	7.00	6.67
2.3	Materiales	7.00	6.67
3	**Emisiones, Contaminación y Residuos**	**24.50**	**23.33**
3.1	Emisiones al aire, tierra o agua	10.50	10.00
3.2	Tierra	7.00	6.67
3.3	Residuos	7.00	6.67
4	**Ecología**	**10.50**	**10.00**
4.1	Ecología	10.50	10.00
5	**Gente y emplazamiento**	**20.00**	**19.05**
5.1	Salud de la comunidad, bien estar y seguridad	5.00	4.76
5.2	Patrimonio cultural	5.00	4.76
5.3	Participación de los intervinientes del proyecto	5.00	4.76
5.4	Diseño urbano y paisajístico	5.00	4.76
6	**Innovación**	**5.00**	**4.76**
6.1	Innovación	5.00	4.76
	Total	**105.00**	**100.00**

3.1.3.3. Envision Sustainable Infrastructure rating system

Envision surgió como resultado de la alianza estratégica entre el Programa de Infraestructuras Sostenibles Zofnass, la Escuela de Diseño de la Universidad de Harvard y el Instituto de Infraestructuras Sostenibles (ISI). ISI es una organización sin ánimo de lucro cuyo objeto es el desarrollo y actualización de sistemas de rating de la sostenibilidad para infraestructuras. ISI, que fue constituida por la Asociación Americana de Obras Públicas, el Consejo Americano de Empresas de Ingeniería y la Sociedad Americana de Ingenieros Civiles lanzó la versión 2.0 stage 2 de Envision en 2012.

Envision está disponible gratuitamente, pudiendo utilizarse durante la fase de planificación del proyecto o para la auto-evaluación de las diferentes variantes del proyecto. El proceso de verificación es opcional y sería realizado por expertos independientes de ISI para comprobar que el proyecto cumple con los criterios de Envision y es acreedor de una certificación. Como requerimiento del sistema, los denominados Profesionales de la Sostenibilidad Envision (ENV SP) capacitados por el ISI deben asesorar al equipo de proyecto para alcanzar los mayores niveles de sostenibilidad posibles.

Envision incluye 60 créditos que se agrupan en 5 categorías relacionadas con el triple pilar de la sostenibilidad según refleja la Tabla 4. Envision dispone de 5 niveles de cumplimiento para la evaluación del desempeño y el fomento de la mejora de los proyectos: 1) Improved (desempeño convencional), 2) Enhanced (el desempeño está alineado con los principios de Envision), 3) Superior (desempeño notable), 4) Conserving (el proyecto genera cero impactos) y 5) Restorative (el proyecto restaura sistemas naturales y sociales). Se distinguen 4 tipos de certificaciones según el porcentaje de créditos obtenidos respecto al total del sistema: Bronce (20 - 30%), Plata (30 - 40%), Oro (40 - 50%) y Platino (> 50%).

Tabla 4. Esquema del sistema de rating ENVISION

Crédito	Concepto	Improved	%	Enhanced	%	Superior	%	Conserving	%	Restorative	%
1	**Calidad de vida**	**13**	**16.46**	**27**	**15.17**	**62**	**17.46**	**150**	**21.43**	**151**	**29.38**
1.1	Objetivo	4	5.06	9	5.06	20	5.63	45	6.43	56	10.89
1.2	Comunidad	6	7.59	12	6.74	23	6.48	70	10.00	52	10.12
1.3	Bienestar	3	3.80	6	3.37	19	5.35	35	5.00	43	8.37
2	**Liderazgo**	**10**	**12.66**	**31**	**17.42**	**56**	**15.77**	**115**	**16.43**	**31**	**6.03**
2.1	Colaboración	5	6.33	17	9.55	33	9.30	60	8.57	0	0.00
2.2	Gestión	2	2.53	6	3.37	13	3.66	25	3.57	31	6.03
2.3	Planificación	3	3.80	8	4.49	10	2.82	30	4.29	0	0.00
3	**Asignación Recursos**	**29**	**36.71**	**66**	**37.08**	**112**	**31.55**	**170**	**24.29**	**62**	**12.06**
3.1	Materiales	15	18.99	34	19.10	59	16.62	80	11.43	0	0.00
3.2	Energía	7	8.86	16	8.99	25	7.04	45	6.43	20	3.89
3.3	Agua	7	8.86	16	8.99	28	7.89	45	6.43	42	8.17
4	**Medio natural**	**15**	**18.99**	**33**	**18.54**	**86**	**24.23**	**165**	**23.57**	**169**	**32.88**
4.1	Emplazamiento	8	10.13	17	9.55	49	13.80	80	11.43	74	14.40
4.2	Legislación	2	2.53	10	5.62	23	6.49	40	5.71	39	7.59
4.3	Biodiversidad	5	6.33	6	3.37	14	3.94	45	6.43	56	10.89
5	**Clima**	**12**	**15.19**	**21**	**11.80**	**39**	**10.00**	**100**	**14.29**	**101**	**19.65**
5.1	Emisiones	6	7.59	13	7.30	13	3.66	30	4.29	40	7.78
5.2	Resistencia	6	7.60	8	4.49	26	7.33	70	10.00	61	11.87
		79	100.00	178	100.00	100.00	100.00	700	100.00	514	100.00

3.1.4. Evaluación de los sistemas para su uso en países subdesarrollados

Existen muchos puntos en común entre los tres sistemas de rating analizados para la evaluación de la sostenibilidad de los proyectos de infraestructuras. Aunque todos ellos contemplan los aspectos más importantes de la sostenibilidad realzando algunos criterios específicos, no existen grandes diferencias entre ellos respecto a lo que es exigible para que un proyecto de infraestructuras sea considerado sostenible. Sin embargo, el papel otorgado a la gestión en la evaluación de los proyectos es algo en el que difieren notablemente las 3 herramientas (Watkins, 2014).

La Tabla 5 resume los criterios principales que examinan estos sistemas de rating. El factor medioambiental es ampliamente desarrollado a través de indicadores que miden aspectos como emisiones de GHG, conservación de hábitats y biosistemas, contaminación (aérea, luminosa, ruido, agua), energía (recursos renovables y eficiencia), inundaciones, uso de la tierra y gestión más eficaz de los recursos naturales. Sin embargo, los aspectos relativos a la economía y a la gestión son apenas considerados. Por otro lado, estos sistemas sólo analizan los aspectos sociales orientándolos a los problemas generales de la comunidad como la participación, la comunicación, la salud, el bienestar y la seguridad y el patrimonio cultural e histórico.

Tabla 5. Principales criterios utilizados en la evaluación de proyectos por los sistemas de calificación

Economía	Medioambiente	Sociedad	Gestión
Minimización desplazamientos de la mano de obra	Normas para el uso de la tierra	Participación de la Comunidad & intervinientes del Proyecto	Gestión Proyecto (diseño, construcción, operación)
	Gestión riesgos inundación	Evaluación de los impactos en vecindades	Gestión sostenible de la procura
Aumento conectividad entre comunidades	Conservación, mejora y restauración de los hábitats y biosistemas	Fomento del empleo local	
	Conservación y mejora de los paisajes	Patrimonio histórico, cultural y arqueológico	
	Uso eficiente del agua	Aumento información pública	
	Conservación y mejora de la calidad del agua	Fomento del bienestar, seguridad y salud de la comunidad,	
	Reducción de las emisiones de GHG		
	Gestión ruido		
	Reducción de contaminantes del aire		
	Gestión contaminación lumínica		
	Reducción del uso de energía		
	Fomento del uso de energía renovable		
	Gestión eficiente recursos naturales		
	Gestión residuos peligrosos		

La Tabla 6 confirma lo antes descrito: el análisis del reparto de la puntuación de los sistemas CEEQUAL, IS y Envision evidencia un notable desequilibrio entre los tres pilares de la sostenibilidad. Medioambiente es la categoría más relevante con unos dos tercios del total de la puntuación, mientras Sociedad y Economía tienen un 20 y un 10%, respectivamente.

Tabla 6. Puntuación de los sistemas de rating respecto al triple pilar de la sostenibilidad

Sistema de rating	Economía		Medioambiente		Sociedad		Total	
	Puntos	%	Puntos	%	Puntos	%	Puntos	%
CEEQUAL	515.66	10.28	3140.16	62.6	1360.16	27.12	5016	100
Infrastructure Sustainable (IS)	13	12.38	74	70.48	18	17.14	105	100
Envision Improved	5.61	7.12	59.11	74.98	14.11	17.9	79	100
Envision Enhanced	15.63	8.79	129.13	72.59	33.13	18.62	178	100
Envision Superior	29.64	8.35	253.64	71.46	71.64	20.18	355	100
Envision Conserving	57.62	8.23	481.62	68.82	160.62	22.95	700	100
Envision Restorative	30.65	5.96	361.15	70.27	122.15	23.77	514	100

La Figura 2 muestra los umbrales de puntuación que delimitan los niveles de cumplimiento de los tres sistemas de calificación. Mientras que los intervalos de puntuación están igualmente distribuidos en CEEQUAL e IS rating system, Envision muestra un desequilibrio muy acusado en sus tres niveles. Envision es también el sistema menos exigente para alcanzar el nivel más elevado de cumplimiento (sobre el 50% del total de la puntuación), mientras que IS y CEEQUAL necesitan alrededor del 75% del total de los puntos.

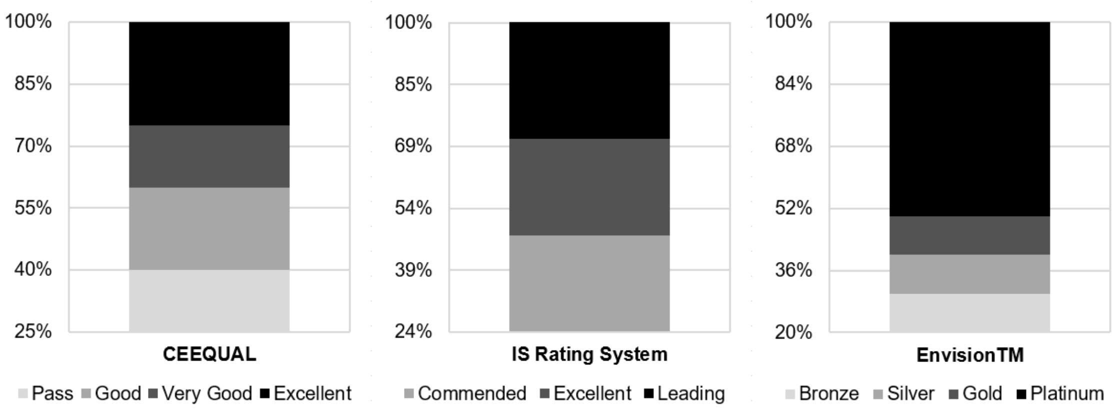

Figura 2. Niveles de cumplimiento de los sistemas de calificación

El principio 11 de la Declaración adoptada en la conferencia de Naciones Unidas de Medioambiente y Desarrollo celebrada en Rio de Janeiro en 1992 (UN, 1992) afirma que los estados deberían emitir legislación medioambiental efectiva para que la normativa, los objetivos y las prioridades de gestión reflejen el contexto de desarrollo para el que se apliquen. Los estándares que se usan en algunos países pueden ser inapropiados provocando importantes costes económicos y sociales a otras naciones, en particular a los países subdesarrollados. Mientras CEEQUAL es capaz de evaluar proyectos en todo el mundo modificando los factores de ponderación que utiliza su línea base de UK, Envision e IS están orientados exclusivamente al área geográfica para la que fueron concebidos: Norte América (USA & Canadá) y Australia y Nueva Zelanda, respectivamente. Por lo tanto, ninguno de los dos refleja adecuadamente el espíritu que emana del principio 11.

El principio 22 afirma que la población indígena y otras comunidades locales juegan un papel fundamental en la gestión medioambiental y en el desarrollo por su conocimiento sobre las prácticas tradicionales. Es por ello que los estados deberían reconocer y apoyar su identidad cultural y sus intereses permitiendo la participación activa en el cumplimiento de los objetivos del desarrollo sostenible.

Como se aprecia en la Tabla 5, CEEQUAL, IS y Envision omiten diversos aspectos relativos a los cambios sociales como la igualdad de oportunidades, las capacidades de organización y los sistemas de educación, la pobreza y las comunidades indígenas. La Declaración del Milenio (UN, 2000) proclamada por las Naciones Unidas estableció un marco de trabajo que incluía 8 objetivos, 18 metas y 48 indicadores para medir el avance de los países hacia la consecución de los objetivos establecidos para el Desarrollo del Milenio. Este enfoque fue adoptado por diversos expertos de las Naciones Unidas, del Fondo Monetario Internacional, de la OCDE y del Banco Mundial. Entre estos objetivos, destacan el 1,3 y 7, que deberían ser considerados en los proyectos de infraestructuras de los países subdesarrollados.

El objetivo 1 (“Erradicar el hambre y la extrema pobreza”) pretende reducir a la mitad la población con ingresos menores a un dólar por día y la que sufre hambre en el período de 1990 a 2015. El objetivo 3 (“Promover la igualdad entre sexos y fortalecer el papel de la mujer”) busca eliminar la desigualdad de género en la educación primaria y secundaria con una fecha máximo objetivo de 2005 y para todos los niveles de educación antes del 2015. El objetivo 7 (“Asegurar la sostenibilidad medioambiental”) tiene como meta integrar los principios del desarrollo sostenible en políticas y programas de los países que eviten la pérdida de recursos medioambientales. Asimismo, se pretendía reducir a la mitad la población sin acceso a agua potable y a sistemas sanitarios en 2015, así como mejorar significativamente las condiciones de vida de al menos 100 millones de “sin techo” hacia 2020.

Desde el punto de vista económico, hay tres temas que deberían ser profundamente considerados por los tres sistemas de rating de infraestructuras en países subdesarrollados: la certeza de que los proyectos apoyen el crecimiento sostenible y el desarrollo económico a través de suministros locales, la viabilidad financiera de los proyectos y su contribución a la reducción del nivel de pobreza, tal y como establecía el objetivo de desarrollo 1 del Milenio.

La falta de un marco definitivo de gestión que identifique los elementos principales que deben de formar parte de un proyecto sostenible confunde tanto a los clientes finales como a los consultores y a otros participantes del proyecto, algunos de los cuales aplican sus propias nociones sobre desarrollo sostenible basado en sus intereses particulares a través de sistemas de nueva creación. Sin embargo, la mayoría carecen de un nexo de unión entre los objetivos globales del desarrollo sostenible y los de los proyectos. La implementación de sistemas de gestión e información de la sostenibilidad es crucial para el cumplimiento de los objetivos del proyecto relativos al desarrollo sostenible y para poder medir el avance hacia su consecución (UNEP, 2006).

3.2. Metodología para el desarrollo de un nuevo sistema de rating de la sostenibilidad de proyectos de infraestructura en países subdesarrollados (SIRSDEC)

3.2.1. Descripción de la metodología adoptada

Inicialmente se realizó una amplia revisión bibliográfica para recabar información sobre las herramientas y sistemas de rating de la sostenibilidad de proyectos de infraestructuras existentes en la actualidad, así como de los objetivos de desarrollo sustentable y de los mecanismos de actuación de diversas organizaciones internacionales, mayoritariamente situadas en la órbita de las Naciones Unidas. Tras establecer los objetivos que debería cumplir el nuevo sistema SIRSDEC, se definió el esquema de toma de decisión en el que se identificaron sus limitaciones.

Este esquema, en el que aparecen varios niveles jerarquizados y que se denominó árbol de decisión, fue elaborado incluyendo todos los requerimientos, criterios e indicadores necesarios para formar el sistema, para ser posteriormente distribuido entre varios expertos internacionales a través de un cuestionario on-line, con la finalidad de recabar sus opiniones sobre la comparación relativa de pares entre los elementos del árbol de decisión. El método Analytical Hierarchy Process (AHP) (Saaty, 1990) se utilizó para transformar los resultados recibidos de las comparaciones entre los elementos del sistema en factores de ponderación, mientras que el modelo de valor integrado para evaluaciones sostenibles (MIVES) (ETCG, 2015) se empleó para convertir los indicadores en índices valor que reflejasen el grado de cumplimiento. El análisis de diferentes alternativas para cada proyecto permitirá su valoración desde una perspectiva multi-criterio a través de sus índices de valor y la selección de la alternativa más adecuada. La Figura 3 ilustra la metodología propuesta para el desarrollo del sistema SIRSDEC.

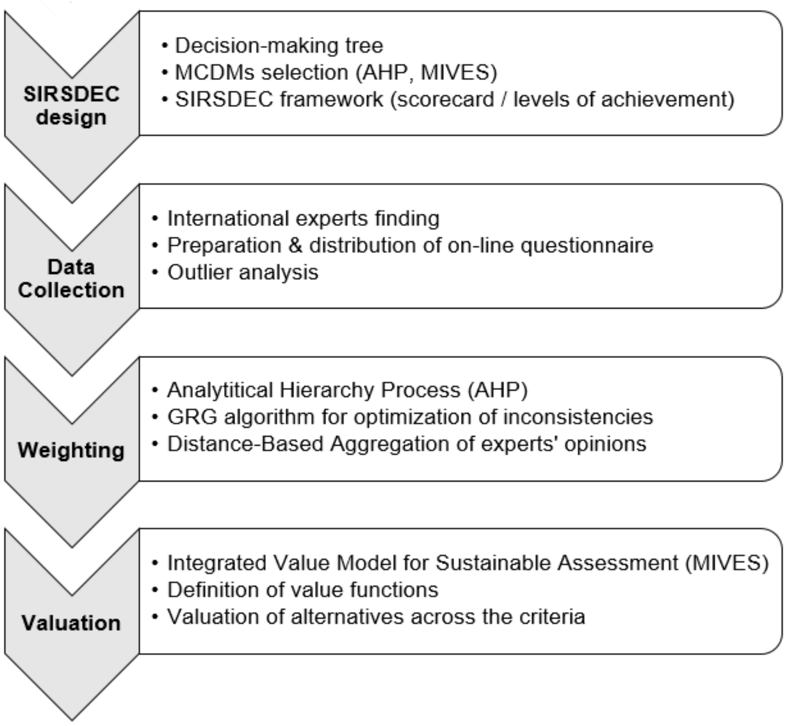

Figura 3. Metodología para el desarrollo de SIRSDEC

3.2.2. Diseño de SIRSDEC

SIRSDEC fue diseñado para equilibrar la importancia de los tres principios de la sostenibilidad, incluyendo los indicadores considerados en la Agenda 21, que están orientados a los países subdesarrollados, durante todas las fases del ciclo de vida del proyecto: diseño, construcción, operación, renovación y demolición/reutilización. La gestión fue otro aspecto que también se consideró necesario para suplir la escasez de directrices existentes y permitir la interconexión entre los objetivos globales del desarrollo sostenible en los países más desfavorecidos.

Asimismo, otras consideraciones globales fueron tenidas en cuenta para seleccionar los criterios e indicadores de SIRSDEC. Entre ellas, la relevancia de los tres principios de la sostenibilidad para reflejar la eficiencia del funcionamiento de los sistemas de rating y su orientación hacia los problemas regulatorios, lo que permitirá la identificación de los cambios que se precisen para avanzar hacia la sostenibilidad. El esquema del árbol de decisión definido para SIRSDEC contempla 4 requerimientos, 23 criterios y 29 indicadores según se muestra en la Tabla 7.

Tabla 7. Árbol de decisión de SIRSDEC

R#	Requerimiento		C #	Criterio	I #	Indicador
R1	Gestión	(*)	C1.1	Estándares internacionales	I1.1.1	ISO 9001 o equivalente
					I1.1.2	ISO 14001 o equivalente
		(*)	C1.2	Plan de gestión sostenibilidad Proyecto (PSM)	I1.2.1	Plan gestión sostenibilidad
			C1.3	Plan de gestión riesgos sostenibilidad (SRM)	I1.3.1	Plan gestión riesgos sostenibilidad
		(*)	C1.4	Plan de procura sostenible	I1.4.1	Plan de procura sostenible
		(*)	C1.5	Plan de Inspección y auditoria (I&A)	I1.5.1	Plan de I&A
			C1.6	Informes & Lecciones aprendidas (R&LL)	I1.6.1	Distribución periódica de informes
					I1.6.2	Registro lecciones aprendidas
R2	Sociedad	(*)	C2.1	Participación comunidad e intervinientes	I2.1.1	Ratio participación intervinientes
			C2.2	Papel población indígena	I2.2.1	Ratio participación indígenas
		(*)	C2.3	Desarrollo igualitario	I2.3.1	Ratio sueldo medio sexos (m/h)
			C2.4	Impactos y beneficios sociales	I2.4.1	Población afectada Proyecto
					I2.4.2	Asentamientos urbanos afectados
		(*)	C2.5	Patrimonio cultural	I2.5.1	Evaluación cultural local
R3	Medioambiente	(*)	C3.1	Conservación ecosistemas naturales	I3.1.1	Área afectada de ecosistemas
			C3.2	Biodiversidad	I3.2.1	Especies en peligro
		(*)	C3.3	Emisión de gases invernadero	I3.3.1	Reducción emisiones
			C3.4	Consumo energía	I3.4.1	Ratio de ahorro energía
					I3.4.2	Uso de energía renovable
		(*)	C3.5	Gestión agua	I3.5.1	Consumo de agua potable
					I3.5.2	Agua de tormenta almacenada
		(*)	C3.6	Riesgo inundación	I3.6.1	Superficie inundable
			C3.7	Calidad del aire	I3.7.1	Reducción de contaminantes del aire
			C3.8	Gestión residuos	I3.8.1	Reducción producción residuos
					I3.8.2	Residuos reciclados / reutilizados
R4	Economía	(*)	C4.1	Combate a la pobreza	I4.1.1	Evaluación economía local
			C4.2	Impactos en agricultura	I4.2.1	Área cultivo afectada
			C4.3	Consumo de materiales locales	I4.3.1	Ratio uso materiales locales
		(*)	C4.4	Empleo mano obra local	I4.4.1	Proporción de mano obra local

(*) Criterios obligatorios

Cada uno de los 23 criterios que conforman SIRSDEC se corresponde con un objetivo que se debería conseguir para que el proyecto pueda considerarse sostenible en los países subdesarrollados. Como prerrequisitos establecidos, SIRSDEC tiene 13 criterios de obligado cumplimiento para asegurar que los proyectos afrontan todas las principales preocupaciones relacionadas con la sostenibilidad en los países más pobres. En el dominio de la gestión, hay 4 criterios requeridos como estándares internacionales (C1.1), plan de gestión de la sostenibilidad de los proyectos (PSM) (C1.2), plan de procura sostenible (C1.4) y plan de inspección y auditoría (C1.5). El aspecto social incluye 4 criterios adicionales como participación de la comunidad e intervinientes (C2.1), desarrollo igualitario (C2.3) y patrimonio cultural (C2.5). El requerimiento medioambiental tiene 4 criterios obligatorios: conservación de ecosistemas naturales (C3.1), emisión de gases invernadero (C3.3), gestión del agua (C3.5) y riesgo de inundación (C3.6).

Combate a la pobreza (C4.1) y empleo de mano de obra local (C4.4) son los requerimientos económicos que completan los criterios obligatorios exigidos a todos los proyectos.

Para monitorizar el desempeño, la comprensión en materia de sostenibilidad y la interacción entre los diferentes participantes del proyecto, SIRSDEC desarrolló un conjunto de 29 indicadores medibles que reflejan las principales preocupaciones relativas a la sostenibilidad de los proyectos de infraestructuras. El requerimiento de gestión incluye 8 indicadores. El indicador I1.1.1 evalúa la implementación y mantenimiento de la ISO 9001 o equivalente para alinear la organización del proyecto con los estándares internacionales de gestión de la calidad, mientras el indicador I1.1.2 juega el mismo papel con la normativa ISO 14001 o equivalente para que el equipo del proyecto cumpla las prácticas de gestión medioambiental. El indicador I1.2.1 recompensa la capacidad de diseñar e implementar proyectos integrando y equilibrando los aspectos sociales, económicos y medioambientales. El uso del plan de gestión de riesgos en la sostenibilidad (SRM) es evaluado a través del indicador I1.3.1, cuyo fin es la identificación, valoración, priorización y mitigación de riesgos en el campo de la sostenibilidad. El plan de procura sostenible evaluado por el indicador I1.4.1 busca la gestión de las cadenas de suministro a través de la integración y equilibrio de los aspectos sociales, económicos y medioambientales. La implementación del plan de I&A asegura el cumplimiento de las practicas sostenibles establecidas, mientras que la distribución de informes de avance entre los participantes del proyecto y el registro y divulgación de las lecciones aprendidas son objeto de los indicadores I1.6.1 and I1.6.2.

Seis indicadores fueron considerados en el requerimiento social. Los indicadores I2.1.1 e I2.2.1 valoran el grado de participación de los intervinientes en el proyecto, así como de la comunidad indígena en relación con el total de población y participantes afectados por el proyecto. La paridad de salarios entre sexos está a cargo del indicador I2.3.1, que calcula la ratio entre el sueldo medio femenino y el masculino. El indicador I2.4.1 muestra la proporción de población impactada negativamente por las infraestructuras durante su ciclo de vida en términos sociales, económicos y medioambientales. La ratio de viviendas temporales/permanentes afectadas por el proyecto es monitorizado por el indicador I2.4.2, mientras que el indicador I2.5.1 premia la identificación, evaluación, gestión y conservación del patrimonio cultural según lo define la UNESCO (UNESCO, 1972).

La sección medioambiental contiene 11 indicadores que pueden ser medidos durante el ciclo de vida del proyecto. Los indicadores I3.1.1 e I3.1.2 reflejan la proporción del área del ecosistema del proyecto y de las especies en peligro que pudieran ser impactadas negativamente durante el desarrollo y la operación de los proyectos, respectivamente. Los indicadores I3.3.1 e I3.4.1 miden la reducción de las emisiones de Gases de Efecto Invernadero (GHG) y del uso de energía implementando un plan de acción en comparación con las estimaciones realizadas derivadas de los estándares existentes aplicables. La proporción de consumo de agua potable con respecto al total de recursos disponibles es evaluada por el indicador I3.5.1, la capacidad de almacenar agua de escorrentía es recompensada por el indicador I3.5.2 y el porcentaje de tierra susceptible de sufrir daños por inundaciones dentro de los límites afectados por el proyecto es evaluado por el indicador I3.6.1. Los indicadores I3.7.1 e I3.8.2 puntúan las medidas tomadas para reducir la emisión de contaminantes al aire y la producción de residuos en relación a los estándares habituales (NEC, 2001). Los cuatro contaminantes del aire que se consideran en el indicador I3.7.1 son: dióxido de azufre, óxido de nitrógeno, partículas en suspensión y amoniaco.

SIRSDEC caracteriza el requerimiento económico a través de 4 indicadores. El indicador I4.1.1 se encarga de la evaluación de los beneficios económicos que aporta el proyecto y que contribuyen a reducir los niveles de pobreza y a promover el crecimiento económico en la región. El impacto que puede suponer el proyecto sobre la tierra en la que existan cultivos permanentes es analizado por el indicador I4.2.1. Finalmente, el fomento del uso de materiales y de mano de obra locales es evaluado respectivamente por los indicadores I4.3.1 e I4.4.1.

El sistema SIRSDEC fue diseñado como una herramienta universal para ayudar a los usuarios a la evaluación de la sostenibilidad de cualquier proyecto de infraestructura en los países subdesarrollados durante cualquiera de las fases de su ciclo de vida.

La máxima puntuación del sistema SIRSDEC es de 121, siempre y cuando los 29 indicadores del sistema que pueden estar valorados en un rango de 0 a 1 punto, alcancen 1 punto cada uno. SIRSDEC diferencia 3 niveles de cumplimiento según la puntuación total obtenida: Pass (63), Silver (63 a 90) y Gold (> 90).

3.2.3. Obtención de datos

Un cuestionario on-line fue la herramienta que se consideró más conveniente para recabar información de expertos internacionales procedentes de varios países del mundo. Este método facilitó la distribución de la encuesta entre un gran número de participantes localizados en diversos continentes, así como la rápida integración de los datos recibidos en un documento único. El cuestionario fue dividido en tres partes. La primera solicitaba información estadística de la consulta, explicando las reglas a seguir para responder correctamente a las cuestiones mientras se describían brevemente los requerimientos, criterios e indicadores de los diferentes niveles en los que se organiza SIRSDEC. La segunda sección invitaba a los expertos a responder diversas cuestiones generales relacionadas con la sostenibilidad y con su evaluación, mientras que la tercera y última parte se centraba en la comparación de pares de los elementos del árbol de decisión, necesaria para valorar la importancia relativa entre cada par de elementos *i* y *j* según los valores de la escala de comparación por pares establecida en la Tabla 8.

El panel que sirvió para la consulta sobre los elementos de SIRSDEC incluía diversos expertos internacionales en el campo de la sostenibilidad y de los sistemas de evaluación medioambiental, así como profesionales y expertos internacionales del mundo académico, industrial, agencias internacionales, instituciones públicas y organizaciones de investigación y desarrollo. La composición del panel se estableció siguiendo diversos criterios: presencia de autores en el ámbito de la sostenibilidad, expertos involucrados en el desarrollado de herramientas de evaluación y usuarios habituales de sistemas de rating.

3.2.4. Cálculo de los factores de ponderación

Los factores de ponderación son un elemento fundamental para cualquier sistema de rating, puesto que son determinantes en la puntuación del proyecto que se analiza (Lee et al., 2002). El hecho de que SIRSDEC fue diseñado como un marco general de trabajo válido para todos los países subdesarrollados hace que no sea necesario el recálculo de los factores de ponderación para los países que se encuentren dentro de esta categoría económica, siendo de aplicación para todos ellos. El método Analytic Hierarchy Process (AHP) (Saaty, 1980), creado por Saaty en 1980, fue seleccionado por su simplicidad y flexibilidad para ser combinado con otros métodos multi-criterio (Vaidya et al., 2006), siendo utilizado para transformar las respuestas de las comparaciones por pares facilitadas por los expertos en valores numéricos. Se plantearon diferentes niveles jerarquizados en los problemas de toma de decisión, en los que las comparaciones fueron valoradas de acuerdo a la escala incluida en la Tabla 8 para que pudieran ser evaluadas y así poder establecer su grado de contribución al sistema desde el nivel más inferior al más superior del árbol de decisión.

Tabla 8. Escala de comparación AHP

Evaluación cualitativa	Puntuación
Absolutamente más importante (AMI)	9
Mucho más importante (MMI)	7
Más importante (MI)	5
Ligeramente más importante (SMI)	3
Igualmente importante (EMI)	1
Ligeramente menos importante (SLI)	1/3
Menos importante (LI)	1/5
Mucho menos importante (MLI)	1/7
Absolutamente menos importante (ALI)	1/9

La aplicación de la escala de comparación de la Tabla 8 permitió la construcción de una matriz de comparaciones de dimensión $n * n$ (Skibniewski et al., 1992). La consistencia de sus elementos fue evaluada a través del máximo autovalor de la matriz (λ_{max}), de forma que se asociaba a cada autovalor un autovector que establecía las prioridades relativas entre las comparaciones. Si λ_{max} era igual a n, se podía afirmar que la matriz de comparaciones era consistente. La consistencia de las comparaciones se midió mediante el coeficiente de consistencia (C.R.), que se expresa como el cociente entre el índice de consistencia (C.I.) (ver Ec. (1)) y el índice aleatorio de consistencia (R.I.) según la Ec. (2). Para valores de C.R. menores o iguales a 0,1, la inconsistencia se considera aceptable. Los valores de R.I. dependen exclusivamente de la dimensión de la matriz n y se expresan habitualmente según los resultados obtenidos de un ejercicio realizado con 500 elementos (ver Tabla 9).

$$C.I. = \frac{\lambda - n}{n} \tag{1}$$

$$C.R. = \frac{C.I.}{R.I} < 0.1 \tag{2}$$

Tabla 9. Índice aleatorio de consistencia (R.I.)

Tamaño de matriz (n)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R. I	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

El ajuste de las inconsistencias encontradas en las respuestas del cuestionario y la agrupación de los factores de ponderación en un conjunto consensuado se llevó a cabo utilizando el método propuesto por Jato-Espino et al. (2017), basado en el algoritmo Generalized Reduced Gradient (GRG) y un sistema de agregación según la proximidad de las opiniones de cada par de encuestados. GRG es un algoritmo no lineal desarrollado a partir del método del gradiente reducido que transforma un problema no lineal en varios problemas lineales de menor tamaño. Así, cada problema lineal es resuelto con el método del gradiente reducido, estableciendo restricciones lineales a las que el problema debe aproximarse.

Si $[A]$ es la matriz inconsistente de comparaciones con respecto a un conjunto de criterios $C_j = \langle C_1, C_2, \dots, C_n \rangle$ y $[A]'$ la matriz consistente que se busca, el algoritmo minimiza las diferencias entre los valores del triángulo superior derecho de ambas matrices siguiendo la Ec. (2) y manteniéndose dentro de los límites inferior y superior de los valores de la escala de comparación de AHP. Las diferencias entre ambas matrices se calculan a través del error cuadrático medio (RMSE) (Chai et al., 2014). La consistencia y la fidelidad de las opiniones facilitadas por los expertos son las dos condiciones que deben de cumplirse durante la resolución del problema. Se utiliza una escala logarítmica para igualar las diferencias entre los límites inferior y superior (ver Ec. (3)).

$$Minimizar \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(ln\, x_{j_1 j_2} - ln\, x'_{j_1 j_2}\right)^2}$$

$$siempre\ que: \quad C.R. \leq 0.1$$

$$\ln a_{ij}^{L.T.} < \ln a'_{ij} < \ln a_{ij}^{U.T.} \tag{3}$$

La distancia euclídea, una variable de medición para evaluar semejanzas entre conjuntos de datos (Xing et al., 2003) fue utilizada para calcular la afinidad entre las opiniones de los expertos según la Ec. (4):

$$s_{e_k e_l} = \sqrt{\sum_{i=1}^{n} \left(a_{ij,e_k} - a_{ij,e_l}\right)^2} \tag{4}$$

donde $s_{e_k e_l}$ es la distancia entre las opiniones de los expertos e_k y e_l, y a_{ij,e_k} y a_{ij,e_l} son la expresión numérica de las opiniones según la importancia relativa del criterio i en comparación con j. Una matriz simétrica $[M]$ de dimensión $m * m$ fue obtenida a partir de las distancias euclídeas, de tal forma que m es el número de expertos. La matriz muestra la proximidad entre las opiniones de cada par de expertos. La asignación de los pesos de cada experto se realizó calculando la inversa ponderada de la suma de distancias de cada experto a los restantes mediante la Ec. (5):

$$w_{e_k} = \frac{1 / \sum_{k=1}^{p} s_{e_k e_l}}{\sum_{k=1}^{p} \left(1 / \sum_{k=1}^{p} s_{e_k e_l} \right)} \tag{5}$$

El conjunto de respuestas individuales resultante se agregó en una única opinión $(a_{ij,c})$ como la media ponderada de n números, expresada como la raíz enésima de su producto (Aczél et al., 1983), (Aczél et al., 1987) de acuerdo a la Ec. (6):

$$a_{ij,c} = \left(\prod_{k=1}^{p} {a'_{ij,e_k}}^{w_{e_k}} \right)^{1 / \sum_{k=1}^{p} w_{e_k}} \tag{6}$$

La previa normalización de la matriz de comparaciones consensuada $[A_c]$ según se muestra en la Ec. (7) permitió el cálculo posterior de los pesos de los criterios $C_i = \langle C_1, C_2, \ldots, C_n \rangle$ aplicando la Ec. (8):

$$a_{ij,cn} = \frac{a_{ij,c}}{\sqrt{\sum_{i=1}^{n} {x_{i,c}}^2}} \tag{7}$$

$$w_i = \frac{\sum_{i=1}^{n} \frac{1}{\sqrt{\sum_{i=1}^{n} a_{ij,c}}}}{\sum \sum_{i=1}^{n} \frac{1}{\sqrt{\sum_{i=1}^{n} a_{ij,c}}}} \tag{8}$$

3.2.5. Valoración de los indicadores

MIVES es un método multi-criterio de toma de decisión (MCDM) que surgió como el resultado de las investigaciones realizadas por diferentes instituciones españolas como la Universidad del País Vasco (UPV), la Universitat Politécnica de Catalunya (UPC) y LABEIN-Tecnalia. El método fue desarrollado a partir de dos proyectos aprobados en concurso público dentro del marco del Plan Nacional de Investigación, usando el análisis de valor como una plataforma para la toma de decisiones a través de la evaluación de soluciones alternativas y con el objetivo permanente de evaluar cuantitativamente la sostenibilidad (San-Jose et al., 2010). La función de valor es la herramienta clave de MIVES que hace posible transformar indicadores con diferentes unidades de medida en un valor adimensional en el rango de 0 a 1.

Las funciones de valor son definidas por 5 parámetros (K_i, C_i, X_{min}, X_{max} and P_i) que determinan 4 curvas diferentes: lineal, cóncava, convexa y forma de S. La Figura 4 muestra las formas de las curvas de las funciones de valor, mientras que la Tabla 10 recoge los valores de los parámetros que determinan sus formas.

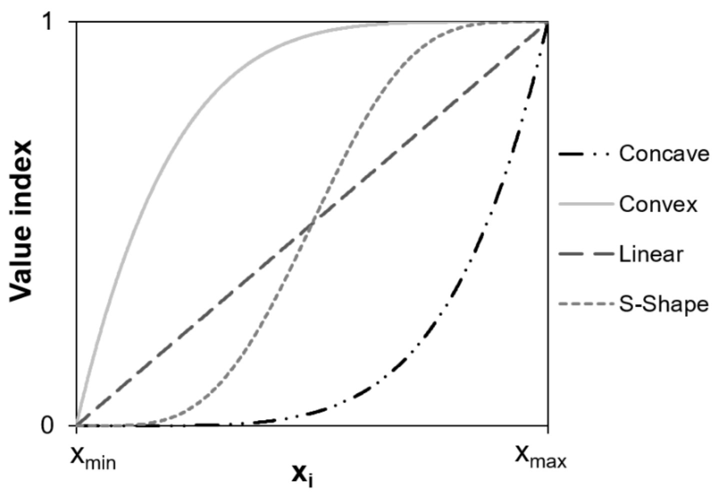

Figura 4. Formas de las funciones de valor de MIVES

Tabla 10. Parámetros P_i y K_i de las funciones de valor

Forma	P_i	K_i
Cóncava	>2	<0,1
Convexa	<0,75	>0,9
Lineal	1	0
Forma de S	2 - 10	0,1 – 0,2

Para funciones crecientes, las funciones de valor se calculan con las Ecs. (9) y (10). Si las funciones son decrecientes, X_{min} debe de ser intercambiada por X_{max}.

$$V_{ind} = B * \left[1 - e^{-K_i * \left(\frac{|X - X_{min}|}{C_i}\right)^{P_i}}\right] \quad (9)$$

$$B = \left[1 - e^{-K_i * \left(\frac{|X_{max} - X_{min}|}{C_i}\right)^{P_i}}\right]^{-1} \quad (10)$$

donde X_{min} es la abscisa para el mínimo valor del indicador, X_{max} la abscisa para el máximo valor del indicador, X la abscisa para esta alternativa, P_i el factor de forma, C_i y K_i la abscisa y ordenada del punto de inflexión, respectivamente, y B un factor de ajuste para evitar que se exceda del rango de valor [0,1].

Las funciones con forma de S muestran un incremento notable de su valor en la zona central de la curva, alejada de los valores X_{min} y X_{max}. Las funciones convexa y cóncava revelan alternativamente sus valores más altos cerca de X_{min} y X_{max}, dependiendo de si las funciones son crecientes o decrecientes. Las funciones lineales reflejan incrementos y decrementos constantes de valores, independientemente de la posición de la abscisa en relación a X_{min} y X_{max}.

El índice de sostenibilidad de una alternativa se obtiene a través de la agregación de los índices de valor del nivel de decisión inferior (indicadores) al superior (requerimientos), tal y como se muestra en la Ec. (11):

$$V_i = \sum_{j=1}^{m} V_{ij} * W_j \quad (11)$$

donde V_i es el índice de sostenibilidad de la alternativa del nivel de decisión i, W_j es el peso que le correspondería al elemento j del árbol de decisión, n es el número de niveles y m el número de elementos de cada nivel del árbol de decisión.

Se asignaron funciones binarias con valores únicos de 0 o 1 a aquellos indicadores que no permitían valores intermedios y eran evaluados según el único criterio de cumplimiento o de incumplimiento total (I1.1.1, I1.12, I1.2.1, I1.3.1, I1.4.1, I1.5.1, I1.6.1, I1.6.2, I2.5.1 y I4.1.1). La información para caracterizar los restantes parámetros de las funciones de valor descritas en la Figura 4 fue obtenida de las métricas encontradas en diversas instituciones y organizaciones internacionales de desarrollo como el Banco Mundial, la Organización Internacional del Trabajo (ILO), el Programa Medioambiental de Naciones Unidas (UNEP), el Programa de Desarrollo de Naciones Unidas (UNDP), el Programa de Asentamientos Humanos de Naciones Unidas (UN-HABITAT) o la UNESCO. En aquellos casos en que esta información difirió de aquella necesaria para correlacionarse con los parámetros establecidos por SIRSDEC, se utilizó como fuente de información alternativa aquella relativa a la existente en los países desarrollados. Los límites establecidos por los 3 sistemas de rating existentes (CEEQUAL, IS y ENVISION) fueron la última referencia utilizada para la determinación de las funciones de valor en el caso de que la información hallada en las entidades internacionales no se ajustase a los indicadores a caracterizar.

3.3. Aplicación del sistema de rating de la sostenibilidad de proyectos de infraestructura en países subdesarrollados (SIRSDEC) a un caso de estudio

3.3.1. Datos obtenidos en la encuesta

El cuestionario se remitió a 118 expertos del área del desarrollo sostenible y del medioambiente, que fueron previamente seleccionados entre diversos sectores como el académico, instituciones públicas, consultoría y contratistas. La encuesta se realizó durante todo el mes de enero de 2016, recibiéndose 24 respuestas al cuestionario de 12 países diferentes, tal y como se refleja en la Figura 5, lo que supuso un porcentaje de respuesta del 20,3%.

No hubo cuestionarios rechazados puesto que su propio formato obligaba a que se respondiesen todas las preguntas relacionadas con las comparaciones relativas entre los requerimientos, criterios e indicadores del árbol de decisión de SIRSDEC, según la escala de comparación del método AHP incluida en la Tabla 8. Todos los participantes de la encuesta habían estado involucrados en proyectos de sostenibilidad en algún momento de su vida profesional y ya conocían previamente los sistemas de rating existentes. 23 de ellos habían trabajado con estas herramientas, mientras solo uno de ellos no tenía experiencia alguna en el uso de las mismas. Las opiniones de la encuesta representaron a un amplio espectro de diferentes sectores de actividad: 11 participantes (45,8%) trabajaban en el campo académico, mientras que dos grupos de 5 expertos (20,8%) cada uno representaban al sector de instituciones públicas y consultoría. Los contratistas formaron un último grupo que incluía 3 expertos (12,6%).

A continuación, se relacionan las entidades a las que estaban adscritos los expertos que participaron en el cuestionario: BHP Billiton, Boluda Shipping Corporation y CWG Metro Riyad Joint Venture (Contratistas); Waterloo University, Malaysia University Technology, Hamad Bin Khalifa University, University of Wisconsin-Madison, Coventry University, Colorado State University and Cardiff University (Academia); Qatar Green Council, AMEC Foster Wheeler, Tecnalia and Atkins (Consultoría); United Nations Office for Project Services (UNOPS), Agencia Española para Cooperación y Desarrollo (AECID), Qatar Foundation, International Organization of Supreme Audit Institutions Working Group on Environmental Auditing (INTOSAI WGEA) (Instituciones públicas de Desarrollo).

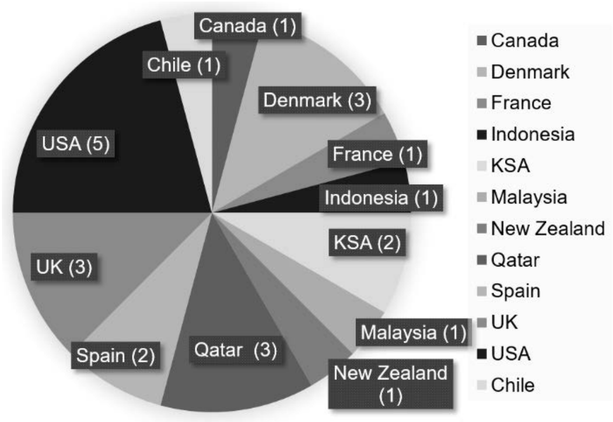

Figura 5. Países de procedencia de los encuestados

La encuesta formulaba tres preguntas generales sobre las características de SIRSDEC en comparación con los otros sistemas de rating existentes. 22 encuestados (91,7%) consideraron útil el desarrollo de un nuevo sistema de rating de la sostenibilidad para proyectos de infraestructuras en países subdesarrollados, mientras que 2 (8,3%) no lo vieron útil. 15 expertos (62,5%) contra 9 (37,5%) afirmaron que los tres pilares de la sostenibilidad deberían ser considerados equitativamente en los sistemas de rating para los países subdesarrollados. La propuesta de incluir la gestión en el nuevo sistema junto a los tres pilares de la sostenibilidad fue apoyada por 19 participantes (79,2%), mientras que 5 (20,8%) rechazaron esta posibilidad. Finalmente, los encuestados fueron invitados a sugerir la inclusión o el descarte de algún criterio o indicador contemplado en SIRSDEC. Sin embargo, los comentarios recibidos de los expertos consultados, que se resumen en la Tabla 11, no fueron de gran trascendencia por lo que fueron desechados en su totalidad. Por otra parte, todas las respuestas recibidas en la encuesta acerca de las comparaciones por pares realizadas entre los elementos del sistema aparecen en la Tabla 12.

Tabla 11. Criterios e Indicadores sugeridos por los encuestados

Criterios adicionales sugeridos	Criterios a descartar	Indicadores adicionales	Indicadores a descartar
- Reducción riesgos de desastre - Contaminación acústica - Resistencia al cambio climático - Relación con las autoridades	C1.3	- Cantidad de tierra desbastada - Energía derrochada durante la construcción	I1.1.1 I1.3.1

Tabla 12. Respuestas recibidas de los expertos

Pairwise Comparison	Expert Number																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
R1 vs R2	SLI	LI	MLI	EI	EI	SMI	MLI	EI	SLI	EI	MI	EI	SLI	SLI	LI	SLI	LI	EI	SLI	EI	SLI	SLI	MLI	SMI
R1 vs R3	SLI	LI	ALI	EI	EI	LI	MLI	AMI	SLI	EI	EI	EI	EI	SLI	EI	SLI	SLI	EI	SLI	EI	MLI	MI	MLI	SMI
R1 vs R4	SLI	LI	ALI	EI	EI	LI	ALI	ALI	SLI	SLI	EI	SLI	EI	SLI	EI	SLI	EI	EI	SLI	SLI	MLI	SMI	MLI	SMI
R2 vs R3	EI	EI	EI	EI	EI	SLI	MI	EI	EI	SLI	EI	SMI	EI	EI	MMI	SLI	EI	EI	EI	SMI	EI	MI	EI	EI
R2 vs R4	EI	MI	MI	EI	EI	LI	SLI	EI	EI	EI	EI	SMI	SMI	SMI	SMI	SLI	SMI	EI	EI	SMI	SMI	MMI	EI	EI
R3 vs R4	EI	MI	MI	SMI	EI	MI	LI	LI	EI	EI	EI	SLI	MI	SMI	LI	SLI	SMI	EI	EI	EI	MI	MI	EI	EI
C1.1 vs C1.2	SLI	SLI	EI	SMI	MLI	EI	MI	LI	LI	LI	SMI	LI	EI	LI	SLI	EI	LI	LI	LI	EI	ALI	EI	MI	MMI
C1.1 vs C1.3	SLI	MLI	SLI	SMI	MLI	EI	MI	AMI	LI	SLI	LI	SMI	LI	LI	MI	EI	MI	SMI	LI	LI	ALI	MMI	SMI	MMI
C1.1 vs C1.4	SLI	MLI	SMI	SMI	MLI	MI	MI	MMI	LI	ALI	EI	SLI	LI	LI	EI	EI	MI	SLI	LI	SMI	ALI	MI	MI	SMI
C1.1 vs C1.5	SLI	MLI	MLI	SMI	ALI	EI	SLI	MI	EI	SLI	MI	SLI	EI	LI	SMI	EI	LI	EI	SLI	SLI	ALI	EI	SMI	MI
C1.1 vs C1.6	SLI	MLI	LI	SMI	MLI	MI	MI	LI	LI	LI	MI	SMI	LI	SLI	EI	SMI	LI	MI	EI	SLI	ALI	MMI	EI	SMI
C1.2 vs C1.3	EI	EI	MI	EI	EI	SMI	MI	SLI	SMI	EI	MI	SLI	EI	SLI	SMI	SMI	SMI	MI	EI	SMI	EI	MMI	SLI	MMI
C1.2 vs C1.4	EI	EI	MMI	EI	EI	SMI	MI	SLI	SMI	EI	EI	SLI	MMI	SLI	EI	EI	MI	SMI	EI	SMI	EI	MMI	SLI	SMI
C1.2 vs C1.5	EI	EI	EI	MI	LI	EI	LI	SLI	EI	EI	MI	SMI	MMI	SLI	EI	EI	EI	EI	EI	SMI	EI	LI	SMI	MI
C1.2 vs C1.6	EI	EI	SMI	EI	LI	EI	MI	EI	SMI	EI	MI	EI	SMI	EI	MI	EI	EI	MI	EI	SMI	MI	EI	SLI	SMI
C1.3 vs C1.4	EI	EI	MI	SLI	SLI	EI	SMI	EI	SMI	EI	EI	SLI	MMI	SMI	EI	EI	SMI	SLI	SLI	SMI	EI	SLI	MI	SMI
C1.3 vs C1.5	EI	EI	EI	SMI	LI	EI	LI	MI	SLI	SLI	EI	EI	MI	SLI	EI	EI	SLI	LI	SMI	SLI	SMI	MLI	SMI	MI
C1.3 vs C1.6	EI	SMI	SLI	SLI	LI	EI	EI	EI	SLI	EI	MI	SMI	EI	SLI	LI	EI	SLI	SLI	EI	SLI	SMI	LI	SLI	SMI
C1.4 vs C1.5	EI	MI	SLI	SMI	LI	EI	SLI	SLI	LI	SMI	MI	SMI	EI	SLI	EI	EI	LI	EI	EI	SLI	SMI	LI	EI	SMI
C1.4 vs C1.6	EI	EI	SLI	EI	LI	EI	MI	SLI	LI	EI	EI	SLI	LI	SLI	LI	EI	LI	SMI	EI	SLI	EI	SLI	SLI	SLI
C1.5 vs C1.6	EI	EI	EI	SLI	EI	EI	MI	EI	EI	SLI	MI	SMI	LI	SMI	EI	EI	EI	EI	SLI	EI	EI	MLI	EI	SMI
C2.1 vs C2.2	EI	SLI	SLI	SLI	EI	EI	MMI	SLI	SMI	LI	MI	SLI	EI	EI	MI	SLI	EI	EI	SLI	LI	EI	EI	EI	MI
C2.1 vs C2.3	SMI	SMI	EI	EI	MI	SMI	SMI	SLI	SLI	LI	MMI	EI	EI	EI	EI	SLI	EI	EI	SLI	SLI	EI	EI	EI	MI
C2.1 vs C2.4	SLI	LI	SLI	EI	EI	SMI	SMI	SLI	EI	EI	MMI	SLI	LI	LI	LI	EI	SMI	EI	SLI	SLI	EI	EI	EI	MI
C2.1 vs C2.5	LI	SMI	SLI	SMI	EI	SLI	LI	SLI	EI	SLI	MMI	SLI	SLI	SLI	EI	EI	MI	EI	SLI	MLI	EI	EI	EI	MI
C2.2 vs C2.3	EI	MI	MI	SMI	MI	EI	SLI	AMI	SLI	EI	EI	SMI	EI	SLI	SMI	SMI	EI	EI	EI	MI	EI	SLI	SLI	EI
C2.2 vs C2.4	EI	EI	MI	EI	MI	SMI	LI	AMI	LI	EI	SMI	SMI	EI	LI	EI	SMI	EI	EI	EI	SMI	EI	LI	EI	EI
C2.2 vs C2.5	EI	MI	EI	SMI	EI	EI	MLI	AMI	SLI	EI	MI	SLI	SLI	SLI	EI	SMI	LI	SMI	SMI	EI	EI	EI	EI	EI
C2.3 vs C2.4	EI	SLI	EI	EI	EI	SMI	SMI	MMI	EI	SMI	MMI	SMI	SMI	SLI	LI	EI	EI	EI	EI	SMI	LI	SMI	MI	SMI
C2.3 vs C2.5	EI	SMI	EI	SMI	EI	SLI	SLI	AMI	SMI	MI	MI	SMI	SMI	SLI	EI	EI	MI	MI	SMI	EI	LI	EI	EI	EI
C2.4 vs C2.5	SMI	MI	MI	EI	EI	EI	SMI	EI	MI	SMI	MMI	SLI	SMI	SMI	EI	EI	MI	MI	SMI	SLI	EI	EI	EI	SMI
C3.1 vs C3.2	EI	EI	EI	EI	EI	SMI	MI	MMI	MI	EI	EI	SMI	MI	EI	EI	EI	EI	EI	EI	EI	EI	EI	EI	EI
C3.1 vs C3.3	EI	SMI	EI	EI	MI	LI	MI	LI	EI	EI	EI	SLI	EI	SMI	EI	EI	EI	EI	SMI	SMI	EI	EI	SLI	EI
C3.1 vs C3.4	EI	SMI	MI	EI	MI	LI	MMI	MI	EI	EI	EI	SMI	SMI	SMI	MI	MMI	EI	MI	EI	SMI	EI	MMI	EI	MI
C3.1 vs C3.5	EI	EI	SMI	EI	EI	LI	MMI	AMI	EI	EI	EI	SMI	SMI	SMI	LI	SMI	EI	MI	EI	SLI	EI	EI	SLI	SMI
C3.1 vs C3.6	EI	SMI	MMI	EI	EI	LI	MI	AMI	EI	EI	EI	MI	MI	SMI	SLI	SMI	SMI	EI	SLI	SLI	EI	LI	SMI	SMI
C3.1 vs C3.7	EI	SMI	EI	SLI	MI	LI	MI	LI	EI	EI	MI	SMI	SMI	SMI	EI	SMI	SLI	EI	EI	SMI	EI	SLI	SLI	SMI
C3.1 vs C3.8	EI	SMI	SLI	SLI	SMI	LI	MI	LI	EI	EI	MI	MI	SMI	SMI	LI	SMI	SMI	MI	EI	SMI	EI	SLI	EI	MI
C3.2 vs C3.3	EI	EI	EI	SLI	MI	LI	MI	AMI	SLI	SLI	MI	MI	SMI	SMI	MI	SMI	EI	EI	SLI	LI	EI	LI	LI	EI
C3.2 vs C3.4	EI	EI	EI	EI	MI	LI	MI	AMI	SLI	EI	MI	MI	MI	SMI	MI	SMI	SMI	MI	SLI	SLI	MI	LI	EI	MI
C3.2 vs C3.5	EI	EI	EI	EI	EI	LI	SMI	AMI	SLI	EI	MI	LI	MI	SMI	EI	SMI	EI	SMI	AMI	SMI	EI	EI	SLI	SMI
C3.2 vs C3.6	EI	EI	SMI	EI	EI	LI	MI	AMI	SLI	EI	MI	SMI	MMI	SMI	LI	SMI	EI	MI	SMI	SMI	MI	SLI	EI	SMI
C3.2 vs C3.7	EI	EI	EI	EI	MI	LI	MI	ALI	SLI	EI	MI	SMI	MI	SMI	LI	SMI	EI	SMI	EI	SMI	SMI	SLI	EI	EI
C3.2 vs C3.8	EI	EI	SMI	EI	SMI	LI	SMI	AMI	SLI	EI	MI	MI	SMI	SMI	LI	SMI	SMI	MI	EI	SMI	EI	EI	SMI	SMI
C3.3 vs C3.4	EI	EI	MI	EI	EI	MI	LI	EI	EI	EI	EI	MMI	LI	SMI	MLI	SLI	EI	SMI	LI	EI	EI	EI	MI	MI
C3.3 vs C3.5	EI	SLI	SMI	EI	LI	SMI	LI	AMI	EI	EI	EI	MI	EI	SMI	MLI	SLI	SLI	EI	SLI	EI	EI	EI	SMI	EI
C3.3 vs C3.6	EI	EI	MI	SLI	LI	MMI	SLI	AMI	EI	EI	EI	MI	MI	SMI	ALI	EI	SLI	EI	SLI	SMI	MI	MI	SMI	EI
C3.3 vs C3.7	EI	EI	EI	EI	EI	AMI	SLI	EI	EI	EI	MMI	EI	EI	EI	LI	EI	SLI	EI	SLI	SMI	MI	MI	EI	EI
C3.3 vs C3.8	EI	EI	SMI	EI	LI	MI	LI	EI	EI	EI	MI	EI	EI	EI	MLI	EI	MI	MI	SLI	SMI	EI	MI	MI	SMI
C3.4 vs C3.5	EI	EI	SLI	SMI	LI	AMI	SLI	MLI	EI	EI	MI	EI	EI	EI	LI	EI	EI	SLI	EI	EI	LI	EI	LI	EI
C3.4 vs C3.6	EI	SLI	SLI	EI	LI	EI	MI	AMI	EI	EI	MI	SLI	MI	SMI	LI	EI	SMI	SLI	SMI	SLI	EI	SMI	SLI	SMI
C3.4 vs C3.7	EI	EI	LI	EI	EI	MI	MI	EI	EI	EI	SLI	SMI	EI	EI	SMI	SMI	SLI	SLI	SMI	SMI	SMI	EI	SLI	SLI
C3.4 vs C3.8	EI	EI	SLI	SMI	EI	SMI	SLI	EI	EI	EI	MMI	SMI	EI	EI	SLI	EI	MI	EI	SMI	EI	LI	SLI	SLI	SMI
C3.5 vs C3.6	MI	EI	EI	EI	EI	MI	MI	AMI	EI	EI	MMI	SMI	MI	SMI	MMI	EI	SLI	EI	EI	EI	MI	MMI	SMI	EI
C3.5 vs C3.7	EI	EI	EI	EI	MI	LI	SMI	AMI	EI	EI	MMI	EI	EI	EI	MMI	SMI	SLI	EI	SMI	SMI	MI	EI	SLI	SLI
C3.5 vs C3.8	EI	SMI	SMI	SMI	EI	EI	SLI	EI	EI	EI	EI	EI	EI	EI	SMI	SMI	SMI	MI	SMI	EI	EI	SLI	SMI	MI
C3.6 vs C3.7	EI	EI	SLI	EI	MI	LI	LI	AMI	EI	EI	EI	EI	LI	SLI	MMI	EI	EI	EI	EI	SMI	EI	LI	SLI	SLI
C3.6 vs C3.8	EI	SMI	MI	EI	EI	LI	LI	EI	EI	EI	SMI	SLI	LI	SLI	SLI	SLI	SMI	MI	SMI	SMI	LI	LI	SLI	SMI
C3.7 vs C3.8	EI	EI	MI	EI	EI	LI	SLI	ALI	EI	EI	EI	EI	EI	EI	SLI	EI	SMI	MI	EI	SLI	LI	SLI	SMI	SMI
C4.1 vs C4.2	EI	EI	MMI	EI	EI	MI	SLI	EI	SMI	MI	EI	EI	SLI	SMI	EI	SMI	MI	MI	EI	MI	EI	AMI	EI	SLI
C4.1 vs C4.3	EI	SMI	MMI	SMI	EI	MI	SLI	AMI	SMI	SMI	EI	SMI	EI	MI	MMI	SMI	MI	MI	EI	MI	MI	EI	MMI	EI
C4.1 vs C4.4	EI	SMI	MI	SMI	EI	MI	LI	AMI	SMI	SMI	MI	MI	EI	SLI	MMI	SMI	EI	EI	EI	SMI	EI	SMI	EI	SMI
C4.2 vs C4.3	EI	MI	MI	SMI	EI	SMI	MLI	EI	EI	SLI	MI	SMI	SMI	MI	AMI	EI	EI	EI	EI	EI	MI	LI	SMI	MI
C4.2 vs C4.4	EI	MI	MI	EI	EI	SMI	MLI	EI	SLI	EI	MI	SMI	MI	MI	AMI	EI	EI	SLI	EI	SLI	EI	MLI	EI	MI
C4.3 vs C4.4	EI	LI	EI	EI	LI	SMI	SLI	EI	EI	EI	MI	SLI	EI	LI	MMI	EI	EI	EI	EI	SLI	MLI	EI	LI	SLI
I1.1.1 vs I1.1.2	EI	LI	LI	EI	EI	EI	SLI	SLI	EI	SLI	SMI	MLI	EI	EI	LI	EI	EI	EI	EI	EI	ALI	MI	EI	SLI
I1.6.1 vs I1.6.2	EI	MI	MI	SLI	MLI	MI	SLI	EI	SLI	MLI	SMI	MLI	SMI	EI	EI	EI	EI	MI	SLI	SLI	ALI	SMI	MI	SLI
I2.4.1 vs I2.4.2	EI	SMI	MMI	SMI	LI	MMI	MMI	MMI	MI	EI	MI	EI	MMI	SMI	EI	SMI	SLI	SMI	MI	SLI	EI	MMI	MI	MI
I3.4.1 vs I3.4.2	SLI	EI	MLI	SLI	LI	AMI	MI	EI	LI	EI	SMI	LI	MLI	LI	MLI	LI	MI	LI	SMI	SMI	EI	LI	LI	MI
I3.5.1 vs I3.5.2	SLI	MI	AMI	SLI	EI	MI	LI	MI	MI	EI	MI	EI	LI	MLI	SLI	EI	MI	EI	SLI	SLI	EI	MLI	MMI	MI
I3.8.1 vs I3.8.2	SLI	MMI	MLI	SLI	MLI	MI	MMI	EI	MI	MI	EI	SMI	MLI	EI	MI	MLI	MI	MLI	LI	SMI	LI	SLI	EI	MI

3.3.2. Cálculo de los factores de ponderación

El cálculo de los factores de ponderación del sistema es esencial para la completa caracterización de la herramienta SIRSDEC. El análisis de la consistencia de las opiniones recibidas de la encuesta a través del ratio de consistencia (C.R.) determinó el grado de contradicciones en las respuestas recibidas de los expertos. Un valor del C.R. menor o igual de 0,1 era aceptable en caso contrario las inconsistencias debían de ser transformadas en datos consistentes ajustándolas mediante una optimización no lineal. La Tabla 13 incluye los autovalores y C.R. obtenidos después de analizar la consistencia de las respuestas recibidas de los expertos, agrupadas en requerimientos y paquetes de criterios. Los resultados mostraron que la cantidad de inconsistencias detectadas fue alta, superando el 50% para cada paquete analizado de comparaciones por pares. Los criterios Económico y Medioambiental revelaron 13 inconsistencias cada uno, mientras que el Social y los Requerimientos incluyeron 14 y 12 respectivamente. El mayor número de inconsistencias correspondió al criterio de Gestión con 16.

Tabla 13. Resultados del análisis de consistencia de las respuestas recibidas de los expertos

Encuestado #	Requerimientos		Criterio Económico		Criterio Social		Criterio Gestión		Criterio Medioambiental	
	λ	C.R.	λ	C.R.	λ	C.R.	λ	C.R.	λ	C.R.
1	0,000	0,000	0,000	0,000	0,265	0,237	0,000	0,000	0,039	0,028
2	0,125	0,139	0,135	0,150	0,085	0,076	0,108	0,087	0,067	0,047
3	0,150	0,166	0,160	0,178	0,285	0,255	0,240	0,193	0,293	0,208
4	0,052	0,058	0,052	0,058	0,090	0,080	0,084	0,068	0,127	0,090
5	0,000	0,000	0,118	0,131	0,138	0,123	0,114	0,092	0,058	0,041
6	0,263	0,292	0,112	0,124	0,184	0,165	0,111	0,090	0,434	0,308
7	0,154	0,171	0,189	0,210	0,453	0,404	0,291	0,235	0,257	0,182
8	0,580	0,644	0,231	0,257	0,421	0,376	0,910	0,734	1,962	1,391
9	0,000	0,000	0,053	0,059	0,085	0,076	0,270	0,218	0,004	0,003
10	0,166	0,184	0,039	0,043	0,155	0,139	0,109	0,088	0,017	0,012
11	0,118	0,131	0,119	0,132	0,280	0,250	0,463	0,373	0,392	0,278
12	0,163	0,181	0,094	0,105	0,307	0,274	0,548	0,442	0,468	0,332
13	0,088	0,098	0,011	0,012	0,293	0,262	0,286	0,231	0,175	0,124
14	0,054	0,059	0,496	0,551	0,052	0,046	0,190	0,153	0,057	0,041
15	0,077	0,086	0,203	0,226	0,314	0,281	0,253	0,204	0,444	0,315
16	0,108	0,120	0,000	0,000	0,038	0,034	0,056	0,045	0,132	0,093
17	0,011	0,012	0,114	0,127	0,470	0,420	0,161	0,130	0,172	0,122
18	0,000	0,000	0,093	0,103	0,078	0,070	0,167	0,135	0,071	0,051
19	0,000	0,000	0,000	0,000	0,039	0,035	0,157	0,126	0,355	0,252
20	0,166	0,184	0,015	0,016	0,096	0,086	0,240	0,193	0,300	0,213
21	0,178	0,197	0,005	0,005	0,118	0,105	0,098	0,079	0,116	0,082
22	0,181	0,201	0,051	0,057	0,141	0,126	0,462	0,373	0,524	0,371
23	0,000	0,000	0,005	0,005	0,082	0,073	0,314	0,254	0,241	0,171
24	0,000	0,000	0,152	0,169	0,110	0,098	0,440	0,355	0,124	0,088
Total Consistentes	12		11		10		8		11	
Total Inconsistentes	12		13		14		16		13	

Se realizó el test de Grubbs a los paquetes de valores de C.R. obtenidos a partir de las opiniones de los expertos (ver Tabla 13) para detectar posibles valores atípicos en el conjunto de datos, asumiendo que éstos seguían una distribución normal. Los datos de la Tabla 14 confirmaron que algunas opiniones de los expertos #8 y #14 estaban fuera de rango. Los diagramas de caja de los C.R. de la Figura 6 ratificaron la existencia de estos valores atípicos.

Tabla 14. Resultados del test de Grubbs a los C.R. de las opiniones de los expertos

Conjunto de datos	N	Media	Desviación Estándar (SD)	Mín.	Máx.	G	P	Experto	Valor atípico
Requerimientos	24	0,1218	0,1408	0,0000	0,6443	3,71	0,000	8	0,6443
Criterio Económico	24	0,1133	0,1215	0,0000	0,5509	3,60	0,000	14	0,5509
Criterio Social	24	0,1704	0,1195	0,0342	0,4197	2,09	0,710		
Criterio Gestión	24	0,2040	0,1608	0,0000	0,7342	3,30	0,003	8	0,7342
Criterio Medioambiental	24	0,2018	0,2768	0,0030	1,3910	4,30	0,000	8	1,3910

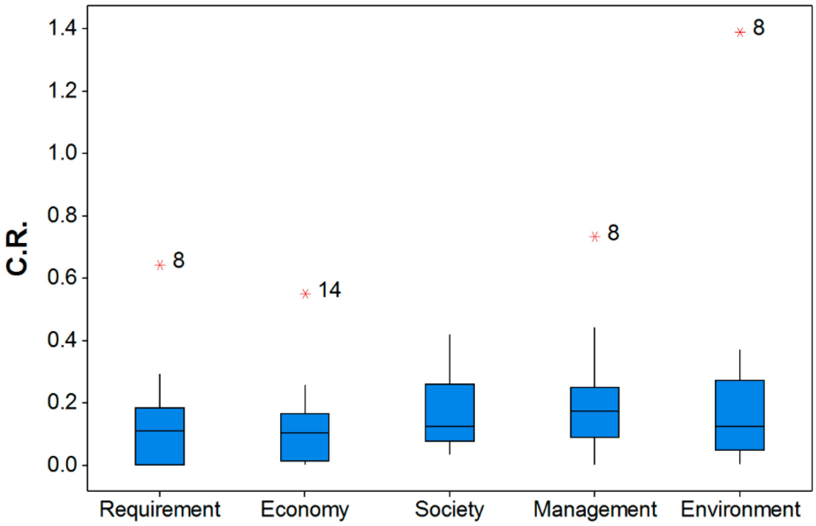

Figura 6. Diagramas de Caja de los C.R. de las opiniones de los expertos

Después de aplicar el método propuesto por Jato-Espino et al. (2017), la mayoría de los datos inconsistentes se convirtieron en consistentes excepto los relativos al experto #8, por lo que las opiniones de este experto fueron descartadas en su totalidad.

3.3.3. Caracterización de las funciones de valor de los indicadores

Los ocho indicadores incluidos en el requerimiento de Gestión fomentan el uso de herramientas efectivas para el buen gobierno de los proyectos, de buenas prácticas sostenibles y de estándares enfocados a la mejora de la gestión de los proyectos. Se asignaron funciones binarias escalonadas a todos los indicadores de esta categoría, recibiendo 0 ó 1 punto según cumplieran o no el objetivo establecido. El mismo principio se aplicó a los indicadores I2.5.1 e I.4.1.1. En cuanto al requerimiento Social, los indicadores I2.1.1 e I2.2.1 fueron puntuados tomando como referencia los estándares de la Asociación para la participación pública (IAP2). Los proyectos con un nivel de participación para los intervinientes del proyecto y de la población o comunidad indígena de al menos “mejora” se puntuarían con 1 punto, mientras que los restantes niveles quedarían sin puntuar. Para ambos indicadores, las funciones de valor tomadas fueron escalonadas.

Se determinaron funciones lineales crecientes para los indicadores I3.3.1, I3.4.1, I3.4.2, I3.5.1, I3.5.2, I3.8.1 e I3.8.2, con el propósito de recompensar proporcionalmente el cumplimiento de sus objetivos. Debido a la escasez de información de las métricas de los países subdesarrollados para estos indicadores, se tuvieron que adoptar como valores mínimos y máximos de las funciones de valor los de otros indicadores equivalentes; es decir, los umbrales fijados en los 3 sistemas de rating de la sostenibilidad existentes para proyectos de infraestructuras: Envision, Civil Engineering Environmental Quality (CEEQUAL) e Infrastructure Sustainability (IS) Rating Tool.

Por la misma razón, los valores mínimos y máximos de los indicadores I2.4.2, I3.1.1, I3.2.1 e I4.2.1 fueron obtenidos utilizando la misma fuente de información. Para estos indicadores, se estableció una forma cóncava decreciente para su función de valor, de manera que se recompensara con alta puntuación a los valores bajos del indicador y viceversa, penalizando los valores altos del indicador. El desempeño de los indicadores I2.3.1 e I4.1.1 fue representado por funciones de valor convexas crecientes, mientras que sus límites máximo y mínimo fueron extraídos de los informes de la Organización Internacional del Trabajo (OIT).

Se determinaron funciones de valor en forma de S como las más idóneas para los indicadores I2.4.1, I3.6.1, I3.7.1 e I4.3.1. Mientras que las funciones de valor de los dos primeros indicadores fueron decrecientes, el resto lo fueron crecientes. La Directiva NEC 2001/81/EC permitió obtener el rango de valores para el indicador I3.7.1, mientras que los valores de los 3 sistemas existentes de rating de proyectos de infraestructuras sirvieron para el resto. La Tabla 15 resume los parámetros utilizados para caracterizar las funciones de valor de los indicadores de SIRSDEC.

Tabla 15. Parámetros de las funciones de valor de los indicadores de SIRSDEC

Indicador	Descripción	Xmín	Xmáx	Pi	Ci	Ki	Función
I 1.1.1	ISO 9001 o equivalente	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 1.1.2	ISO 14001 o equivalente	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 1.2.1	Plan Gestión Sostenibilidad del Proyecto	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 1.3.1	Plan de Gestión riesgos Sostenibilidad	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 1.4.1	Plan Procura sostenible	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 1.5.1	Plan de Inspección y Auditoria	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 1.6.1	Distribución informes	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 1.6.2	Registro lecciones aprendidas	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 2.1.1	Participación intervinientes	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 2.2.1	Participación de indígenas	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 2.3.1	Ratio de salarios por sexos	51,00	99,00	0,75	51,00	4,000	Convexa
I 2.4.1	Población afectada Proyecto	25,00	0,00	3,00	5,00	0,020	Forma S
I 2.4.2	Asentamientos urbanos afectados	20,00	0,00	5,00	3,00	0,002	Cóncava
I 2.5.1	Evaluación cultural local	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 3.1.1	Superficie ecosistemas afectada	30,00	0,00	2,50	15,00	0,050	Cóncava
I 3.2.1	Especies en peligro	30,00	0,00	2,50	15,00	0,050	Cóncava
I 3.3.1	Reducción emisiones GHG	10,00	40,00	1,00	40,00	1,000	Lineal
I 3.4.1	Energía ahorrada	10,00	30,00	1,00	30,00	1,000	Lineal
I 3.4.2	Uso energía renovable	10,00	25,00	1,00	25,00	1,000	Lineal
I 3.5.1	Reducción consume agua	5,00	20,00	1,00	20,00	1,000	Lineal
I 3.5.2	Agua escorrentía almacenada	0,00	30,00	1,00	30,00	1,000	Lineal
I 3.6.1	Área inundable	15,00	0,00	5,00	8,00	0,250	Forma S
I 3.7.1	Reducción contaminantes aire	0,00	52,00	5,50	11,00	0,015	Forma S
I 3.8.1	Reducción producción residuos	0,00	20,00	1,00	20,00	1,000	Lineal
I 3.8.2	Reciclaje/reúso de residuos	20,00	50,00	1,00	50,00	1,000	Lineal
I 4.1.1	Evaluación económica local	0,00	1,00	n.a.	n.a.	n.a.	Escalonada
I 4.2.1	Área cultivo afectada	30,00	0,00	2,50	15,00	0,050	Cóncava
I 4.3.1	Ratio del uso de materiales locales	0,00	30,00	3,00	5,00	0,025	Forma S
I 4.4.1	Ratio de empleo local	10,00	30,00	0,70	30,00	2,000	Convexa

3.3.4. Tabla de ponderación del sistema

La integración de las respuestas de los expertos en una única opinión se llevó a cabo utilizando la media ponderada de n números como la enésima raíz de su producto. La Tabla 16 muestra los factores de ponderación obtenidos para SIRSDEC tras aplicar este proceso a las respuestas de los expertos. El peso del aspecto Social resultó el más alto (0,324), por encima de los requerimientos Medioambiental (0,289), Económico (0,247) y de Gestión (0,140). Entre los criterios, Combate a la pobreza (C4.1) obtuvo un peso de 0,398, siendo el factor más relevante en el aspecto Económico. La conservación de los ecosistemas naturales (C3.1) y la biodiversidad (C3.2), con valores de 0,169 y 0,155, respectivamente, fueron los más importantes en el dominio Medioambiental. Hubo tres criterios en la dimensión Social con factores de ponderación similares: Papel de la población (C2.2) con 0,214, Desarrollo igualitario (C2.3) con 0,211 e Impactos y beneficios sociales (C2.4) con 0,222. Finalmente, el Plan de Gestión sostenibilidad Proyecto (C1.2) obtuvo el valor más alto (0,230) en la categoría de Gestión.

Tabla 16. Factores de ponderación de los elementos de SIRSDEC

R#	$W_{R\#}$	C#. #	$W_{C\#.\#}$	I#.#. #	$W_{I\#.\#.\#}$
R1 Gestión	0,140	C1.1 Estándares internacionales	0,112	I1.1.1 ISO 9001 o equivalente	1,000
				I1.1.2 ISO 14001 o equivalente	1,000
		C1.2 Plan de Gestión sostenibilidad Proyecto (PSM)	0,230	I1.2.1 Plan gestión sostenibilidad	1,000
		C1.3 Plan de Gestión riesgos Sostenibilidad (SRM)	0,148	I1.3.1 Plan gestión riesgos sostenibilidad	1,000
		C1.4 Plan de Procura sostenible	0,135	I1.4.1 Plan procura sostenible	1,000
		C1.5 Plan de Inspección & Auditoría (I&A)	0,171	I1.5.1 Plan de I&A plan	1,000
		C1.6 Informes & Lecciones aprendidas (R&LL)	0,204	I1.6.1 Distribución periódica informes	1,000
				I1.6.2 Registro lecciones aprendidas	1,000
R2 Social	0,324	C2.1 Participación comunidad e intervinientes	0,179	I2.1.1 Ratio participación intervinientes	1,000
		C2.2 Papel población indígena	0,214	I2.2.1 Ratio participación indígenas	1,000
		C2.3 Desarrollo igualitario	0,211	I2.3.1 Ratio medio sueldos sexos (m/h)	1,000
		C2.4 Impactos y beneficios sociales	0,222	I2.4.1 Población afectada Proyecto	1,000
				I2.4.2 Asentamientos urbanos afectados	1,000
		C2.5 Patrimonio cultural	0,174	I2.5.1 Evaluación cultural local	1,000
R3 Medioambiental	0,289	C3.1 Conservación ecosistemas naturales	0,169	I3.1.1 Área afectada de ecosistemas	1,000
		C3.2 Biodiversidad	0,155	I3.2.1 Especies en peligro	1,000
		C3.3 Emisión de gases invernadero	0,130	I3.3.1 Reducción emisiones	1,000
		C3.4 Consumo energía	0,102	I3.4.1 Ratio de ahorro energía	1,000
				I3.4.2 Uso energía renovable	1,000
		C3.5 Gestión agua	0,143	I3.5.1 Consumo de agua potable	1,000
				I3.5.2 Agua de tormenta almacenada	1,000
		C3.6 Riesgo de inundación	0,094	I3.6.1 Superficie inundable	1,000
		C3.7 Calidad del aire	0,109	I3.7.1 Reducción contaminantes del aire	1,000
		C3.8 Gestión de residuos	0,098	I3.8.1 Reducción producción residuos	1,000
				I3.8.2 Residuos reciclados / reutilizados	1,000
R4 Económico	0,247	C4.1 Combate a la pobreza	0,398	I4.1.1 Evaluación economía local	1,000
		C4.2 Impactos en agricultura	0,256	I4.2.1 Área cultivo afectada	1,000
		C4.3 Consumo de materiales locales	0,145	I4.3.1 Ratio uso materiales locales	1,000
		C4.4 Empleo mano obra local	0,201	I4.4.1 Proporción de mano obra local	1,000

3.3.5. Análisis de caso: el proyecto Tía María en Arequipa, Perú

Southern Copper es una empresa multinacional minera líder en el Mercado del cobre que está desarrollando el Proyecto “Tía María” en la provincia de Islay, ubicada en la región de Arequipa (Perú). El inicio de las operaciones está previsto para el año 2017, con una producción estimada de 120.000 toneladas de cobre para el primer año de actividad. El proyecto incluye la construcción de una balsa de lixiviados con una superficie de 37.500 m^2 y un volumen aproximado de 131.250 m^3.

El Índice de Desarrollo Humano (HDI) del 2015 para Perú fue de 0,734. Según las especificaciones de las Naciones Unidas, los países con un HDI inferior a 0,8 son considerados como subdesarrollados. Por lo tanto, Perú puede ser incluido en esta categoría. El Estudio de Impacto Ambiental (EIA) del proyecto Tía María fue aprobado por el Ministerio de Energía y Minería en agosto de 2014. Sin embargo, el rechazo frontal al proyecto por parte de la comunidad de Islay obligó a Southern Copper a paralizar temporalmente el proyecto para disipar las preocupaciones de los habitantes de la zona.

El proyecto de construcción de la balsa de lixiviados fue considerado como caso de estudio para esta investigación, para lo cual se utilizó la información del EIA aprobado para evaluar la sostenibilidad del proyecto a través del sistema SIRSDEC. La Tabla 17 recoge los resultados obtenidos después de analizar los indicadores del sistema con la información del EIA aprobado. Aunque el proyecto alcanzó inicialmente un índice SIRSDEC de 69,66 (Nivel Silver), que está por encima de 63,00 (Nivel Pass), no se cumplieron los requerimientos asociados a algunos de los indicadores que se establecieron como obligatorios del sistema: I2.1.1, I3.1.1, I3.3.1, I3.5.2 e I4.4.1, consecuentemente el proyecto no superó la evaluación. Por otro lado, los valores alcanzados por los indicadores I2.4.1, I3.2.1, I3.4.1, I3.4.2 e I4.2.1 estaban fuera del rango establecido por el sistema.

Tabla 17. Evaluación de los indicadores de SIRSDEC para el proyecto Tía María

	Indicador	Indicador SIRSDEC	X del Indicador	Valor del Indicador
(*)	I 1.1.1	ISO 9001 o equivalente	1,00	1,00
(*)	I 1.1.2	ISO 14001 o equivalente	1,00	1,00
(*)	I 1.2.1	Plan gestión sostenibilidad	1,00	1,00
	I 1.3.1	Plan gestión riesgos sostenibilidad	1,00	1,00
(*)	I 1.4.1	Plan procura sostenible	1,00	1,00
(*)	I 1.5.1	Plan de I&A plan	1,00	1,00
	I 1.6.1	Distribución periódica informes	1,00	1,00
	I 1.6.2	Registro lecciones aprendidas	1,00	1,00
(*)	I 2.1.1	Ratio participación intervinientes	No involved	0,00
	I 2.2.1	Ratio participación indígenas	No involved	0,00
(*)	I 2.3.1	Ratio medio sueldos sexos (m/h)	100%	1,00
	I 2.4.1	Población afectada Proyecto	35%	0,00
	I 2.4.2	Asentamientos urbanos afectados	0,00	1,00
(*)	I 2.5.1	Evaluación cultural local	1,00	1,00
(*)	I 3.1.1	Área afectada de ecosistemas	8%	0,50
	I 3.2.1	Especies en peligro	37%	0,00
(*)	I 3.3.1	Reducción emisiones	18%	0,34
	I 3.4.1	Ratio de ahorro energía	0%	0,00
	I 3.4.2	Uso energía renovable	0%	0,00
(*)	I 3.5.1	Consumo de agua potable	8%	0,26
(*)	I 3.5.2	Agua de tormenta almacenada	0%	0,00
(*)	I 3.6.1	Superficie inundable	0%	1,00
	I 3.7.1	Reducción de contaminantes del aire	23%	0,58
	I 3.8.1	Reducción producción residuos	15%	0,83
	I 3.8.2	Residuos reciclados / reutilizados	47%	0,95
(*)	I 4.1.1	Evaluación economía local	1,00	1,00
	I 4.2.1	Área cultivo afectada	0%	1,00
	I 4.3.1	Ratio uso materiales locales	12%	0,29
(*)	I 4.4.1	Proporción de mano obra local	10%	0,00
		Puntuación SIRSDEC		**69,66**

(*) Indicadores de obligado cumplimiento

Con el objetivo de que el proyecto alcanzase el nivel de cumplimiento requerido, se sugirieron algunas acciones para ser implementadas siguiendo los principios de SIRSDEC y así minimizar la situación de rechazo social que el proyecto estaba sufriendo. Estas acciones pretendían facilitar la participación de los afectados por el proyecto y de la comunidad indígena de la zona, para así poder aumentar el nivel de conocimiento del proyecto entre la población mediante una amplia campaña de información y de reuniones periódicas con la comunidad. La principal preocupación de los habitantes de la zona radicaba en el potencial impacto negativo del proyecto minero sobre los campos de cultivo, ya que la agricultura es su principal fuente de ingresos. El incremento de la ratio de población local contratada por la compañía minera hasta alcanzar el 25% del total de la mano de obra requerida por la mina podría contribuir a reducir las preocupaciones económicas de los pobladores de la zona.

Asimismo, el proyecto de la balsa de lixiviados podría incorporar mejoras adicionales en su diseño para evitar la rotura y desbordamiento del líquido lixiviado, lo que impactaría muy negativamente en el ecosistema y en la fauna existentes. Estos cambios contribuirían también a la reducción de las emisiones de gases de invernadero al aire. La construcción de un estanque de tormentas permitiría rebajar el consumo de agua potable de la mina. Asimismo, la instalación de paneles fotovoltaicos ahorraría energía, aumentando el uso de energía renovable. La Tabla 18 resume los resultados obtenidos tras considerar las medidas propuestas en la re-evaluación de los indicadores afectados del sistema. Después de implementar estas nuevas acciones, la puntuación de SIRSDEC para el proyecto Tía María pasó a ser 95,10 (Gold), cumpliendo todos los indicadores obligatorios y manteniéndolos dentro del rango de valores establecidos por el sistema.

Tabla 18. Re-evaluación de los indicadores afectados

	Indicador	Acción	Anterior X del indicador	Nueva X del indicador	Anterior valor del indicador	Nuevo valor del Indicador
(*)	I2.1.1	Ratio participación intervinientes	N/A	N/A	0,00	1,00
	I2.2.1	Ratio participación indígenas	N/A	N/A	0,00	1,00
	I2.4.1	Población afectada Proyecto	35%	23%	0,00	0,01
(*)	I3.1.1	Área afectada de ecosistemas	8%	0%	0,50	1,00
	I3.2.1	Especies en peligro	37%	23%	0,00	0,03
(*)	I3.3.1	Reducción emisiones	18%	40%	0,34	1,00
	I3.4.1	Ratio de ahorro energía	0%	11%	0,00	0,07
	I3.4.2	Uso energía renovable	0%	14%	0,00	0,33
(*)	I3.5.1	Consumo de agua potable	8%	15%	0,26	0,75
(*)	I3.5.2	Agua de tormenta almacenada	0%	20%	0,00	0,77
	I3.7.1	Reducción de contaminantes del aire	23%	29%	0,58	0,96
	I4.4.1	Proporción de mano obra local	10%	25%	0,00	0,91

4. CONCLUSIONES Y FUTURAS LÍNEAS DE INVESTIGACIÓN

4.1. Conclusiones generales

Las ingentes inversiones internacionales destinadas a promover el desarrollo sostenible en los países subdesarrollados requieren de sistemas eficientes que permitan realizar el seguimiento de los progresos alcanzados por los objetivos establecidos en materia de sostenibilidad. Sin embargo, la falta de indicadores apropiados para medir el desempeño de la sostenibilidad dificulta su seguimiento. Los indicadores contemplados en la Agenda 21 y en los Objetivos de Desarrollo del Milenio, que sirven de guía a todos los países para su desarrollo sostenible, no reflejan convenientemente el progreso en materia social, económica y medioambiental de estos países. La información recogida por las diversas agencias y organizaciones de las Naciones Unidas y de otras instituciones internacionales de desarrollo, así como de los bancos de desarrollo internacional está enfocada mayoritariamente a la salud y a la educación, mientras que sólo unas pocas métricas están ligadas al triple pilar de la sostenibilidad. La creación e implementación de nuevas métricas asociadas a los dominios social, económico y medioambiental debería ser fomentada por las instituciones y organizaciones internacionales para hacer un seguimiento más riguroso de los avances en el campo del desarrollo sostenible.

El análisis de los tres sistemas existentes de rating de la sostenibilidad de los proyectos de infraestructuras demostró que su orientación primordial a las cuestiones medioambientales minimizaba la importancia de los aspectos sociales y económicos, por lo que estas herramientas no se consideraron idóneas para su aplicación en los países subdesarrollados. La presente tesis palió esta carencia mediante el desarrollo de un nuevo sistema de rating de la sostenibilidad de proyectos de infraestructuras en países subdesarrollados (SIRSDEC) con el objetivo principal de equilibrar la importancia de los tres pilares de la sostenibilidad

Los resultados obtenidos mediante la aplicación de la metodología establecida en esta investigación a un caso de estudio de un proyecto minero en Perú demostraron su validez para evaluar la contribución al desarrollo sostenible de proyectos de infraestructuras en países subdesarrollados. Las opiniones recibidas de un panel de expertos internacionales, a quienes se dirigió un cuestionario on-line, permitió el cálculo de los factores de ponderación del sistema. La nueva distribución de estos factores confirmó el equilibro entre los pilares social, medioambiental y económico, además de incluir también el nuevo aspecto de gestión. De esta manera, el desarrollo de SIRSDEC cumplió el principal objetivo establecido en la investigación, que no era otro que el de equilibrar los factores de ponderación de los tres pilares del desarrollo sostenible. Por tanto, SIRSDEC constituye una herramienta destinada a apoyar a instituciones y organizaciones internacionales de desarrollo en la evaluación de proyectos de infraestructuras, con el objetivo de priorizar la construcción de aquellos proyectos que más contribuyan a la sostenibilidad de los países más pobres.

4.2. Conclusiones específicas

Se resumen para cada artículo que forma parte de la presente tesis las conclusiones específicas alcanzadas en esta investigación, que derivan del cumplimiento de los objetivos específicos que se establecieron en su inicio:

4.2.1. Artículo 1: Evaluation of existing sustainable infrastructure rating systems for their application in developing countries

- Los tres sistemas de rating existentes para la evaluación de los proyectos de infraestructuras están más orientados hacia las cuestiones medioambientales que hacia las sociales y económicas, siendo estas dos de mayor trascendencia para los países menos desarrollados.

- Se sugiere la incorporación de la Gestión a los sistemas de rating como complemento de los tres pilares de la sostenibilidad. De esta manera, quedarían reforzadas las escasas directrices y marcos de actuación normativos de los países subdesarrollados, lo que mejoraría el seguimiento y la evaluación del avance en la consecución de sus objetivos de desarrollo.

- Los indicadores recogidos en la Agenda 21 y en los Objetivos de Desarrollo del Milenio no reflejan la importancia de las variables asociadas a los aspectos sociales, económicos y medioambientales que intervienen en el desarrollo sostenible de los países más desfavorecidos.

4.2.2. Artículo 2: Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC)

- La aplicación del algoritmo no lineal basado en el denominado Generalized Reduced Gradient (GRG) fue esencial para hacer que todas las comparaciones extraídas de las respuestas recibidas del cuestionario on-line fueran consistentes, asegurando de esta manera el correcto cálculo de los factores de ponderación de los elementos del SIRSDEC.

- Las funciones de valor que definen los indicadores de SIRSDEC siguiendo las directrices del Modelo Integrado de Valor para Evaluaciones de Sostenibilidad (MIVES) permitió asignar un valor más aproximado a los indicadores, lo que redunda a una evaluación más precisa de la evaluación de la sostenibilidad de los proyectos.

- Las métricas utilizadas por las instituciones y organizaciones internacionales para monitorear el progreso del desarrollo sostenible en los países subdesarrollados no abarcan todos los aspectos relevantes de los tres pilares de la sostenibilidad, lo que dificulta significativamente la caracterización de las funciones de valor de los indicadores de SIRSDEC.

4.2.3. Artículo 3: Application of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) to a case study

- Los factores de ponderación de los requerimientos de SIRSDEC obtenidos de las respuestas del cuestionario confirmaron que los expertos internacionales consideran que la importancia de las dimensiones social, económica y medioambiental debe de ser equitativa, si bien el aspecto social predomina sobre los otros dos.

- La existencia de una serie de prerrequisitos de obligado cumplimiento en SIRSDEC, necesarios para poder obtener una evaluación positiva, garantiza que todos los proyectos consideren aquellos aspectos fundamentales que afectan al desarrollo sostenible de los países más pobres.

- La simplicidad en el uso de SIRSDEC facilita la rápida selección y evaluación de alternativas para fomentar la aplicación de prácticas sostenibles en los proyectos de infraestructuras en países subdesarrollados.

4.3. Futuras líneas de investigación

El desarrollo de esta tesis ha planteado las siguientes futuras líneas de investigación para dar continuidad y extender el diseño e implementación de SIRSDEC:

- Desarrollo de nuevas métricas de seguimiento que permitan evaluar los indicadores establecidos para las dimensiones social, económica, medioambiental y de gestión en los países subdesarrollados.

- Adecuación del sistema SIRSDEC a las necesidades y métricas de las entidades financieras internacionales de desarrollo para el seguimiento eficiente de la aportación de los proyectos de inversión en el desarrollo sostenible de los países subdesarrollados.

- Incorporación de SIRSDEC en el proceso de evaluación del desarrollo urbano sostenible en los países subdesarrollados.

- Integración de los Objetivos globales de Desarrollo establecidos por las Naciones Unidas en SIRSDEC.

- Implementación de SIRSDEC como un requerimiento obligatorio para la evaluación preliminar de la sostenibilidad de los proyectos de infraestructuras en el proceso de licitación de los proyectos de desarrollo financiados por instituciones y organizaciones internacionales.

- Desarrollo de un sistema de rating de la sostenibilidad urbana que integre aspectos tanto del sector de infraestructuras como del de edificación para su aplicación en el desarrollo urbano sostenible de los países subdesarrollados.

EXTENDED ABSTRACT

Title

DEVELOPMENT AND APPLICATION OF A NEW SUSTAINABLE INFRASTRUCTURE RATING SYSTEM FOR DEVELOPING COUNTRIES (SIRSDEC)

1. Introduction

1.1. Framework

The Brundtland Commission Report defined Sustainable Development in 1987 as "development to meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Sustainability is based on the balance of three key aspects named the Triple Bottom Line (TBL): Economy, Environment and Society (Elkington, 1997). Economics seeks to fulfil the main goal of producing a long-term and positive economic impact, whilst Environment encourages organisations to benefit the planet as much as possible through sustainable practices, including the consideration of negative factors to the environment. Society aims to improve the lives of those with whom the projects interact. Because of the rising energy consumption and greenhouse gas emissions in the last century, which accounts for 30 and 40% of the total quantities for the building sector in developed countries (EIA, 2008), climate change has accelerated the development of international declarations and policies to preserve the environment and foster the use of assessment systems aimed at improving sustainability.

Sustainability assessments have been defined as the processes of identifying, predicting and evaluating the potential impact of different initiatives and alternatives on the TBL (Devuyst, 2000). Furthermore, rating systems provide an effective framework for assessing environmental aspects and integrating sustainable development into building and construction processes. They can be used as design tools by setting sustainable design priorities and goals, developing appropriate sustainable design strategies and determining performance measures to guide sustainable designs and decision making-processes. Rating tools for buildings emerged more than two decades ago in the UK and US before spreading worldwide (Häkkinen, 2007), but the use of assessment tools focused on major infrastructures has not been very common so far. Only three rating systems were developed to evaluate all types and sizes of civil infrastructures, including ports, airports, highways, dams, bridges, wastewater treatment facilities, tunnels and railways: Envision in the USA (ISI, 2012), CEEQUAL in the UK (BRE Group, 2015) and the Infrastructure Sustainability (IS) Rating scheme in Australia (ISCA, 2012).

The improvement of infrastructures in developing countries has become a priority for richer countries which undertake their projects worldwide with the support of international development institutions. Infrastructures play the role of a trigger (UNCTAD, 2014) able to balance the relevance of the TBL in those countries. Because of existing sustainable infrastructure tools are not appropriate for achieving this goal (Diaz-Sarachaga et al., 2016), the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) is highly required.

1.2. Aims and Assumptions

The main goal of this research is the development of a new sustainable infrastructure rating system focused on the context of poorer countries to foster the proper sustainable development of these geographical areas and support international development agencies and institutions through an efficient tool.

The achievement of the following specific aims, which are included in the methodology proposed in this research, is highly necessary to fulfill the above mentioned main goal:

- Evaluation of existing sustainable infrastructure rating systems to ascertain the suitability of their application in developing countries.
- Design of the SIRSDEC decision-making tree, including all the requirements, criteria and indicators necessary to assess the sustainability of projects in developing countries under the balanced consideration of the TBL.
- Validation of SIRSDEC through its application to a case study based on a mining project located in Arequipa (Peru).

Below are listed the set of assumptions established for the development of SIRSDEC:

- SIRSDEC is a generic tool implementable in all developing countries worldwide, which is the reason why re-weighting is not required to adapt the system to the specifics of each country.
- Because of its current increasing relevance, Management was included as the fourth SIRSDEC requirement to strengthen the TBL and act as a linkage between Economics, Environment and Society.
- Due to the lack of proper monitoring metrics, the definition of the value functions for the indicators considered in SIRSDEC was carried out using data provided by international agencies and institutions related to similar aspects.

2. Methodology, results and discussion

This chapter includes three sections, each of which is associated with the methodology, results and discussion corresponding to the three articles annexed in this PhD thesis. The first section emphasized the crucial role played by infrastructures in the sustainable development of poorer countries and reviewed the frameworks created for assessing transport infrastructure project sustainability in developed countries. These tools were considered as the starting point for the subsequent development of the 3 main existing sustainable rating systems for infrastructures: Civil Engineering Environmental Quality (CEEQUAL), Infrastructure Sustainability (IS) Rating Tool and Envision. A brief description of each of them enabled appraising their suitability for their application in developing countries. The next two sections include a detailed description of the methodology conceived for developing SIRSDEC and the subsequent validation of the new system through its application to the construction project of a raft leaching in a Peruvian mine.

2.1. Evaluation of existing sustainable infrastructure rating systems for their application in developing countries

2.1.1. Sustainable infrastructures in developing countries

The Human Development Index (HDI) is a composite statistic of life expectancy, education and income per capita used by the United Nations to rank countries (UN-Habitat, 2015), such that those countries with a HDI below 0.8 are considered developing countries. Nations with low human development indices are likely to emphasise paternalistic socio-economic development instead of environmental aspects when formulating their sustainability agenda in the short to medium term. Social priorities are associated with the stimulation of micro-economic activities and the capacity of building through the generation of employment and other interventionist socio-economic policies.

Developing countries require a major increase in infrastructure investment to reduce growth constraints, contribute to urbanisation needs and meet their development, inclusion and environmental goals. Global trade plays an important role in the development of countries and consequently in infrastructure. This includes traditional transport infrastructure such as roads, railways, ports and information technology infrastructure. The investment budget is predicted to rise from the current level of $1 trillion per year to approximately $1.8-2.3 trillion per year by 2020, assuming 4% of annual growth rate of the Gross Domestic Product (GDP), which means about 3-8% of total GDP. An additional $200-300 billion is also destined to measures aimed at ensuring lower emissions and more resilience to climate change (Fardoust et al., 2010).

The concentration of world population in cities and the rapid growth of the number of megacities in the world, which are phenomena mainly located in developing countries, emphasise the key role of infrastructure in urban development to achieve the goal of sustainable living (UN-DESA, 2014). Urban settlements as the main driver of economic growth and development require attention to be paid to social and economic aspects without neglecting environmental issues. The development of sustainability in urban areas requires a balance among urban development, environmental protection and the specific demands of citizens (incomes, employment, shelter, basic services, social infrastructure and transportation).

2.1.2. Assessment of Green Infrastructure tools focused on Transportation

Transportation industry has developed several methodologies and assessment tools, especially in the US, to evaluate performance and sustainability in this field through a large variety of paths such as sustainable transportation guidelines, policy initiatives and self-assessment or third party tools.

Greenroads Rating System is an independent third party rating system for roadway design and construction that was launched in 2009. This system considers two types of activities: Project Requirements and Voluntary Activities. Project Requirements comprises 11 mandatory activities, whilst the 37 Voluntary Activities are arranged in five categories named “Voluntary Credits (VC)”: Environmental & Water (EW), Access & Equity (AE), Construction Activities (CA), Materials & Resources (MR) and Pavement Technologies (PT). Each voluntary credit is worth between one and five points for a total amount of 108 points. Furthermore, an additional VC category, named “Custom Credits”, awards new or innovative ideas up to 10 points (total of 118 altogether). There are four Greenroads levels that can be achieved by fulfilling all the Project Requirements and earning a minimum number of voluntary points: Bronze (32 to 42 VC), Silver (43 to 53 VC), Gold (54 to 63 VC) and Evergreen (over 63 VC).

The New York State Department of Transportation (NYSDOT) created GreenLITES (Green Leadership in Transportation Environmental Sustainability) in 2008 (NYSDOT, 2008) as a rating program to recognize transportation project designs, operations and maintenance practices that incorporate a high level of environmental sustainability. This tool is a self-certification program that distinguishes transportation projects and operations based on the extent to which they incorporate sustainable choices. GreenLITES Design identifies more than 175 sustainable credits in five categories: Sustainable Sites, Water Quality, Materials & Resources, Energy & Atmosphere and Innovation/Unlisted. The rating system recognizes 4 certification levels depending on the number of credits achieved by the project or operation: GreenLITES Certified (15 to 29 points), GreenLITES Silver (30 to 44), GreenLITES (45 to 59) and GreenLITES Evergreen (more than 60).

The Building Environmentally and Economically Sustainable Transportation-Infrastructure-Highways (BE^{2}ST-in-Highways) is a sustainability self-rating system created in 2010 as a guide of sustainable highway construction (BE^{2}ST-in-Highways). After defining a reference highway design, the tool identifies quantitative differences between the reference and the proposed alternative design. A previous mandatory screening layer is undertaken to evaluate mandatory requirements and required prerequisite assessments, in which a regulatory/social indicator and a project-specific indicator are used to measure the conformance of the project to a set of laws, regulations, local ordinances and project specific requirements. An amount of 100 credits are equally divided into nine categories: Energy Consumption, Global Warming Potential, In Situ Recycled Rate, Total Recycled Material, Water Consumption, Life Cycle Cost Analysis, Social Carbon Cost, Traffic Noise and Hazardous Waste. The guide differences three certification levels: Bronze (more than 50% of credits), Silver (more than 75% of credits) and Gold (more than 90% of points).

INVEST (Infrastructure Voluntary Evaluation Sustainability Tool) is a free website self-evaluation tool developed by FHWA (Federal Highway Administration) in the USA and formed by voluntary sustainability best practices which cover the full lifecycle of transportation services, including system planning, project planning, design, construction, operations and maintenance (FHA). INVEST tool includes three categories: System Planning for States (SP), Project Development (PD), and Operations and Maintenance (OM). The SP and OM modules are intended to evaluate agencies' programs and the PD module is for the assessment of projects, from early planning to construction. The tool is not designed to assign points and certification levels to award sustainability efforts.

I-LAST (Illinois Livable and Sustainable Transportation) Rating System is a sustainability performance metric system whose aim was to evolve the free website INVEST by using the inputs provided by industry users, but no revisions have been introduced since the release of version 2 in January 2012 (Illinois Department of Transportation, 2010). The I-LAST score contains 153 sustainable best practices (credits) divided into eight categories: Planning, Design, Environmental, Water Quality, Transportation, Lighting, Materials and Innovation. Each credit identified as applicable to a project is awarded with a point value per its fulfillment of score criteria. No certification levels are considered by I-LAST, which is not an official policy or procedure of IDOT either.

The voluntary self-evaluation tool STEED (Sustainable Transportation Engineering & Environmental Design) was launched in 2008 to make the project under evaluation as sustainable as possible based on the TBL incorporating sustainable alternatives throughout the different stages of the project: planning, environmental assessment, design and construction. STEED divides each of these three principles into seven sub-categories amounting to 153 points. The Economic category (45) includes Life-Cycle Consideration (5), Construction Duration (7), Freight

Mobility (8), Innovative Use (9), Modal connectivity (6), Operation & Maintenance (6) and User Economic Impacts (4). Environment (62) encompasses Air Quality (8), Biodiversity (8), Energy (8), Environmental cleanup (8), Light & Noise (11), Material & Resources (10) and Water Resources (9) sub-categories. Finally, Social Responsibility considers 46 points arranged in Aesthetics & Livability (10), Culture & History (5), Equity (6), Land & Geology (7), Land use/Transportation (5), Public Involvement (6) and Safety & Security (7). STEED does not provide certification levels for projects (Abdul, 2012).

The North American Sustainable Transportation Council (STC) developed and piloted the Sustainable Transportation Analysis & Rating System (STARS), an integrated planning framework for transportation plans and projects to evaluate the impacts of transportation plans and projects, identify innovative strategies and improve decision-making. STARS is organized into twelve credits so that an applicant must take specific actions to achieve a credit. These twelve credits are arranged into four categories: Integrated Process, Access, Climate & Energy and Cost Effectiveness Analysis. The first credit in each of the categories is a "required" credit. The four "required" credits must be achieved to consider a project for STARS pilot certification, along with five "user-choice" credits. Of the five user-choice credits, at least two must be from Access and two from Climate and Energy. The STC reviews the documentation and decides to "Pass" or "Improve" each credit. Projects that "Pass" all four required credits and at least five user choice credits are designated a "STARS 1.2 Certified Pilot Project" (STC, 2013).

2.1.3. Overview of mainstream Sustainable Infrastructure scoring systems

The main features of the three mainstream Sustainable Infrastructure rating systems under analysis, namely CEEQUAL, Infrastructure Sustainability (IS) and Envision, are listed in Table 1. The next subsections detail the basis behind each of these scoring tools.

Table 1. Summary of existing Sustainable Infrastructure rating tools

Characteristics	Civil Engineering Environment Quality (CEEQUAL) (Version 5)	Infrastructure Sustainability (IS) (Version 1.0)	Envision (Version 2.0 Stage 2)
Supporting Institution	CEEQUAL ltd	Infrastructure Sustainability Council of Australia (ISCA)	Institute for Sustainable Development (ISI)
Geographical Context	UK & Ireland / International	Australia & New Zealand	USA & Canada
Year of launching	2003	2012	2012
Manuals	CEEQUAL for Projects / CEEQUAL for Term Contracts	Infrastructure Sustainability (IS)	Envision
Categories	9	6	5
Sub-categories	48	15	60
Levels of Achievement	4 (Pass, Good, Very Good, Excellent)	3 (Commended, Excellent, Leading)	4 (Bronze, Silver, Gold, Platinum)
Awards	6 (CEEQUAL for Projects) and 2 (CEEQUAL for Term Contracts)	3 (Design, As Built, Operation)	1 (Planning and Design)
Verification Agents	Independent CEEQUAL-trained Verifiers	Independent ISCA-trained Verifiers	ISI independent third-party Verifiers

2.1.3.1. Civil Engineering Environmental Quality (CEEQUAL)

The Institution of Civil Engineers (ICE) led the development of CEEQUAL (BRE Group, 2015), which was launched in September 2003 and became public in June 2004 after publishing Version 3 of the Assessment Manual for Projects. Since then, CEEQUAL has been updated until its latest Version 5.

CEEQUAL includes a range of environmental and social issues arranged in nine sections and 48 sub-sections from the perspective of the three key stakeholders (Clients, Designers and Contractors) involved in the project (see Table 2). “Project Strategy” assesses the link between the project and sustainability, as well as its contribution to sustainable development. “Project Management” considers how sustainability issues are being incorporated into the overall project management. “People & Communities” includes the assessment related to people affected by projects, the potential effects on the local population and the important actions of consultation and engagement with project stakeholders. The “Land use & Landscape” category attempts to monitor the efficient use of land as a scarce resource. “The Historic Environment” comprises those buildings, structures and other features which have survived in the current landscape, townscape and seascape as evidence of environmental management over past centuries. “Ecology & Biodiversity” considers concerns about the damage to wildlife habitats and the species that occupy them. “Water environment” aims to protect fresh and marine water bodies. “Physical Resources - Use & Management” considers the responsible use of construction materials and how to deal with them at the end of their lifetime. Finally, “Transport” evaluates a wide range of effects such as land use changes, road accidents, air, noise and water pollution, as well as the consumption of resources. Four levels of achievement are considered in CEEQUAL: Pass (more than 25%), Good (more than 40%), Very Good (more than 60%) and Excellent (more than 75%).

CEEQUAL encompasses two different manuals: CEEQUAL for Projects and CEEQUAL for Term Contracts. Depending on the location of the projects, the score is available in two editions: CEEQUAL for International Projects and CEEQUAL for UK & Ireland Projects.

Table 2. Score of Civil Engineering Environmental Quality (CEEQUAL) rating system (Version 5)

Credit	Concept	Score	%
1	**Project Strategy**	**625**	**12.46**
1.1	Overall strategy for the project concept and design	500	9.97
1.2	Overall strategy for construction	125	2.49
2	**Project Management**	**545**	**10.87**
2.1	Basic Principles	100	1.99
2.2	Sustainability management	160	3.19
2.3	Contractual and procurement processes	116	2.31
2.4	Delivering performance on environmental and social aspects	132	2.63
2.5	Communicating sustainability performance	37	0.74
3	**People and Communities**	**530**	**10.57**
3.1	Brief and design	66	1.32
3.2	Consultation with stakeholders	27	0.54
3.3	Effects on local population and planning of mitigation measures	44	0.88
3.4	Implementation and monitoring during construction	148	2.95
3.5	Continuing engagement with relevant local interest groups	74	1.48
3.6	Effectiveness of the community engagement plan	69	1.38
3.7	Human environment, aesthetics and employment	102	2.03
4	**Land use and landscape**	**1004**	**20.02**
4.1	Basic principles on the use of land (above or below water)	233	4.65
4.2	Contamination of land and beds of the sea, estuaries, rivers & lakes	242	4.82
4.3	Flood risk	264	5.26
4.4	Basic principles of landscapes issues	55	1.10
4.5	Landscape-related legal requirements	85	1.69
4.6	Implementation and management	83	1.65
4.7	Completion and aftercare	42	0.84
5	**The historic environment**	**230**	**4.59**
5.1	Baseline studies	23	0.46
5.2	Legal requirements, planning guidance and consultation	17	0.34
5.3	Conservation and enhancement	141	2.81
5.4	Information Dissemination and Public Access	49	0.98
6	**Ecology and biodiversity**	**315**	**6.28**
6.1	Basic Principles	61	1.22
6.2	Legal requirements	76	1.52
6.3	Conservation and enhancement of biodiversity	79	1.57
6.4	Habitat creation measures	64	1.28
6.5	Monitoring and maintenance	35	0.70
7	**The water environment**	**283**	**5.64**
7.1	Basic principles	70	1.40
7.2	Legal requirements	24	0.48
7.3	Protection of the freshwater and marine environments	141	2.81
7.4	Enhancement of the water environment	48	0.96
8	**Physical resources - use and management**	**1217**	**24.26**
8.1	Basic principles	44	0.88
8.2	Embodied impacts	112	2.23
8.3	Design for resource efficiency	109	2.17
8.4	Design for reduced energy consumption and carbon emissions in use	97	1.93
8.5	Energy and carbon performance on site	109	2.17
8.6	Water use	291	5.80
8.7	Responsible sourcing, re-use and recycling of materials	106	2.11
8.8	Minimising use and impacts of hazardous materials	47	0.94
8.9	Site waste management planning & legal compliance	89	1.77
8.10	Waste and management of arising	213	4.25
9	**Transport**	**267**	**5.32**
9.1.	Basic Principles	65	1.30
9.2	Operational Transport	99	1.97
9.3	Construction transport, including nuisance and disruption	79	1.57
9.4	Minimising workforce travel	24	0.48
	Total	**5016**	**100**

2.1.3.2. Infrastructure Sustainability (IS) Rating Tool

The Australian Green Infrastructure Council (AGIC) was created to develop the Infrastructure Sustainability (IS) Rating Tool, which was concluded in 2011 after undertaking different trials and weighting surveys. The IS Rating Tool Version 1.0 was released nationally in 2012, a year in which AGIC was renamed the Infrastructure Sustainability Council of Australia (ISCA) (ISCA, 2012).

Table 3 shows the IS rating scheme Version 1.0, which consists of 15 categories organised in 6 topics. The rating tool is based on three performance levels: Design, Build and Operation ratings. Three levels of achievement are considered by the IS rating tool: Commended (25 to 50 points), Excellent (50 to 75 points) and Leading (75 to 105).

Table 3. Score of Infrastructure Sustainability (IS) Rating Tool (Version 1.0)

Credit		Concept	Score	%
1		**Management and Governance**	**20.5**	**19.52**
	1.1	Management Systems	10.50	10.00
	1.2	Procurement and Purchasing	5.00	4.76
	1.3	Climate Change Adaptation	5.00	4.76
2		**Using Resources**	**24.5**	**23.33**
	2.1	Energy and Carbon	10.50	10.00
	2.2	Water	7.00	6.67
	2.3	Materials	7.00	6.67
3		**Emissions, Pollution and Waste**	**24.5**	**23.33**
	3.1	Discharge to air, land and water	10.50	10.00
	3.2	Land	7.00	6.67
	3.3	Waste	7.00	6.67
4		**Ecology**	**10.50**	**10.00**
	4.1	Ecology	10.50	10.00
5		**People and Place**	**20.00**	**19.05**
	5.1	Community Health, Well-being and Safety	5.00	4.76
	5.2	Heritage	5.00	4.76
	5.3	Stakeholder Participation	5.00	4.76
	5.4	Urban and Landscape Design	5.00	4.76
6		**Innovation**	**5.00**	**4.76**
	6.1	Innovation	5.00	4.76
		Total	**105.00**	**100.00**

2.1.3.3. Envision Sustainable Infrastructure rating system

The Institute for Sustainable Infrastructure (ISI) launched the Envision Version 2.0 in 2012 (ISI, 2012). Like its building counterpart (LEED), this planning and design guidance tool provides industry-wide sustainability metrics for all infrastructure types.

Envision Version 2.0 Stage 2 has 60 sustainability credits consisting of a series of yes/no questions arranged in five categories that address major impact areas in terms of the TBL (see Table 4). Envision provides innovation points for projects with advanced sustainable infrastructure practices or exceptional performance beyond expectations. Five levels of achievement are defined by Envision to assess performance and foster project improvement: Improved (performance is above conventional), Enhanced (sustainable performance adheres to Envision principles), Superior (sustainable performance is noteworthy), Conserving (performance results in zero impact) and Restorative (performance restores natural or social systems). There are 4 Envision award levels according to the percentage of credits obtained: Bronze (20 to 30%), Silver Award (30 to 40%), Gold Award (40 to 50%) and Platinum Award (over 50%).

Table 4. Score of Envision Sustainable Infrastructure rating system (Version 2.0 Stage 2)

Credit	Concept	Improved	%	Enhanced	%	Superior	%	Conserving	%	Restorative	%
1	**Quality of Life**	**13**	**16.46**	**27**	**15.17**	**62**	**17.46**	**150**	**21.43**	**151**	**29.38**
1.1	Purpose	4	5.06	9	5.06	20	5.63	45	6.43	56	10.89
1.2	Community	6	7.59	12	6.74	23	6.48	70	10.00	52	10.12
1.3	Wellbeing	3	3.80	6	3.37	19	5.35	35	5.00	43	8.37
2	**Leadership**	**10**	**12.66**	**31**	**17.42**	**56**	**15.77**	**115**	**16.43**	**31**	**6.03**
2.1	Collaboration	5	6.33	17	9.55	33	9.30	60	8.57	0	0.00
2.2	Management	2	2.53	6	3.37	13	3.66	25	3.57	31	6.03
2.3	Planning	3	3.80	8	4.49	10	2.82	30	4.29	0	0.00
3	**Resource Allocation**	**29**	**36.71**	**66**	**37.08**	**112**	**31.55**	**170**	**24.29**	**62**	**12.06**
3.1	Materials	15	18.99	34	19.10	59	16.62	80	11.43	0	0.00
3.2	Energy	7	8.86	16	8.99	25	7.04	45	6.43	20	3.89
3.3	Water	7	8.86	16	8.99	28	7.89	45	6.43	42	8.17
4	**Natural Word**	**15**	**18.99**	**33**	**18.54**	**86**	**24.23**	**165**	**23.57**	**169**	**32.88**
4.1	Siting	8	10.13	17	9.55	49	13.80	80	11.43	74	14.40
4.2	Land &Water	2	2.53	10	5.62	23	6.48	40	5.71	39	7.59
4.3	Biodiversity	5	6.33	6	3.37	14	3.94	45	6.43	56	10.89
5	**Climate**	**12**	**15.19**	**21**	**11.80**	**39**	**10.99**	**100**	**14.29**	**101**	**19.65**
5.1	Emission	6	7.59	13	7.30	13	3.66	30	4.29	40	7.78
5.2	Resilience	6	7.59	8	4.49	26	7.32	70	10.00	61	11.87
	Total	**79**	**100.00**	**178**	**100.00**	**355**	**100.00**	**700**	**100.00**	**514**	**100.00**

2.1.3.4. Evaluation of existing rating systems to be applied in developing countries

There are many commonalities among Envision, CEEQUAL and IS to ensure and assess sustainability in infrastructure projects. Although they all include the main aspects of sustainability emphasising some criteria, the boundaries that delimit whether a project is sustainable or not are not clearly defined. Process and outcome assessments are often mixed in these approaches, which also have differences in the way in which they address the different sustainability needs that occur at different stages of the project life-cycle. Furthermore, the importance given to management by these systems in the sustainability assessment is very unequal (Watkins, 2014).

Table 5 summarises the main criteria of the examined sustainable infrastructure rating systems. The environmental dimension is mostly considered through very common aspects such as GHG emissions, habitats and biodiversity preservation, pollution (air, lighting, noise and water), energy consumption (renewable resources and efficiency), flooding risk, land use and more efficient resource management. These frameworks deal with the social dimension through general community issues such as stakeholders' engagement, communication, health, well-being and historical and cultural heritage. Management covers further aspects such as procurement, project and risk management, decision-making processes and regulations and policies. Finally, the economic pillar focuses on workforce conditions, sustainable growth and development, improvement of the community's quality of life and connectivity.

Table 5. Main criteria considered by the rating systems under assessment

Economy	Environment	Society	Management
Minimising workforce travel	Principles on the use of land	Stakeholders & Community engagement	Project Management (design, construction, contract)
Increase of community's connectivity	Flood risk management	Assessment of impacts in neighbours	Sustainable procurement management
Employment growth	Maintenance, enhancement or restoration of biodiversity and habitats	Promotion of local employment	Decision-making processes
Resource efficiency	Maintenance or enhancement of landscapes	Historical, cultural and archaeological heritage	Risk and Opportunity management
Business development	Efficient water use	Increase in public information	Conflicting regulations and policies
Procurement practices	Maintenance or enhancement of water quality	Promotion of community health, well-being and safety	
Workforce development	Reduction of GHG emissions	Workforce safety	
Stimulation of sustainable growth and development	Noise management	Focus on accessibility	
Improvement of community Quality of Life	Reduction of Air pollutants	Enhancement of public space	
	Lighting pollution management	Preservation of views and local character	
	Reduction of energy use		
	Promotion of renewable energy		
	Efficient resource management		
	Hazardous materials management		

All points awarded by the tools can be grouped into the three sustainable pillar categories as shown in Table 6. Only the superior level of achievement has been considered for Envision, because its sustainable performance is the same than that of CEEQUAL and IS systems. The share of points awarded by CEEQUAL, IS and Envision included in Table 6 reveals that all systems are fundamentally dominated by an environmentally-based approach. The average trend in the three systems reflects that Environment is the most relevant category with around two thirds of the total score, whilst Society and Economy represent around 20% and 10% of points, respectively. This unbalanced integration of the sustainability dimensions may lead to the promotion of weak sustainability.

Table 6. Share of Triple Bottom Line pillars score

Rating System	Economy		Environment		Society		Total	
	Points	%	Points	%	Points	%	Points	%
CEEQUAL	515.66	10.28	3140.16	62.6	1360.16	27.12	5016	100
Infrastructure Sustainability (IS)	13	12.38	74	70.48	18	17.14	105	100
Envision Superior	29.64	8.35	253.64	71.46	71.64	20.18	355	100

The score thresholds leading to the different levels of achievement established by the three systems show that limits are approximately equally set in CEEQUAL and the IS rating system, whilst Envision Superior includes an important difference. Despite CEEQUAL and IS require higher score to reach the top level of achievement with around 75% of all points, Envision, which only needs 50% of those points, puts a strong focus on some criteria (e.g. restorative actions) that can make it even more demanding in some ways.

2.2. Methodology for the development of a new sustainable infrastructure rating system focused on developing countries (SIRSDEC)

A literature review was conducted to collect information related to existing Sustainable Infrastructure Rating Systems. Once the objectives to be achieved by SIRSDEC were established, the decision-making problem was defined following a hierarchical three-level scheme, usually called decision-making tree, consisting of a series of requirements, criteria and indicators. A questionnaire form was distributed to international experts to collect their opinion regarding the relative importance among the elements in the decision-making tree. The Analytic Hierarchy Process (AHP) (Saaty, 1990) was selected to transform the linguistic pairwise comparisons provided by the experts into the weights of requirements, criteria and indicators. The Integrated Value Model for Sustainable Assessments (MIVES) (ETCG, 2015) was proposed to convert the ratings of infrastructures across the indicators into value indices reflecting the satisfaction degree they produced. The definition of different feasible alternatives to the decision-making problem allows their appraisal from the perspective of multiple criteria and objectives and the subsequent determination of their contribution to sustainability.

2.2.1. SIRSDEC design

Sustainability assessments consist of the identification, prediction and evaluation of the potential impact of different solutions or alternatives across the TBL. Developing countries emphasise socio-economic development over environmental aspects when formulating their sustainability agenda. Therefore, the achievement of sustainable development goals in these areas requires a balance among environmental awareness and the specific socio-economic demands of citizens (incomes, employment, shelter, basic services, social infrastructure and transportation).

Consequently, the assessment of sustainability in poorer nations requires the design of decision support tools to facilitate the selection of indicators based on country and location-specific needs through the study of local priorities in relation to the sustainability agenda and the incorporation of international indicators.

Under these premises, SIRSDEC was designed to include indicators mainly referred to Agenda 21 issues to achieve a balance between the three pillars of sustainable development focused on the specific context of developing countries and considering all the stages of a long-term project life-cycle such as design, construction, operation, renovation and demolition/reuse. The management dimension was also considered to overcome the existing shortage of guidelines to interconnect the overall goals of sustainable development in poorer countries. The breakdown of the SIRSDEC decision-making tree is shown in Table 7, including 4 requirements, 23 criteria and 29 indicators.

Table 7. SIRSDEC decision-making tree

R#	Requirement	C #	Criteria	I #	Indicator
R1	Management	C1.1	International Standards	I1.1.1	ISO 9001 or equivalent
				I1.1.2	ISO 14001 or equivalent
		C1.2	Project Sustainability Management (PSM) plan	I1.2.1	Project Sustainability Management plan
		C1.3	Sustainability Risk Management (SRM) plan	I1.3.1	Sustainability Risk Management plan
		C1.4	Sustainable Procurement plan	I1.4.1	Sustainable Procurement plan
		C1.5	Inspection & Auditing (I&A) plan	I1.5.1	I&A plan
		C1.6	Reporting & Lessons Learned (R&LL)	I1.6.1	Periodic reports distribution
				I1.6.2	Lessons Learned Log
R2	Society	C2.1	Community & Stakeholders involvement	I2.1.1	Stakeholders involvement ratio
		C2.2	Role of indigenous people	I2.2.1	Indigenous involvement ratio
		C2.3	Equitable development	I2.3.1	Gender average wage ratio (f/m)
		C2.4	Social impacts & benefits	I2.4.1	Population impacted by project
				I2.4.2	Settlements area disturbed
		C2.5	Cultural Heritage	I2.5.1	Local cultural assessment
R3	Environment	C3.1	Natural Ecosystem conservation	I3.1.1	Impacted ecosystem area ratio
		C3.2	Biodiversity Ecosystem	I3.2.1	Endangered species ratio
		C3.3	Greenhouse gases emissions	I3.3.1	GHG emissions reduction rate
		C3.4	Energy consumption	I3.4.1	Energy savings rate
				I3.4.2	Renewable energy use rate
		C3.5	Water management	I3.5.1	Fresh water consumption
				I3.5.2	Runoff water stored
		C3.6	Flooding risk	I3.6.1	Floodplains area
		C3.7	Air Quality	I3.7.1	Air pollutants reduction
		C3.8	Waste management	I3.8.1	Waste production decrease
				I3.8.2	Recycled/reused waste
R4	Economy	C4.1	Combating poverty	I4.1.1	Local economic assessment
		C4.2	Agriculture impacts	I4.2.1	Farmland area impacted
		C4.3	Local materials consumption	I4.3.1	Local materials use rate
		C4.4	Local employment	I4.4.1	Local employment rate

Each of the 23 criteria that forms SIRSDEC corresponds to an objective that infrastructure projects must achieve to be considered “sustainable” in developing countries. As a prerequisite, SIRSDEC has 13 mandatory criteria to ensure all projects face key issues related to sustainability in less developed countries. In the domain of management, there are 4 compulsory criteria: International Standards (C1.1), Project Sustainability Management (PSM) plan (C1.2), Sustainable Procurement plan (C1.4) and Inspection & Auditing (I&A) plan (C1.5). The social aspect encompasses 3 additional mandatory criteria, such as Community & Stakeholders involvement (C2.1), Equitable development (C2.3) and Culture Heritage (C2.5). The environmental requirement includes 4 indispensable criteria: Natural Ecosystem conservation (C3.1), Greenhouse gases emissions (C3.3.), Water management (C3.5) and Flooding risk (C3.6). Combating poverty (C4.1) and Local employment (C4.4) in the economic requirement complete the set of 13 essential criteria demanded for all projects.

SIRSDEC includes a set of 29 measurable indicators that represent key issues in infrastructure projects delivery to monitor the performance, sustainability understanding and appropriate linkage between stakeholders. The system was designed to help users to evaluate the sustainability of any infrastructure project carried out in developing countries at any stage in their life cycles. The set of 29 indicators included in SIRSDEC are graded in a range from 0 to 1 point each, according to the value functions assigned to them. If all 29 indicators are rewarded with 1 point, the maximum possible SIRSDEC score is 121. Hence, SIRSDEC differentiates three levels of performance: Pass (63), Silver (from 63 to 90) and Gold (>90).

2.2.2. Data collection

An on-line questionnaire was prepared using Google Forms to collect and summarize the opinions from international leading experts belonging to several countries worldwide in an easy and automatic manner. This approach facilitated the distribution of the survey among a larger number of participants located in different continents and the quick integration of the data received using the same tool. The profiles sought to form the panel of respondents included international leading experts in the domain of sustainability and environmental assessment systems such as professionals from academia, industry, public development institutions and research organizations.

The survey was divided into three parts. The first part defined the purpose of each element in the decision-making tree represented in Table 7, guided the respondents about how to fill in the questionnaire and requested some information related to their profile for making statistics. The second section invited the experts to answer several general questions related to sustainability and its assessment, whilst the last part focused on the pairwise comparisons between indicators, criteria and requirements in accordance with questions like “How important is element *i* with respect to element *j*?”.

2.2.3. Weighting of the elements in SIRSDEC

The comparisons provided by the experts in the last step of the questionnaire were processed to obtain the weights of the elements in the decision-making tree using the Analytic Hierarchy Process (AHP) (Saaty, 1980). This method was selected for weighting because of its simplicity and flexibility to be combined with other multi-criteria techniques (Vaidya et al., 2006). Table 8 shows the numerical scale considered in the AHP method to quantify a list of pairwise comparisons as that collected from the questionnaires returned by the experts.

Table 8. AHP pairwise comparison scale

Qualitative evaluation	Rating
Absolutely more important (AMI)	9
Much more important (MMI)	7
More important (MI)	5
Slightly more important (SMI)	3
Equally important (EMI)	1
Slightly more important (SLI)	1/3
Less important (LI)	1/5
Much less important (MLI)	1/7
Absolutely less important (ALI)	1/9

The application of the comparison scale shown in Table 8 enables the construction of a $n * n$ reciprocal matrix of pairwise comparisons (Skibniewski et al., 1992) whose consistency is evaluated throughout its maximum eigenvalue (λ_{max}), so that the matrix is completely consistent when $\lambda_{max} = n$ and becomes increasingly inconsistent as the eigenvalue grows, according to the consistency ratio (C.R.) defined in Eq. (1):

$$C.R. = \frac{C.I.}{R.I} < 0.1 \tag{1}$$

Where C.I. is the consistency index and R.I. is the random consistency index. A matrix is considered consistent when the ratio between C.I. and R.I. is less than 0.1, with C.I. being expressed as in Eq. (2). The values of R.I. listed in Table 9 represent the average C.I. for 500 randomly generated matrices of the same order.

$$C.I. = \frac{\lambda - n}{n} \tag{2}$$

Table 9. Random consistency index

Matrix size (n)	2	3	4	5	6	7	8	9	10
R. I	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The method proposed by Jato-Espino et al. (2017), which is based on the Generalized Reduced Gradient (GRG) algorithm and an aggregation system according to the proximity between the judgments of each pair of respondents, was used to adjust possible inconsistencies in the questionnaires and synthetize them all into a consensual set of weights.

Therefore, if $[A]$ is the inconsistent comparison matrix related to a set of criteria $C_j = \langle C_1, C_2, \ldots, C_n \rangle$ and $[A]'$ is the consistent matrix being sought, the algorithm minimizes the differences between the upper right triangles of both matrices to fulfil Eq. (1), with the limitation of remaining within the corresponding lower and upper threshold values of the AHP comparison scale (see Table 8). The differences between both matrices were measured using the Root Mean Square Error (RMSE) (Chai et al., 2014). A logarithmic scale was applied to equalize the differences between lower and higher thresholds, so that the minimization problem was expressed as shown in Eq. (3):

$$Minimizar \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(ln\, x_{j_1 j_2} - ln\, x'_{j_1 j_2}\right)^2}$$

$$siempre\ que: \quad C.R. \leq 0.1$$
$$\ln a_{ij}^{L.T.} < \ln a'_{ij} < \ln a_{ij}^{U.T.} \qquad (3)$$

The Euclidean distance, a common metric to assess similarities between datasets (Xing et al., 2003), was used to evaluate the affinity between the judgments provided by the respondents, so that a symmetric $m * m$ matrix $[M]$ was obtained from the Euclidean distances between each pair of experts, with m being the number of respondents. Therefore, the weight for each expert was determined as the inverse of the sum of the distances from each respondent to the remaining ones.

These weights were aggregated using the geometric mean, which has been proven to be the proper method to integrate a set of n individual opinions into a unique agreed judgment $(a_{ij,c})$ as the n-th root of their product. Finally, the weights w_i of the elements in the decision-making tree were calculated through Eq. (5), whose application must be preceded by the normalization $(a_{ij,cn})$ of the values in the consensual comparison matrix formed of n values of $a_{ij,c}$ as shown in Eq. (4):

$$a_{ij,cn} = \frac{a_{ij,c}}{\sqrt{\sum_{i=1}^{n} a_{i,c}{}^2}} \qquad (4)$$

$$w_i = \frac{\sum_{i=1}^{n} \frac{1}{\sqrt{\sum_{i=1}^{n} a_{ij,c}}}}{\sum \sum_{i=1}^{n} \frac{1}{\sqrt{\sum_{i=1}^{n} a_{ij,c}}}} \qquad (5)$$

2.2.4. Valuation of indicators

MIVES is a multi-criteria decision-making (MCDM) method that uses value analysis as a platform for decision-making to evaluate alternatives and assess sustainability quantitatively (San-Jose et al., 2010). Value functions are the key elements of MIVES, since they enable the transformation of the ratings of alternatives across the indicators, which are commonly measured in different units, into non-dimensional values in the range between 0 and 1 that represent the degree of satisfaction they provide.

Value functions are defined through five parameters (K_i, C_i, X_{min}, X_{max} and P_i) which determine four different shapes to model these transformations: linear, concave, convex and S-shape. Figure 1 illustrates the parameters to be taken by these functions, as well as the shapes in which they result. S-shape functions include the most relevant increase in satisfaction in the central zone of the curve. On the contrary, convex and concave curves reveal increases in satisfaction in areas close to X_{min} and X_{max}, depending on whether the function is increasing or decreasing. Linear functions consist of a steady increasing or decreasing of satisfaction regardless of the value of the abscissa.

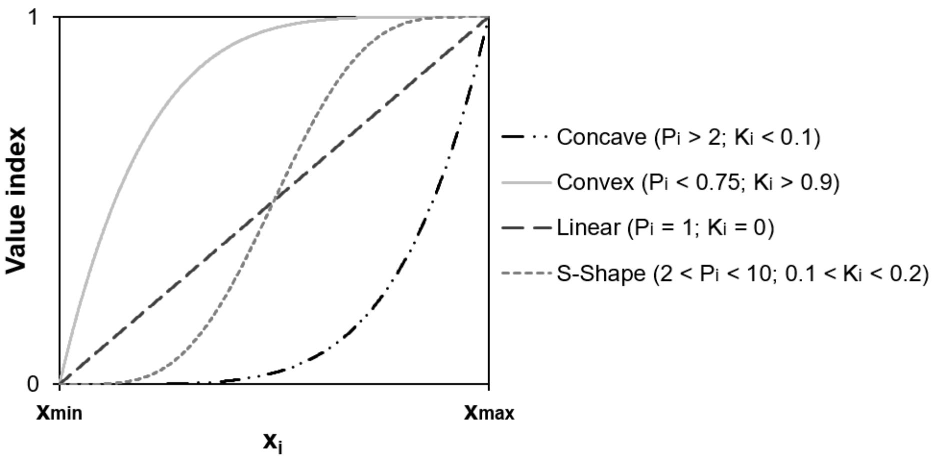

Figure 1. Different shapes of MIVES curves

Value functions for increasing indicators are calculated in accordance with Eq. (6). If the value of the indicator decreases as its rating increases, X_{min} is replaced by X_{max} in both formulations.

$$V_{ind} = B * \left[1 - e^{-K_i * \left(\frac{|X - X_{min}|}{C_i}\right)^{P_i}}\right] \quad (6)$$

where X_{min} is the abscissa for the minimum value reachable by the indicator, X is the actual rating of the alternative with respect to the indicator, P_i is the form factor and C_i and K_i are the abscissa and ordinate in the inflection point of the curve, respectively. B is an adjusting factor to ensure that value indices remain in the range $[0{,}1]$ and is determined by Eq. (7):

$$B = \left[1 - e^{-K_i*}\left(\frac{|X_{max} - X_{min}|}{C_i}\right)^{P_i}\right]^{-1} \quad (7)$$

Where X_{max} is the abscissa for the maximum value the indicator might achieve. The overall sustainability index V_i of an alternative (see Eq. (8)) is calculated through the aggregation of the value indices from the lower (indicators) to the upper (requirements) levels of the decision-making tree:

$$V_i = \sum_{j=1}^{m} V_{ij} * W_j \quad (8)$$

where V_{ij} and W_j are the sustainability index and weight for an alternative in relation to the i level in the decision-making tree and m is the number of elements in each level forming the decision-making tree.

Binary stepped value functions (0 or 1) were assigned to those indicators that do not consider intermediate values and are simply evaluated in accordance with whether their purpose is met or not (I1.1.1, I1.12, I1.2.1, I1.3.1, I1.4.1, I1.5.1, I1.6.1, I1.6.2, I2.5.1 and I4.1.1). The parameters to characterize the remaining indicators using the value functions depicted in were defined from data found in Figure 1 international development organizations such as the World Bank, the International Labour Office (ILO), the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), the United Nations Human Settlements programme (UN-HABITAT) and the United Nations Educational Scientific and Cultural Organization (UNESCO). Since these data were collected by international agencies to monitor specific metrics which can differ from the goals sought by some of the indicators included in SIRSDEC, additional information corresponding to developed countries in relation to similar parameters could be considered instead. Furthermore, data included in existing sustainable rating systems were another reference to be used in the definition of value functions if international data did not positively correlate to the set of indicators considered in SIRSDEC.

2.3. Application of the sustainable infrastructure rating system focused on developing countries (SIRSDEC) to a case study

The set of judgments received from international experts to the on-line questionnaire enabled the determination of the weights of the elements in SIRSDEC, whilst the characterization of the indicators in the system was undertaken through the selection of suitable value functions. A case study based on a mining project located in Peru was used to validate SIRSDEC.

2.3.1. Summary of questionnaire judgments

The on-line questionnaire was addressed to 118 experts in the field of environmental and sustainable development, including professionals from public and private sectors such as development institutions, academia and industry. The survey was conducted over the entire month of January 2016. 24 questionnaires were returned from experts belonging to 12 different countries as shown in Figure 2, which involves a response rate of 20.3%. There were no invalid answers because the questionnaire format forced experts to reply all questions linked to the pairwise comparisons among the requirements, criteria and indicators of SIRSDEC in accordance with the AHP scale (see Table 8). All these respondents had been involved in sustainability-driven projects and were aware of sustainable frameworks. 23 of them had worked with sustainable rating tools, whilst only one had no experience in this matter. 11 respondents (45.8%) were academics, consultant and public sectors were represented by 5 participants (20.8%) each and 3 experts (12.6%) belonged to the contractor industry. The set of entities to which these experts were related are the following: BHP Billiton, Boluda Shipping Corporation and CWG Metro Riyad Joint Venture (Contractor industry); Waterloo University, Malaysia University Technology, Hamad Bin Khalifa University, University of Wisconsin-Madison, Coventry University, Colorado State University and Cardiff University (Academy); Qatar Green Council, AMEC Foster Wheeler, Tecnalia and Atkins (Consultancy); United Nations Office for Project Services (UNOPS), Agencia Española para Cooperación y Desarrollo (AECID), Qatar Foundation, International Organization of Supreme Audit Institutions Working Group on Environmental Auditing (INTOSAI WGEA) (Public development institutions).

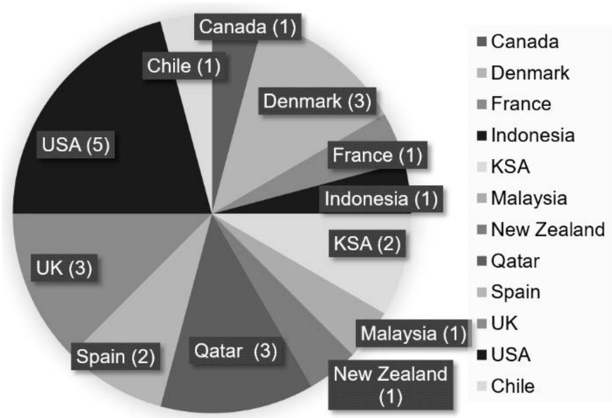

Figure 2. Countries of origin of the experts who responded to the questionnaire

The survey also included three general questions to compare SIRSDEC with existing rating tools for infrastructures. 22 respondents (91.7%) considered a sustainable infrastructure rating system focused on developing countries an effective framework for guiding development projects. 15 respondents (62.5%) thought that the three sustainable principles should be equally weighted in the design process of a rating system for developing countries. The addition of management aspects to the sustainable Triple Bottom Line (TBL) was supported by 19 respondents (79.2%).

2.3.2. Weighting of the elements in SIRSDEC decision-making tree

The AHP method was used to assess the pairwise comparisons provided by the experts. Table 10 includes the values of C.R. obtained after evaluating the consistency of the comparisons received from each expert in relation to requirements and criteria. The results showed that the number of inconsistent comparisons exceeded 50% for each group (C.R. > 0.1). The comparisons associated with the economic and environmental criteria included 13 inconsistencies each, whilst those related to social criteria and the four requirements involved 14 and 12 inconsistencies, respectively. The highest number of inconsistencies (16) corresponded to the management criteria. The Grubbs' test was undertaken to detect outliers in the values of C.R. Respondent #8 provided extreme comparisons in relation to requirements, management criteria and environmental criteria, whilst respondent #14 was too inconsistent with respect to the economic criteria.

Table 10. Summary of the consistency analysis of the comparisons provided by the respondents

Respondent #	Requirement	Economic criteria	Social criteria	Management criteria	Environmental criteria
	C.R.	**C.R.**	**C.R.**	**C.R.**	**C.R.**
1	0.000	0.000	0.237	0.000	0.028
2	0.139	0.150	0.076	0.087	0.047
3	0.166	0.178	0.255	0.193	0.208
4	0.058	0.058	0.080	0.068	0.090
5	0.000	0.131	0.123	0.092	0.041
6	0.292	0.124	0.165	0.090	0.308
7	0.171	0.210	0.404	0.235	0.182
8	0.644	0.257	0.376	0.734	1.391
9	0.000	0.059	0.076	0.218	0.003
10	0.184	0.043	0.139	0.088	0.012
11	0.131	0.132	0.250	0.373	0.278
12	0.181	0.105	0.274	0.442	0.332
13	0.098	0.012	0.262	0.231	0.124
14	0.059	0.551	0.046	0.153	0.041
15	0.086	0.226	0.281	0.204	0.315
16	0.120	0.000	0.034	0.045	0.093
17	0.012	0.127	0.420	0.130	0.122
18	0.000	0.103	0.070	0.135	0.051
19	0.000	0.000	0.035	0.126	0.252
20	0.184	0.016	0.086	0.193	0.213
21	0.197	0.005	0.105	0.079	0.082
22	0.201	0.057	0.126	0.373	0.371
23	0.000	0.005	0.073	0.254	0.171
24	0.000	0.169	0.098	0.355	0.088
Consistent comparisons	12	11	10	8	11
Inconsistent comparisons	12	13	14	16	13

The methodology proposed by Jato-Espino et al. (2017) was applied to adjust the inconsistent judgments found in the returned questionnaires and integrate them into a consensual set of weights. The application of the GRG algorithm made consistent every comparison with a value of C.R. > 0.1, except those provided by the respondent #8, who proved to be too inconsistent with respect to several comparisons and was therefore discarded for further analyses. Since the remaining experts were found to be too inconsistent only for one isolated comparison each at most, their remaining judgments were considered henceforth.

Table 11 shows the consensual weights obtained for each element in the decision-making tree after aggregating the consistent judgments of the experts in accordance with their similarity of thought, to give more importance to those who proved to have closer points of view. The social dimension reached the highest weight (0.324), followed by Environment (0.289), Economy (0.247) and Management (0.140). These values ensured the achievement of a balance among the weights of the pillars of sustainable development. Combating poverty (C4.1) was found to be the most important factor in economic terms, whilst Natural Ecosystems conservation (C3.1) and Biodiversity Ecosystem (C3.2) were the criteria with the highest weights in the environmental domain. As for the social requirement, three criteria highlighted over the rest: Role of indigenous people & communities (C2.2), Equitable Development (C2.3) and Social impacts & Benefits (C2.4). Finally, the results demonstrated that Project Sustainability Management plan (C1.2) was the most relevant criterion in the management category. Although SIRSDEC was originally designed as an easy-to-use tool to be widely deployed worldwide, the specifics of some geographical areas might require the customization and reweighting of indicators in very particular cases.

Table 11. Weights for the elements in the SIRSDEC decision-making tree

R#	$W_{R\#}$	C#. #	$W_{C\#.\#}$	I#.#. #	$W_{I\#.\#.\#}$
R1	0.140	C1.1	0.112	I1.1.1	1.000
				I1.1.2	1.000
		C1.2	0.230	I1.2.1	1.000
		C1.3	0.148	I1.3.1	1.000
		C1.4	0.135	I1.4.1	1.000
		C1.5	0.171	I1.5.1	1.000
		C1.6	0.204	I1.6.1	1.000
				I1.6.2	1.000
R2	0.324	C2.1	0.179	I2.1.1	1.000
		C2.2	0.214	I2.2.1	1.000
		C2.3	0.211	I2.3.1	1.000
		C2.4	0.222	I2.4.1	1.000
				I2.4.2	1.000
		C2.5	0.174	I2.5.1	1.000
R3	0.289	C3.1	0.169	I3.1.1	1.000
		C3.2	0.155	I3.2.1	1.000
		C3.3	0.130	I3.3.1	1.000
		C3.4	0.102	I3.4.1	1.000
				I3.4.2	1.000
		C3.5	0.143	I3.5.1	1.000
				I3.5.2	1.000
		C3.6	0.094	I3.6.1	1.000
		C3.7	0.109	I3.7.1	1.000
		C3.8	0.098	I3.8.1	1.000
				I3.8.2	1.000
R4	0.247	C4.1	0.398	I4.1.1	1.000
		C4.2	0.256	I4.2.1	1.000
		C4.3	0.145	I4.3.1	1.000
		C4.4	0.201	I4.4.1	1.000

2.3.3. Characterization of indicators using value functions

The eight indicators included in the management requirement promote the use of effective project governance frameworks, sustainable best practices and standards focused on enhancing management in infrastructure projects. Binary stepped value functions were assigned to all indicators in this category. Hence, 0 or 1 points are allocated to them depending on whether the goals they seek are met or not. The same principle was also applied to indicators I2.5.1 and I4.1.1. Regarding the social requirement, indicators I2.1.1 and I2.2.1 are also rated using binary stepped functions in accordance with standards of the International Association for Public Participation (IAP2). Projects in which stakeholders, population and/or indigenous community are at least involved are rewarded with 1 point, otherwise they are rated with 0 points.

Increasing linear functions were set for indicators I3.3.1, I3.4.1, I3.4.2, I3.5.1, I3.5.2, I3.8.1 and I3.8.2 to reward the performance of indicators proportionally. Due to the scarcity of metrics for developing countries, the lower and upper values for these value functions were based on thresholds established by existing sustainable infrastructure rating systems (Envision, CEEQUAL and Infrastructure Sustainability (IS) Rating Tool) for equivalent indicators. The minimum and maximum values for indicators I2.4.2, I3.1.1, I3.2.1 and I4.2.1 were extracted from the same data source. These indicators were characterized through concave value functions to reward projects that have low values with respect to them. Indicators I2.3.1 and I4.1.1 were represented by increasing convex value functions, with their bounds delimited in accordance with reports from the International Labor Organization (ILO).

S-shape was found to be the most appropriate value function for indicators I2.4.1, I3.6.1, I3.7.1 and I4.3.1. These indicators were defined again from thresholds found in existing infrastructure rating systems, except I3.7.1, whose range of values was taken from the NEC directive 2001/81/EC. Table 12 summarizes the parameters that characterize the value functions defined for each indicator included in SIRSDEC.

Table 12. Parameters established for the value functions to characterize each indicator in SIRSDEC

Indicator	Xmin	Xmax	Pi	Ci	Ki	Function
I 1.1.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.1.2	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.2.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.3.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.4.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.5.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.6.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 1.6.2	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 2.1.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 2.2.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 2.3.1	51.00	99.00	0.75	51.00	4.000	Convex
I 2.4.1	25.00	0.00	3.00	5.00	0.020	S-Shape
I 2.4.2	20.00	0.00	5.00	3.00	0.002	Concave
I 2.5.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 3.1.1	30.00	0.00	2.50	15.00	0.050	Concave
I 3.2.1	30.00	0.00	2.50	15.00	0.050	Concave
I 3.3.1	10.00	40.00	1.00	40.00	1.000	Linear
I 3.4.1	10.00	30.00	1.00	30.00	1.000	Linear
I 3.4.2	10.00	25.00	1.00	25.00	1.000	Linear
I 3.5.1	5.00	20.00	1.00	20.00	1.000	Linear
I 3.5.2	0.00	30.00	1.00	30.00	1.000	Linear
I 3.6.1	15.00	0.00	5.00	8.00	0.250	S-Shape
I 3.7.1	0.00	52.00	5.50	11.00	0.015	S-Shape
I 3.8.1	0.00	20.00	1.00	20.00	1.000	Linear
I 3.8.2	20.00	50.00	1.00	50.00	1.000	Linear
I 4.1.1	0.00	1.00	n.a.	n.a.	n.a.	Stepped
I 4.2.1	30.00	0.00	2.50	15.00	0.050	Concave
I 4.3.1	0.00	30.00	3.00	5.00	0.025	S-Shape
I 4.4.1	10.00	30.00	0.70	30.00	2.000	Convex

2.3.4. A case study in the Arequipa Region, Peru: The Tia Maria project

Southern Copper, a multinational leading copper mining company, is developing the Tia Maria project at the province of Islay in the Peruvian Arequipa Region. The project, which is scheduled to start operations by 2017 and foresees an initial estimated production of 120,000 tons of copper for the first year, involves the construction of a raft leaching with a capacity of 131,250 m^3 across a surface of 37,500 m^2. The Environmental Impact Assessment (EIA) of the Tia Maria project was approved by the Peruvian Ministry of Energy and Mines in August 2014. However, the outright rejection of the project by the community of Islay has forced Southern Copper to temporarily paralyze it to clarify a series of issues with the inhabitants of the area.

The aim of the case study is the application of SIRSDEC to the raft leaching project in Peru, considering information of the approved EIA to appraise its sustainability. In accordance with the United Nations specifications, countries with a Human Development Index (HDI) below 0.8 are considered developing countries. The 2015 HDI of Peru is 0.734, which justifies the use of SIRSDEC to assess this project from the perspective of the TBL.

Because of the application of mandatory Southern Copper policies and standards, every project developed by the firm must be aligned with ISO 9001 and 14001 specifications (C1.1) and include

Project Sustainability Management and Sustainability Risk Management plans (C1.2 and C1.3). In addition, Sustainable procurement and Inspection & Auditing plans (C1.4 and C1.5) are also implemented in all projects carried out by this company. Lessons learned from the past are logged and distributed among the organization staff to decrease the repetition of the same mistakes in the future (C1.6). Consequently, all management indicators for the Tia Maria project were rewarded with 1 point each.

The involvement of community, stakeholders and indigenous people during the project development was null. Furthermore, 35% of local population might be impacted by the project. Consequently, the value of I2.1.1, I2.2.1 and I2.4.1 was 0. The fact that there was no disturbance to settlements, farmland area and floodplains granted 1 point to I2.4.2, I4.2.1 and I3.6.1. Company standards also demanded the assessment of local cultural heritage and economy and the equality of wages for both sexes, which rewarded I2.4.2, I2.5.1, I4.1.1 and I2.3.1 with 1 point.

The project did not envisage energy savings, use of renewables and runoff water storage, which allocated 0 points to I3.4.1, I3.4.2 and I3.5.2. The impact of the project was estimated to affect 37% of endangered species and 10% of local employment, which rewarded I3.2.1 and I4.4.1 with 0 points. 8% of impacted ecosystem area and fresh water consumption reduction granted 0.5 and 0.26 points to I3.1.1 and I3.5.1, respectively. Waste production and waste recycled/reused experienced a decrease in 15% and 47%, so that indicators I3.8.1 and I3.8.2 received 0.83 and 0.95 points each. Local materials consumption was calculated to be 12%, which means a value of 0.29 for I.4.3.1. GHG emissions and Air pollutants reduction were 18% and 23%, which resulted in values of 0.34 and 0.58 for indicators I3.3.1 and I3.7.1. Table 13 summarizes the ratings and values reached by the SIRSDEC indicators for the Tia Maria project. The combination of these values with the weights shown in Table 11 resulted in a SIRSDEC score of 69.66.

Even though the SIRSDEC score reached 69.66 (Silver), which is over 63.00 (Pass), the project did not fulfil some mandatory indicators such as I2.1.1, I3.1.1, I3.3.1, I3.5.2 and I4.4.1. Consequently, the Tia Maria project did not reach the minimum score required to pass the SIRSDEC evaluation. Moreover, the values for indicators I2.4.1, I3.2.1, I3.4.1, I3.4.2 and I4.2.1 were out of the system thresholds.

Table 13. Assessment of SIRSDEC Indicators for the Tia Maria project

	Indicator	Tia Maria project Indicator rating	Tia Maria project indicator value
(*)	I 1.1.1	1.00	1.00
(*)	I 1.1.2	1.00	1.00
(*)	I 1.2.1	1.00	1.00
	I 1.3.1	1.00	1.00
(*)	I 1.4.1	1.00	1.00
(*)	I 1.5.1	1.00	1.00
	I 1.6.1	1.00	1.00
	I 1.6.2	1.00	1.00
(*)	I 2.1.1	Not involved	0.00
	I 2.2.1	Not involved	0.00
(*)	I 2.3.1	100%	1.00
	I 2.4.1	35%	0.00
	I 2.4.2	0.00	1.00
(*)	I 2.5.1	1.00	1.00
(*)	I 3.1.1	8%	0.50
	I 3.2.1	37%	0.00
(*)	I 3.3.1	18%	0.34
	I 3.4.1	0%	0.00
	I 3.4.2	0%	0.00
(*)	I 3.5.1	8%	0.26
(*)	I 3.5.2	0%	0.00
(*)	I 3.6.1	0%	1.00
	I 3.7.1	23%	0.58
	I 3.8.1	15%	0.83
	I 3.8.2	47%	0.95
(*)	I 4.1.1	1.00	1.00
	I 4.2.1	0%	1.00
	I 4.3.1	12%	0.29
(*)	I 4.4.1	10%	0.00
SIRSDEC score			69.66

(*) Mandatory indicators

Some actions were suggested to be implemented in the project to fulfill the principles being sought by SIRSDEC and reach the Pass level of achievement, including the reduction of current social rejection. These actions intended to enhance the involvement of social stakeholders and indigenous community to increase the knowledge about the project among population throughout a broad information campaign and periodic meetings with the community. The main concern of inhabitants is the negative impact of mining project on farmlands, because agriculture is their primary source of income. In this sense, most manpower might be appointed among local inhabitants during the construction stage and remain during the operation of the mine. Hence, the rise of the local employment ratio up to 25% of population could contribute to mitigate economic concerns.

The raft leaching project would also incorporate additional design improvements to prevent from the break and overflow of the infrastructure, which might have very negative impacts on both ecosystem and biodiversity. These changes would also reduce GHG and air pollutants emissions. The construction of a runoff water tank would enable the reduction of fresh water consumption. Furthermore, the installation of new photovoltaic panels would contribute to saving energy and increasing the use of renewables. Table 14 includes the proposed actions and their impact in the re-assessment of the affected indicators. The implementation of these new measures would result in a SIRSDEC score for the Tia Maria project of 95.10 (Gold), including the fulfillment of all mandatory indicators and keeping within the ranges established by the framework.

Table 14. Re-assessment of affected SIRSDEC indicators

	Indicator	Action	Initial indicator rating	Final indicator rating	Initial indicator value	Final indicator value
(*)	I2.1.1	Information Campaign and meetings	Not involved	Involved	0.00	1.00
	I2.2.1	Information Campaign and meetings	Not involved	Involved	0.00	1.00
	I2.4.1	Design improvements & increase of local employment rate	35%	23%	0.00	0.01
(*)	I3.1.1	Design improvements	8%	0%	0.50	1.00
	I3.2.1	Design improvements	37%	23%	0.00	0.03
(*)	I3.3.1	Design improvements	18%	40%	0.34	1.00
	I3.4.1	Design improvements	0%	11%	0.00	0.07
	I3.4.2	Photovoltaic panels	0%	14%	0.00	0.33
(*)	I3.5.1	Runoff water tank construction	8%	15%	0.26	0.75
(*)	I3.5.2	Runoff water tank construction	0%	20%	0.00	0.77
	I3.7.1	Design improvements	23%	29%	0.58	0.96
	I4.4.1	local employment priority	10%	25%	0.00	0.91

(*) Mandatory indicators

3. Conclusions and future lines of research

3.1. General conclusions

Huge international investments intended to promote the sustainable development in poorer countries require efficient frameworks which allow the monitoring of established sustainable goals, but the lack of appropriate sustainable metrics hinders this mission. Indicators included in Agenda 21 and Millennium Development Goals, which are the guidelines of sustainable development for all countries worldwide, do not reflect properly the progress related to society, economy and environment in these countries. Data collected by UN agencies, international development banks and other international development institutions are mainly oriented to health and education, whilst only a few metrics are associated with the TBL. The development and implementation of new metrics linked to social, economic and environmental domains should be fostered by international organizations and institutions to allow a more accurate monitoring of sustainable development progress.

The assessment of the three-existing sustainable infrastructure rating systems demonstrated that they were focused on environmental issues and minimized the relevance of social and economic aspects, which is the reason why these frameworks are not suitable to be applied in developing countries. This PhD thesis overcame this shortcoming through the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC), with the main aim of balancing the importance of the three pillars of the TBL.

The results obtained through the application of SIRSDEC to a case study consisting of a mining project in Peru proved its validity to evaluate the contribution of infrastructure projects to sustainable development in developing countries. The judgements received from international experts through an on-line questionnaire enabled the assessment of the weights of the elements included in the system. The new distribution of weights for the requirements emphasized the balance among the social, environmental and economic dimensions, with the inclusion of the new managerial aspect. Consequently, SIRSDEC achieved the main goal of balancing the importance of the pillars of the TBL. Therefore, SIRSDEC constitutes a tool aimed at supporting international development institutions and organization in the assessment of infrastructure projects, in order to prioritize the construction of those of them which contribute to more sustainable outcomes in poorer countries.

3.2. Specific conclusions

The specific conclusions drawn from each article included in this research, which correlate to the specific aims established in the thesis, are summarized below.

3.2.1. Article 1: Evaluation of existing sustainable infrastructure rating systems for their application in developing countries

- The three-existing sustainable infrastructure rating systems are mainly focused on environmental issues instead of social and economic ones, whose relevance is higher in less developed countries.

- The consideration of Management as a complement of the TBL in rating tools strengthens weak policy directives in developing countries. As a consequence, the monitoring and assessment of development goals progress will improve significantly.

- Indicators included in Agenda 21 and Millennium Development Goals do not properly reflect the relevance of the social, economic and environmental aspects involved in the sustainable development of poorer countries.

3.2.2. Article 2: Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC)

- The application of the non-linear algorithm based on the Generalized Reduced Gradient (GRG) is crucial to make consistent every comparison obtained from the on-line questionnaire, ensuring the fair calculation of weights in SIRSDEC.

- The value functions that define the indicators in SIRSDEC according to the Integrated Value Model for Sustainable Assessments (MIVES) improved the characterization of indicators, which leads to more accurate sustainability appraisals.

- The metrics implemented by international organizations and institutions to monitor the progress of sustainable development in these countries do not include relevant aspects of the TBL, which hinders the characterization of the value functions that define the indicators in SIRSDEC.

3.2.3. Article 3: Application of the Sustainable Infrastructure Rating System for Developing Countries (SIRSDEC) to a case study

- The weights obtained for the requirements in SIRSDEC from the judgements of the questionnaire confirmed that international experts considered that the relevance of the social, economic and environmental dimensions should be equal, even though the social aspect slightly prevails over the two others.

- The existence of some mandatory requirements to obtain a positive evaluation in SIRSDEC obliges all projects to consider every essential aspect concerning the sustainable development in poorer countries.

- The simplicity in the use of SIRSDEC facilitates the quick selection and appraisal of alternatives to foster the application of sustainable practices to infrastructure projects in developing countries.

3.3. Future lines of research

The development of this thesis posed the next future lines of research to give continuity and extend the design and implementation of SIRSDEC:

- Development of new monitoring metrics to assess the set of indicators established for the social, economic, environmental and managerial dimensions in developing countries.

- Adjustment of SIRSDEC to the needs and metrics of international development financial institutions for tracking the contribution of their projects to the sustainable development of poorer countries.

- Inclusion of SIRSDEC in the assessment of urban sustainable development in developing countries.

- Integration of sustainable development goals set by the UN in the framework of SIRSDEC.

- Implementation of SIRSDEC as a mandatory requirement for preliminary sustainable assessments of infrastructure projects during the bidding procedure for projects funded by international organizations and institutions.

- Development of a conjoint sustainable rating system for urban communities in developing countries including both building and infrastructure fields.

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